

Oat Response in Plant Morphological Parameters and Panicle Productivity Elements in Relation to Soil Tillage and Fertilization Systems

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Abstract. The study evaluated the influence of the soil preparation and fertilization system on some morphological parameters and productivity elements in oats. The field experiments were organized within the ARDS Lovrin, agricultural year 2024 - 2025. The culture was located on a plot with chernozem soil, medium fertility, in a non-irrigated system. The biological material was represented by the spring oat, 'Ovidiu' variety. Four land preparation options were considered: soil preparation by plowing at 18 cm (P); soil preparation by discing (D); soil preparation by superficial scarification (SS); soil preparation by deep scarification (DS). Three types of fertilization were applied to each soil tillage option: NPK complexes (15:15:15) at a dose of 150 kg/ha commercial product (F1); NPK complexes (15:15:15) at a dose of 150 kg/ha + ammonium nitrate 150 kg/ha, commercial products (F2); NPK complexes (15:15:15) at a dose of 150 kg/ha + ammonium nitrate 200 kg/ha, commercial products (F3). Complex fertilizers were applied in autumn, and ammonium nitrate was applied in spring. The parameters plant height (PH, cm), number of leaves (LN), panicle length (PL, cm), number of grains in panicle (PGN), and weight of grains in panicle (PGW, g) were determined. The PH parameter showed low variability in all variants. Parameters LN and PL showed low and moderate variability, and parameters PGN and PGW showed low, moderate and high variability in relation to experimental variants. The difference between the mean and median values was confirmed (ANOVA Test, Kruskal-Wallis Test) for the parameters considered in relation to the experimental variants. The Post Hoc Test confirmed significant differences between certain experimental variants, in relation to each parameter considered.

Keywords: agricultural crops, climate changes, clustering, crop technology, oat, PCA, variability

INTRODUCTION

Climate change influences food systems globally, in the medium and long term, and the dynamics of adaptations and the scale at which they will be made will partially mitigate these effects (Yuan et al., 2024; Hultgren et al., 2025; Waqas et al., 2025).

Soil dynamics, the physical, chemical, biological properties of the soil, the water regime in the soil, are influenced by climate change and have recorded variable changes in intensity in relation to the type of soil and the degree of manifestation of climatic conditions (Horel et al., 2022; Zare et al., 2022; Filho et al., 2025; Mammadov et al., 2026). Changes in the "soil - agricultural crops - environment" relationship have been recorded, associated with climate change (Oishy et al., 2025). Variations in soil fertility and plant nutrition were evaluated in relation to the effects generated in crop yields, crop stability and quality (Kaplan and Öztürk, 2025; Mahdavi et al., 2025).

In the context of climate change, the resilience of crop systems, the sustainability of agricultural crops, the sustainability and perspective of farmers were analyzed (Wolf et al., 2023; Sun et al., 2024; Hultgren et al., 2025; Verma et al., 2025).

Agricultural technologies have been analyzed and are being adjusted to compensate, to the greatest extent possible, the effect of climate change, in relation to the requirements of crop plants (Ritchie, 2024; Hultgren et al., 2025).

New strategies for plant cultivation are being considered, involving modern technologies and plant breeding programs, biotechnologies and agricultural technologies adapted to climate challenges (Raza et al., 2019; Ukhurebor and Aidonjio, 2021; Serrano-Vincenti et al., 2025). Soil work and crop fertilization are being reviewed in the context of climate change, to ensure good conditions for agricultural crops (Abd-Alla et al., 2023; Oishy et al., 2025).

Oats are an important crop plant due to their main (seeds) and secondary (straw) production, seed quality and active ingredient content, for the food industry, human nutrition, functional foods, and animal feed (Ahmad et al., 2014; Paudel et al., 2021; Chand et al., 2025).

The present study analyzed morphological parameters of oat plants and productivity elements at the panicle level, in relation to soil preparation and fertilization systems, non-irrigated culture, under the specific conditions of the Western Plain of Romania.

MATERIAL AND METHODS

The research took place within ARDS Lovrin, with the aim of evaluating the variation of some morphological parameters in oats, under different conditions of land preparation and fertilization. Land preparation was done in four variants: soil preparation by plowing at 18 cm (P); soil preparation by discing (D); soil preparation by superficial scarification (SS); soil preparation by deep scarification (DS).

Three types of fertilization were applied to each tillage variant: NPK complexes (15:15:15) at a dose of 150 kg/ha commercial product (F1); NPK complexes (15:15:15) at a dose of 150 kg/ha + ammonium nitrate 150 kg/ha, commercial products (F2); NPK complexes (15:15:15) at a dose of 150 kg/ha + ammonium nitrate 200 kg/ha, commercial products (F3). Complex fertilizers were applied in autumn, and ammonium nitrate was applied in spring. The size of an experimental plot was 145 m². The experiment was organized in three repetitions. The biological material was represented by the spring oat variety 'Ovidiu'. Sowing was done on February 25, 2025. A uniform maintenance technology was ensured. The climatic conditions during the experiment period are presented in Figure 1.

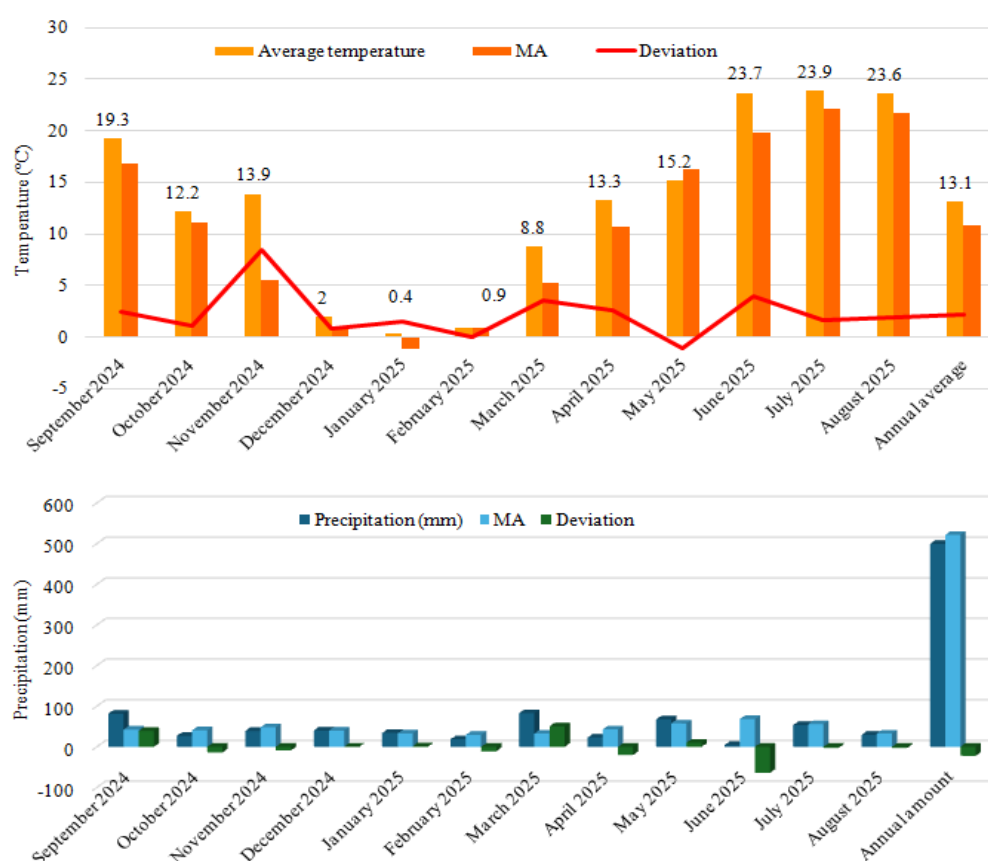


Figure 1. Climatic data

Biometric parameters of oat plants were evaluated in relation to the experimental variants: plant height (PH, cm), number of leaves per plant (LN), panicle length (PL, cm), number of grains per panicle (PGN) and grain weight per panicle (PGW, g). The determinations were made on a number of 30 plants per experimental variant. The experimental data were analyzed for general statistical characterization. Comparative analysis was performed between the experimental variants for each biometric parameter. Appropriate mathematical and statistical analysis tests were used, in relation to the purpose of the study. PAST software was used for the analysis of the experimental data and the generation of graphs (Hammer et al., 2001).

RESULTS AND DISCUSSIONS

In relation to the experimental variants, differentiated values of the biometric parameters considered in oat plants, the 'Ovidiu' variety, were recorded. Descriptive statistical analysis of the data series for each parameter led to the results in Table 1 to Table 5.

Table 1. Results of descriptive statistical analysis, PH parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	68.00	66.00	62.00	68.00	70.00	64.00	60.00	57.00	51.00	68.00	67.00	60.00
Max	98.00	101.00	97.00	115.00	108.00	105.00	96.00	103.00	84.00	103.00	103.00	95.00
Sum	2551.00	2574.50	2400.00	2671.00	2636.00	2623.00	2364.00	2582.00	2057.00	2484.50	2670.00	2352.00
Mean	85.03	85.82	80.00	89.03	87.87	87.43	78.80	86.07	68.57	82.82	89.00	78.40
Std. error	1.66	1.77	1.26	1.98	2.06	1.97	1.73	2.28	1.66	1.72	1.70	1.97
Stand. dev	9.09	9.72	6.91	10.84	11.30	10.79	9.47	12.48	9.09	9.41	9.29	10.79
Median	86.00	87.00	79.50	88.50	89.00	88.00	78.00	87.50	68.00	80.00	92.50	79.50
25 prentil	79.50	79.50	75.75	81.75	77.75	80.75	72.75	79.50	62.00	75.75	82.75	69.25
75 prentil	92.25	94.63	86.25	98.00	96.50	96.00	86.50	96.25	75.75	90.13	95.25	87.25
Kurtosis	-0.68	-0.81	1.07	-0.14	-1.16	-0.19	-0.60	-0.10	-0.70	-0.84	0.30	-1.25
Coeff. var	10.69	11.33	8.64	12.17	12.86	12.34	12.02	14.50	13.26	11.36	10.44	13.76

Table 2. Results of descriptive statistical analysis, LN parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	4.00	4.00	4.00	3.00	3.00	3.00	2.00	2.00	2.00	4.00	3.00	4.00
Max	7.00	6.00	6.00	7.00	6.00	7.00	8.00	10.00	6.00	7.00	7.00	7.00
Sum	163.00	164.00	147.00	143.00	146.00	136.00	135.00	140.00	127.00	155.00	164.00	171.00
Mean	5.43	5.47	4.90	4.77	4.87	4.53	4.50	4.67	4.23	5.17	5.47	5.70
Std. error	0.12	0.10	0.10	0.20	0.16	0.18	0.24	0.25	0.23	0.13	0.17	0.12
Stand. dev	0.68	0.57	0.55	1.10	0.90	0.97	1.31	1.35	1.25	0.70	0.94	0.65
Median	5.00	5.50	5.00	4.00	5.00	4.00	4.00	5.00	4.00	5.00	5.00	6.00
25 prentil	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	3.00	5.00	5.00	5.00
75 prentil	6.00	6.00	5.00	6.00	6.00	5.00	5.00	5.00	5.00	6.00	6.00	6.00
Kurtosis	-0.08	-0.75	0.59	-0.76	-0.62	1.24	1.01	8.07	-1.10	0.59	0.55	0.52
Coeff. var	12.50	10.45	11.18	23.17	18.48	21.47	29.03	28.88	29.55	13.53	17.14	11.43

Table 3. Results of descriptive statistical analysis, PL parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	10.00	10.00	9.00	10.00	10.00	10.00	7.00	5.00	7.00	11.00	9.00	8.00
Max	17.50	18.00	17.00	22.00	19.00	19.00	19.00	18.00	17.00	18.00	19.00	20.00
Sum	460.50	445.50	454.00	474.00	416.00	429.00	375.00	363.00	356.00	454.50	450.00	382.00
Mean	15.35	14.85	15.13	15.80	13.87	14.30	12.50	12.10	11.87	15.15	15.00	12.73
Std. error	0.35	0.42	0.31	0.45	0.44	0.44	0.52	0.53	0.36	0.34	0.41	0.57
Stand. dev	1.92	2.33	1.69	2.46	2.39	2.39	2.83	2.93	1.96	1.86	2.26	3.12
Median	16.00	16.00	15.00	16.00	13.50	14.00	12.00	12.00	12.00	15.00	15.00	13.00
25 prentil	14.75	13.88	14.38	14.00	12.00	12.00	10.75	10.75	11.00	13.88	15.00	10.00
75 prentil	17.00	17.00	16.00	17.00	15.25	16.00	14.00	14.25	13.00	17.00	16.00	15.00
Kurtosis	2.46	-0.11	4.99	1.03	-0.33	-0.85	-0.02	0.57	1.17	-0.70	1.37	-0.57
Coeff. var	12.52	15.67	11.18	15.54	17.23	16.75	22.60	24.20	16.52	12.29	15.09	24.48

Table 4. Results of descriptive statistical analysis, PGN parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	20.00	24.00	18.00	20.00	12.00	2.47	1.00	5.00	11.00	19.00	21.00	17.00
Max	81.00	82.00	70.00	46.00	48.00	41.00	41.00	38.00	39.00	80.00	107.00	68.00
Sum	1471.00	1436.00	1333.00	938.00	860.00	800.47	675.00	817.00	715.00	1298.00	1638.00	1181.00
Mean	49.03	47.87	44.43	31.27	28.67	26.68	22.50	27.23	23.83	43.27	54.60	39.37
Std. error	3.08	3.08	2.45	1.12	1.64	1.58	1.62	1.47	1.29	2.77	3.32	2.61
Stand. dev	16.87	16.85	13.44	6.11	9.00	8.65	8.90	8.07	7.09	15.18	18.20	14.32
Median	51.50	44.00	40.50	30.50	28.00	28.00	23.00	28.50	24.00	41.00	54.50	40.00
25 prentil	33.50	33.25	36.50	27.50	22.00	21.75	17.00	23.50	18.50	30.00	43.75	26.00
75 prentil	58.50	58.75	56.00	33.25	34.25	33.25	28.50	34.00	28.75	53.25	63.25	52.25
Kurtosis	-0.58	-0.76	-0.76	0.74	-0.33	0.65	0.73	0.75	-0.56	-0.09	1.30	-0.76
Coeff. var	34.40	35.19	30.24	19.55	31.41	32.43	39.54	29.62	29.73	35.09	33.34	36.38

Table 5. Results of descriptive statistical analysis, PGW parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
N	30	30	30	30	30	30	30	30	30	30	30	30
Min	0.47	0.58	0.48	1.70	0.73	0.81	0.63	0.11	0.51	0.45	0.53	0.42
Max	2.20	2.24	1.60	5.08	3.36	4.11	3.30	2.27	2.56	2.01	2.39	2.12
Sum	40.48	39.41	34.89	80.72	62.11	73.71	42.46	45.87	45.62	34.70	42.83	32.94
Mean	1.35	1.31	1.16	2.69	2.07	2.46	1.42	1.53	1.52	1.16	1.43	1.10
Std. error	0.08	0.09	0.05	0.14	0.13	0.13	0.10	0.09	0.09	0.07	0.09	0.09
Stand. dev	0.46	0.50	0.28	0.78	0.74	0.73	0.56	0.52	0.51	0.38	0.47	0.48
Median	1.41	1.28	1.19	2.49	2.16	2.49	1.32	1.58	1.64	1.15	1.41	1.10
25 prentil	0.94	0.84	0.95	2.28	1.53	2.06	1.06	1.14	1.09	0.81	1.17	0.69
75 prentil	1.62	1.78	1.37	2.97	2.57	3.04	1.64	2.09	1.87	1.47	1.71	1.34
Kurtosis	-0.43	-1.25	-0.26	2.62	-0.68	0.30	3.63	0.45	-0.55	-0.66	-0.23	-0.50
Coeff. var	34.33	38.16	23.82	28.84	35.54	29.57	39.53	33.76	33.56	32.87	32.62	43.91

The data series for the analyzed morphological parameters presented a normal distribution, with correlation coefficient values ranging between $r = 0.960$ (DSF2) and $r = 0.993$ (SSF3) for the PH parameter; $r = 0.848$ (PF3) and $r = 0.959$ (SSF3) for the LN parameter; $r = 0.896$ (PF1) and $r = 0.986$ (DF3) for the LN parameter; $r = 0.957$ (SSF2) and $r = 0.991$ (SSF3) for the PGN parameter; $r = 0.931$ (DF1) and $r = 0.992$ (DSF2) for the PGW parameter.

In the case of the PH parameter, low variability was recorded in all experimental variants. In the case of the LN parameter, low variability was recorded in seven variants and moderate variability in five variants. In the case of the PL parameter, low variability was recorded in nine variants and moderate variability in three variants. In the case of the PGN parameter, one variant showed low variability, two variants showed moderate variability and three variants showed high variability. In the case of the PGW parameter, the data showed moderate variability in three variants and high variability in nine variants.

Outlier tests were applied (Grubbs test, Dixon Q test), and the data series were analyzed for each parameter considered in oat plants, and each experimental variant. The recorded results are presented in Table 6.

In the case of the PH parameter, no outlier values were identified. In the case of the LN parameter, an outlier value was identified for the PF1 variant (value 7 in row 1, $p < 0.05$), an outlier value for the PF2 variant (value 4, in row 14, $p < 0.05$), an outlier value for the SSF2 variant (val 10, row 23, $p < 0.05$), a value for the DSF2 variant (val 3, row 21, $p < 0.005$) and an outlier value for the DSF3 variant (val 3, row 21, $p < 0.005$). In the case of the PL parameter, an outlier value for the PF3 variant (val 9, row 10, $p < 0.05$) was identified. In the case of the PGN parameter, no outlier values were identified.

In the case of the PGW parameter, an outlier value was identified for the DF1 variant (value 5.08, row 23, $p < 0.05$), and an outlier value for the SSF1 variant (value 3.3, row 16, $p < 0.05$).

Table 6. Outlier test results

Test and parameters		Experimental trials											
		PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PH													
Grubbs test	G	1.874	2.039	2.604	2.396	1.782	2.171	1.984	2.330	1.932	2.145	2.369	1.705
	p	1.000	1.000	0.173	0.361	1.000	0.732	1.000	0.449	1.000	0.791	0.396	1.000
	Sig	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso
Dixon Q test	Q(r22)	0.034	0.125	0.375	0.333	0.139	0.086	0.069	0.227	0.156	0.188	0.091	0.063
	p	0.996	0.862	0.091	0.168	0.821	0.947	0.970	0.501	0.765	0.652	0.938	0.977
	Sig	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso
LN													
Grubbs test	G	2.308	2.567	2.008	2.022	2.075	2.535	2.679	3.958	1.786	2.623	2.632	2.632
	p	0.482	0.199	1.000	1.000	0.966	0.223	0.130	0.000	1.000	0.161	0.156	0.156
	Sig	nso	nso	nso	nso	nso	nso	nso	so	nso	nso	nso	nso
Dixon Q test	Q(r22)	0.500	0.500	0.000	0.333	0.000	0.250	0.200	0.571	0.000	0.333	0.500	0.500
	p	0.006	0.006	1.000	0.168	1.000	0.416	0.607	0.001	1.000	0.166	0.006	0.006
	Sig	so	so	nso	nso	nso	nso	nso	so	nso	nso	so	so
PL													
Grubbs test	G	2.784	2.084	3.626	2.525	2.149	1.963	2.301	2.424	2.618	2.228	2.651	2.331
	p	0.085	0.942	0.001	0.231	0.781	1.000	0.492	0.328	0.164	0.616	0.145	0.447
	Sig	nso	nso	so	nso	nso	nso	nso	nso	nso	nso	nso	nso
Dixon Q test	Q(r22)	0.091	0.125	0.500	0.300	0.111	0.125	0.200	0.111	0.375	0.308	0.125	0.250
	p	0.939	0.861	0.006	0.252	0.894	0.861	0.607	0.896	0.090	0.232	0.860	0.418
	Sig	nso	nso	so	nso	nso	nso	nso	nso	nso	nso	nso	nso
PGN													
Grubbs test	G	1.895	2.026	1.967	2.410	2.147	2.798	2.417	2.756	2.140	2.419	2.879	1.999
	p	1.000	1.000	1.000	0.345	0.785	0.080	0.337	0.096	0.802	0.334	0.057	1.000
	Sig	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso
Dixon Q test	Q(r22)	0.088	0.083	0.111	0.210	0.138	0.353	0.259	0.323	0.240	0.224	0.369	0.146
	p	0.944	0.951	0.896	0.565	0.824	0.128	0.384	0.193	0.454	0.513	0.098	0.798
	Sig	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso	nso
PGW													
Grubbs test	G	1.898	1.848	2.465	3.080	1.821	2.275	3.368	2.749	2.036	2.244	2.066	2.120
	p	1.000	1.000	0.285	0.022	1.000	0.533	0.005	0.098	1.000	0.587	0.989	0.850
	Sig	nso	nso	nso	so	nso	nso	so	nso	nso	nso	nso	nso
Dixon Q test	Q(r22)	0.064	0.132	0.314	0.337	0.094	0.375	0.463	0.404	0.245	0.269	0.125	0.062
	p	0.976	0.843	0.213	0.158	0.930	0.089	0.016	0.055	0.438	0.347	0.858	0.978
	Sig	nso	nso	nso	nso	nso	nso	so	nso	nso	nso	nso	nso

Note: nso – no significant outlier; so – significant outlier

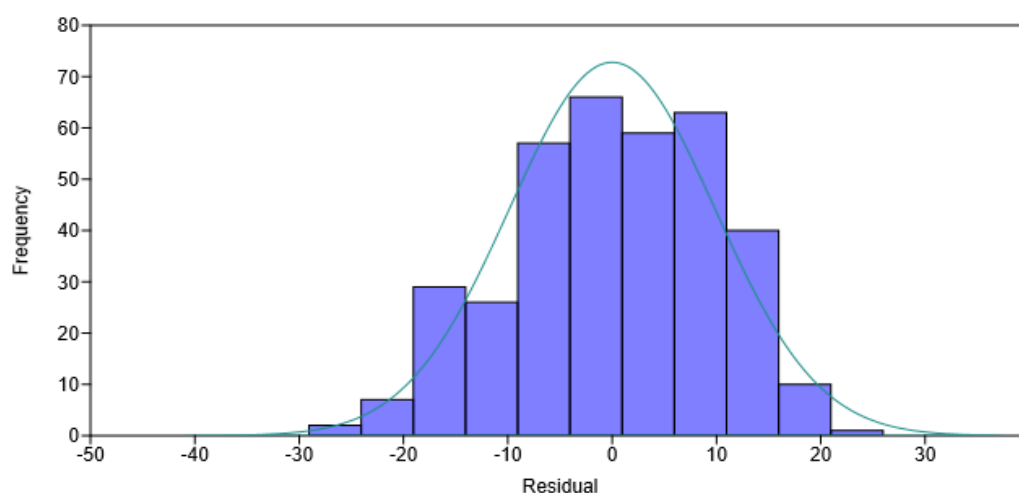
The comparative analysis was made between the experimental variants, in relation to each parameter determined in oat plants. In the case of the PH parameter, the difference between the mean values was confirmed (ANOVA Test), Table 7. The Kruskal-Wallis test confirmed significant differences between the median values, $H(\text{Chi}^2) = 0.83$, H_c (tie corrected) = 83.07, $p < 0.001$. The Post hoc test was applied with the results in Table 8. The residual values from the comparative analysis presented a normal distribution, Figure 2.

Table 7. ANOVA Test result for PH parameter

Statistical parameters	Sum of sqrs	df	Mean square	F	p (same)
Between groups:	11780.9	11	1071	10.66	6.20E-17
Within groups:	34967.5	348	100.481	Permutation p (n=99999)	
Total:	46748.4	359	1.00E-05		
Components of variance (only for random effects):					
Var(group):	32.3505	Var(error):	100.481	ICC:	0.243545
omega ² :	0.2279				
Levene's test for homogeneity of variance, from means	p (same):	0.1347			
Levene's test, from medians	p (same):	0.1913			
Welch F test in the case of unequal variances:		F=11.29, df=137, p=1.012E-14			
Bayes factor:		6.598E13 (decisive evidence for unequal means)			

Table 8. Post Hoc test results, for PH parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PF1		y	0.0119	0.1598	0.3362	0.3907	0.0140	0.4961	1.64E-07	0.2800	0.0769	0.0194
PF2	0.6841		0.0111	0.2934	0.5245	0.5490	0.0094	0.7060	1.51E-07	0.1880	0.1852	0.0109
PF3	0.0119	0.0111		0.0008	0.0084	0.0013	0.4959	0.0076	8.11E-06	0.3586	6.85E-05	0.7169
DF1	0.1598	0.2934	0.0008		0.7672	0.7114	0.0007	0.5391	1.08E-08	0.0245	0.8533	0.0010
DF2	0.3362	0.5245	0.0084	0.7672		0.9351	0.0039	0.7281	8.93E-08	0.0770	0.5840	0.0036
DF3	0.3907	0.5490	0.0013	0.7114	0.9351		0.0021	0.8186	7.02E-08	0.0677	0.4913	0.0032
SSF1	0.0140	0.0094	0.4959	0.0007	0.0039	0.0021		0.0105	0.0002	0.1449	0.0002	0.9528
SSF2	0.4961	0.7060	0.0076	0.5391	0.7281	0.8186	0.0105		1.27E-06	0.1578	0.4683	0.0130
SSF3	1.64E-07	1.51E-07	8.11E-06	1.08E-08	8.93E-08	7.02E-08	0.0002	1.27E-06		2.28E-06	1.04E-08	0.0009
DSF1	0.2800	0.1880	0.3586	0.0245	0.0770	0.0677	0.1449	0.1578	2.28E-06		0.0109	0.1513
DSF2	0.0769	0.1852	6.85E-05	0.8533	0.5840	0.4913	0.0002	0.4683	1.04E-08	0.0109		0.0002
DSF3	0.0194	0.0109	0.7169	0.0010	0.0036	0.0032	0.9528	0.0130	0.0009	0.1513	0.0002	

**Figure 2.** Residual values related to the PH parameter

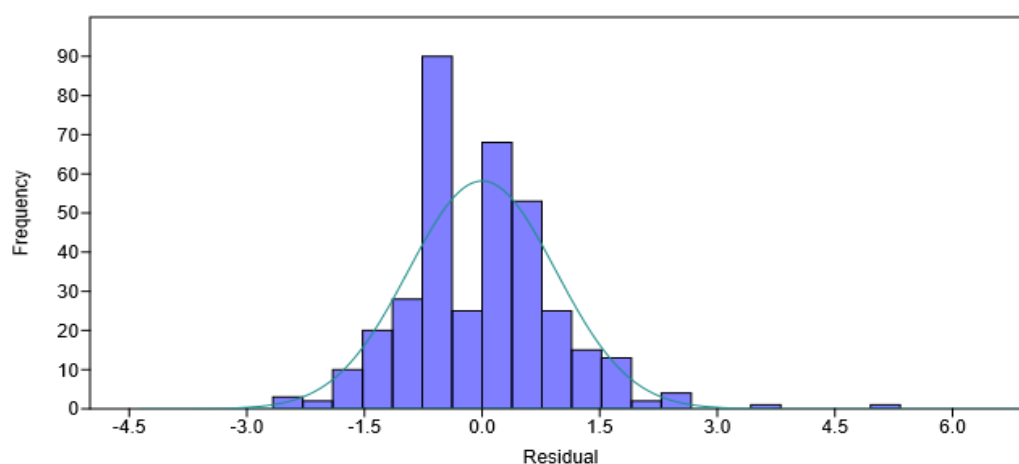
In the case of the LN parameter, the difference between the mean values was confirmed (ANOVA Test), Table 9, and the Kruskal-Wallis test confirmed significant differences between the median values, $H(\text{Chi}^2) = 70.13$, H_c (tie corrected) = 77.40, $p < 0.001$. The Post hoc test was applied with the results in Table 10. The residual values from the comparative analysis presented a normal distribution, Figure 3.

Table 9. ANOVA Test result for LN parameter

Table 3: ANOVA Test result for EN parameter						
Statistical parameters		Sum of sqrs	df	Mean square	F	p (same)
Between groups:		71.475	11	6.49773	7.126	6.08E-11
Within groups:		317.3	348	0.911782	Permutation p (n=99999)	
Total:		388.775	359	1.00E-05		
Components of variance (only for random effects):						
Var(group):		0.186198	Var(error):	0.911782	ICC:	0.169583
omega²:		0.1577				
Levene’s test for homogeneity of variance, from means		p (same):	1.82E-06			
Levene’s test, from medians		p (same):	0.002148			
Welch F test in the case of unequal variances:			F=7.935, df=136.7, p=1.444E-10			
Bayes factor:			6.22E07 (decisive evidence for unequal means)			

Table 10. Post Hoc test results, for LN parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PF1		0.8166	0.0018	0.0071	0.0151	0.0001	0.0002	0.0003	1.64E-04	0.1130	0.9936	0.1157
PF2	0.8166		0.0004	0.0040	0.0069	0.0000	0.0001	0.0001	7.73E-05	0.0550	0.8261	0.1446
PF3	0.0018	0.0004		0.3011	0.9935	0.0215	0.0187	0.0907	2.55E-02	0.1242	4.84E-03	0.0000
DF1	0.0071	0.0040	0.3011		0.5206	0.4947	0.3330	0.7200	1.19E-01	0.0643	0.0083	0.0005
DF2	0.0151	0.0069	0.9935	0.5206		0.0964	0.0802	0.2035	4.44E-02	0.2390	0.0227	0.0003
DF3	0.0001	0.0000	0.0215	0.4947	0.0964		0.6779	0.6645	3.94E-01	0.0018	0.0002	0.0000
SSF1	0.0002	0.0001	0.0187	0.3330	0.0802	0.6779		0.4505	0.5674	0.0027	0.0004	0.0000
SSF2	0.0003	0.0001	0.0907	0.7200	0.2035	0.6645	0.4505		2.98E-01	0.0083	0.0006	0.0000
SSF3	1.64E-04	7.73E-05	2.55E-02	1.19E-01	4.44E-02	3.94E-01	0.5674	2.98E-01		2.99E-03	2.91E-04	0.0000
DSF1	0.1130	0.0550	0.1242	0.0643	0.2390	0.0018	0.0027	0.0083	2.99E-03		0.1586	0.0026
DSF2	0.9936	0.8261	4.84E-03	0.0083	0.0227	0.0002	0.0004	0.0006	2.91E-04	0.1586		0.1842
DSF3	0.1157	0.1446	0.0000	0.0005	0.0003	0.0000	0.0000	0.0000	0.0000	0.0026	0.1842	

**Figure 3.** Residual values related to the LN parameter

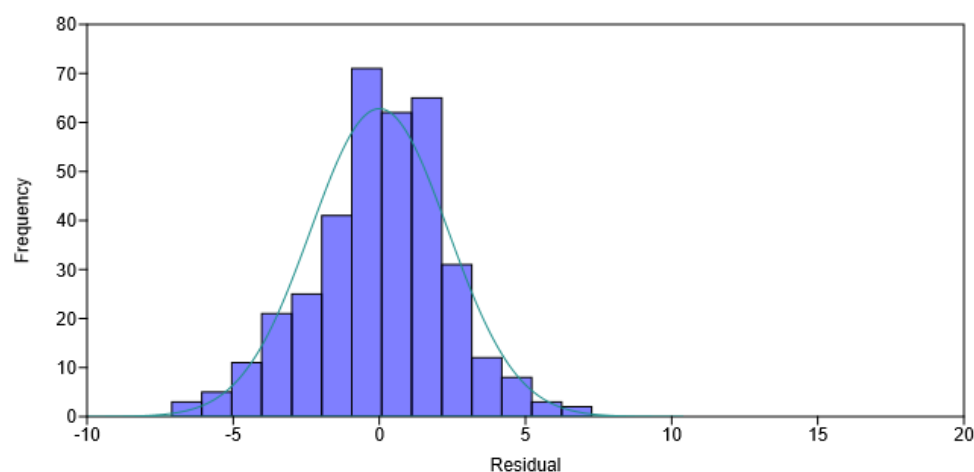
In the case of the PL parameter, the difference between the mean values was confirmed (ANOVA Test), Table 11, and the Kruskal-Wallis test confirmed significant differences between the median values, $H(\text{Chi}^2) = 88.07$, H_c (tie corrected) = 89.09, $p < 0.001$. The Post hoc test was applied with the results in Table 12. The residual values from the comparative analysis presented a normal distribution, Figure 4.

Table 11. ANOVA Test result for PL parameter

Table 11. ANOVA Test result for FE parameter						
Statistical parameters		Sum of sqrs	df	Mean square	F	p (same)
Between groups:		644.402	11	58.582	10.32	2.30E-16
Within groups:		1976.29	348	5.679	Permutation p (n=99999)	
Total:		2620.69	359	1.00E-05		
Components of variance (only for random effects):						
Var(group):		1.76343	Var(error):	5.679	ICC:	0.236943
omega²:		0.2216				
Levene’s test for homogeneity of variance, from means		p (same):	1.27E-02			
Levene’s test, from medians		p (same):	0.03086			
Welch F test in the case of unequal variances:			F=10.58, df=136.9, p=6.84E-14			
Bayes factor:			1.78E13 (decisive evidence for unequal means)			

Table 12. Post Hoc test results, for PL parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PF1		0.4879	0.3182	0.5217	0.0055	0.0471	0.0001	0.0000	1.67E-07	0.4913	0.3089	0.0002
PF2	0.4879		0.9940	0.1972	0.0625	0.2691	0.0012	0.0004	1.08E-05	0.8755	0.8988	0.0031
PF3	0.3182	0.9940		0.1811	0.0086	0.1109	0.0001	0.0000	4.86E-08	0.9463	9.88E-01	0.0008
DF1	0.5217	0.1972	0.1811		0.0027	0.0210	0.0000	0.0000	1.33E-07	0.2187	0.1771	0.0001
DF2	0.0055	0.0625	0.0086	0.0027		0.4473	0.0371	0.0140	1.40E-03	0.0205	0.0224	0.1509
DF3	0.0471	0.2691	0.1109	0.0210	0.4473		0.0100	0.0032	2.40E-04	0.1640	0.2035	0.0432
SSF1	0.0001	0.0012	0.0001	0.0000	0.0371	0.0100		0.7261	0.5250	0.0001	0.0004	0.7325
SSF2	0.0000	0.0004	0.0000	0.0000	0.0140	0.0032	0.7261		8.52E-01	0.0000	0.0001	0.4986
SSF3	1.67E-07	1.08E-05	4.86E-08	1.33E-07	1.40E-03	2.40E-04	0.525	8.52E-01		1.79E-07	1.49E-06	0.2543
DSF1	0.4913	0.8755	0.9463	0.2187	0.0205	0.1640	0.0001	0.0000	1.79E-07		0.9761	0.0011
DSF2	0.3089	0.8988	9.88E-01	0.1771	0.0224	0.2035	0.0004	0.0001	1.49E-06	0.9761		0.0022
DSF3	0.0002	0.0031	0.0008	0.0001	0.1509	0.0432	0.7325	0.4986	0.2543	0.0011	0.0022	

**Figure 4.** Residual values related to the PL parameter

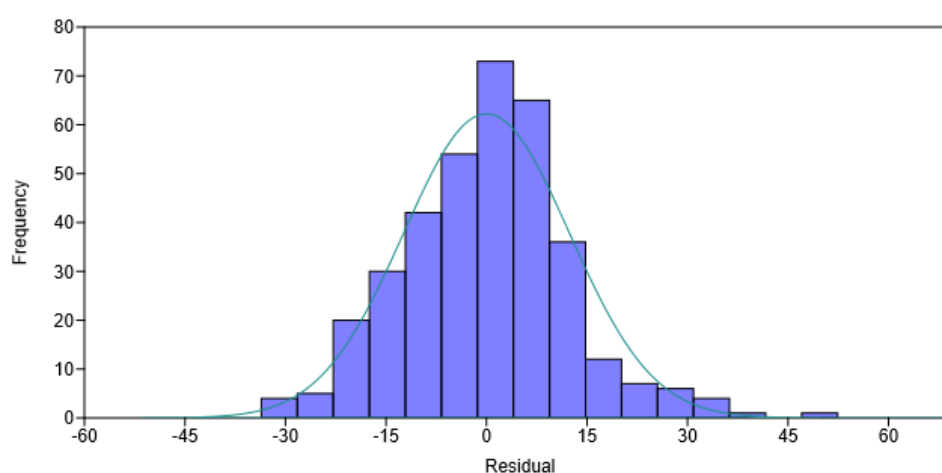
In the case of the PGN parameter, the difference between the mean values was confirmed (ANOVA Test), Table 13, and the Kruskal-Wallis test confirmed significant differences between the median values, $H(\text{Chi}^2) = 155.50$, H_c (tie corrected) = 155.60, $p < 0.001$. The Post hoc test was applied with the results in Table 14. The residual values from the comparative analysis presented a normal distribution, Figure 5.

Table 13. ANOVA Test result for PGN parameter

Table 15: ANOVA Test result for FCN parameter						
Statistical parameters		Sum of sqrs	df	Mean square	F	p (same)
Between groups:		40747.3	11	3704.3	23.35	9.17E-36
Within groups:		55205.1	348	158.635	Permutation p (n=99999)	
Total:		95952.4	359	1.00E-05		
Components of variance (only for random effects):						
Var(group):		118.189	Var(error):	158.635	ICC:	0.426945
omega²:		0.4058				
Levene’s test for homogeneity of variance, from means		p (same):	2.08E-11			
Levene’s test, from medians		p (same):	5.27E-10			
Welch F test in the case of unequal variances:			F=21.55, df=136.5, p=7.918E-25			
Bayes factor:			3.588E32 (decisive evidence for unequal means)			

Table 14. Post Hoc test results, for PGN parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PF1		0.7115	0.3073	0.0000	0.0000	0.0000	0.0000	0.0000	4.78E-08	0.1432	0.2517	0.0194
PF2	0.7115		0.5791	0.0000	0.0000	0.0000	0.0000	0.0000	1.27E-08	0.3326	0.1240	0.0796
PF3	0.3073	0.5791		0.0000	0.0000	0.0000	0.0000	0.0000	4.39E-08	0.6733	2.75E-02	0.2113
DF1	0.0000	0.0000	0.0000		0.2894	0.0792	0.0001	0.1407	1.90E-04	0.0008	0.0000	0.0330
DF2	0.0000	0.0000	0.0000	0.2894		0.4950	0.0126	0.7442	2.04E-02	0.0001	0.0000	0.0038
DF3	0.0000	0.0000	0.0000	0.0792	0.4950		0.0553	0.7056	9.57E-02	0.0000	0.0000	0.0009
SSF1	0.0000	0.0000	0.0000	0.0001	0.0126	0.0553		0.0209	0.6251	0.0000	0.0000	0.0000
SSF2	0.0000	0.0000	0.0000	0.1407	0.7442	0.7056	0.0209		3.49E-02	0.0000	0.0000	0.0013
SSF3	4.78E-08	1.27E-08	4.39E-08	1.90E-04	2.04E-02	9.57E-02	0.6251	3.49E-02		4.56E-07	2.01E-09	0.0000
DSF1	0.1432	0.3326	0.6733	0.0008	0.0001	0.0000	0.0000	0.0000	4.56E-07		0.0105	0.3868
DSF2	0.2517	0.1240	2.75E-02	0.0000	0.0000	0.0000	0.0000	0.0000	2.01E-09	0.0105		0.0008
DSF3	0.0194	0.0796	0.2113	0.0330	0.0038	0.0009	0.0000	0.0013	0.0000	0.3868	0.0008	

**Figure 5.** Residual values related to the PGN parameter

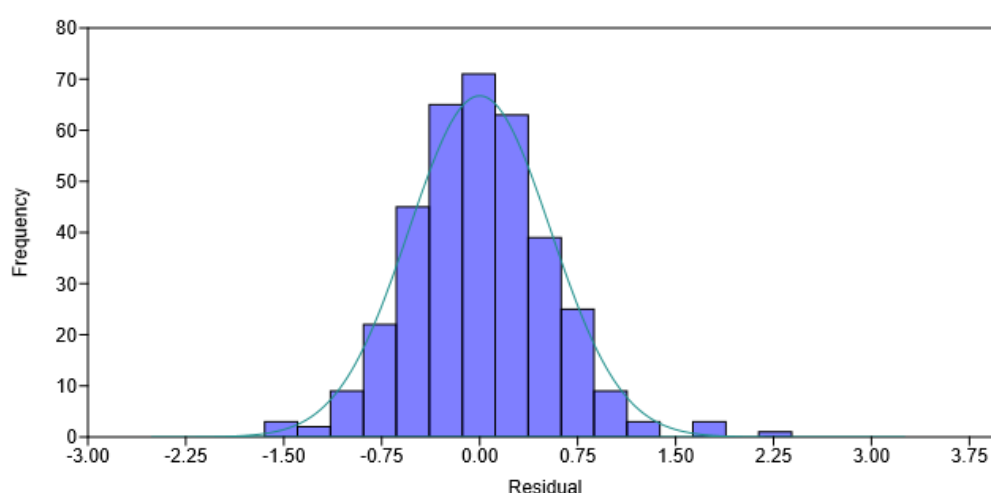
In the case of the PGW parameter, the difference between the mean values was confirmed (ANOVA Test), Table 15, and the Kruskal-Wallis test confirmed significant differences between the median values, $H(\text{Chi}^2) = 144.70$, H_c (tie corrected) = 144.80, $p < 0.001$. The Post hoc test (TEST NAME) was applied with the results in Table 16. The residual values from the comparative analysis presented a normal distribution, Figure 6.

Table 15. ANOVA Test result for PGN parameter

Statistical parameters	Sum of sqrs	df	Mean square	F	p (same)
Between groups:	90.1405	11	8.19459	26.96	2.07E-40
Within groups:	105.785	348	0.30398	Permutation p (n=99999)	
Total:	195.925	359	1.00E-05		
Components of variance (only for random effects):					
Var(group):	0.26302	Var(error):	0.30398	ICC:	0.463881
omega²:	0.4423				
Levene’s test for homogeneity of variance, from means	p (same):	9.30E-04			
Levene’s test, from medians	p (same):	4.17E-03			
Welch F test in the case of unequal variances:		F=19.27, df=136.6, p=7.386E-23			
Bayes factor:		1.479E37 (decisive evidence for unequal means)			

Table 16. Post Hoc test results, for PGW parameter

	PF1	PF2	PF3	DF1	DF2	DF3	SSF1	SSF2	SSF3	DSF1	DSF2	DSF3
PF1		0.8418	0.0836	0.0000	0.0001	0.0000	0.9058	0.1353	9.62E-02	0.0835	0.5443	0.0219
PF2	0.8418		0.3671	0.0000	0.0001	0.0000	0.6100	0.0785	1.52E-01	0.2281	0.4464	0.0823
PF3	0.0836	0.3671		0.0000	0.0000	0.0000	0.0614	0.0009	1.44E-03	0.6734	1.41E-02	0.2938
DF1	0.0000	0.0000	0.0000		0.0046	0.5691	0.0000	0.0000	7.73E-09	0.0000	0.0000	0.0000
DF2	0.0001	0.0001	0.0000	0.0046		0.0625	0.0004	0.0031	1.56E-03	0.0000	0.0007	0.0000
DF3	0.0000	0.0000	0.0000	0.5691	0.0625		0.0000	0.0000	2.06E-06	0.0000	0.0000	0.0000
SSF1	0.9058	0.6100	0.0614	0.0000	0.0004	0.0000		0.1452	0.1737	0.0736	0.5153	0.0232
SSF2	0.1353	0.0785	0.0009	0.0000	0.0031	0.0000	0.1452		9.47E-01	0.0023	0.4597	0.0015
SSF3	9.62E-02	1.52E-01	1.44E-03	7.73E-09	1.56E-03	2.06E-06	0.1737	9.47E-01		3.18E-03	3.87E-01	0.0032
DSF1	0.0835	0.2281	0.6734	0.0000	0.0000	0.0000	0.0736	0.0023	3.18E-03		0.0173	0.3830
DSF2	0.5443	0.4464	1.41E-02	0.0000	0.0007	0.0000	0.5153	0.4597	3.87E-01	0.0173		0.0074
DSF3	0.0219	0.0823	0.2938	0.0000	0.0000	0.0000	0.0232	0.0015	0.0032	0.3830	0.0074	

**Figure 6.** Residual values related to the PGW parameter

Cluster analysis was applied to find out the variants that led to similar results within each parameter. For the PH parameter, the cluster analysis led to the dendrogram in Figure 7 (Coph. corr. = 0.813). With the highest value for plant height (PH) was recorded the variant DF1, and in the same cluster were positioned, based on similarity, other variants.

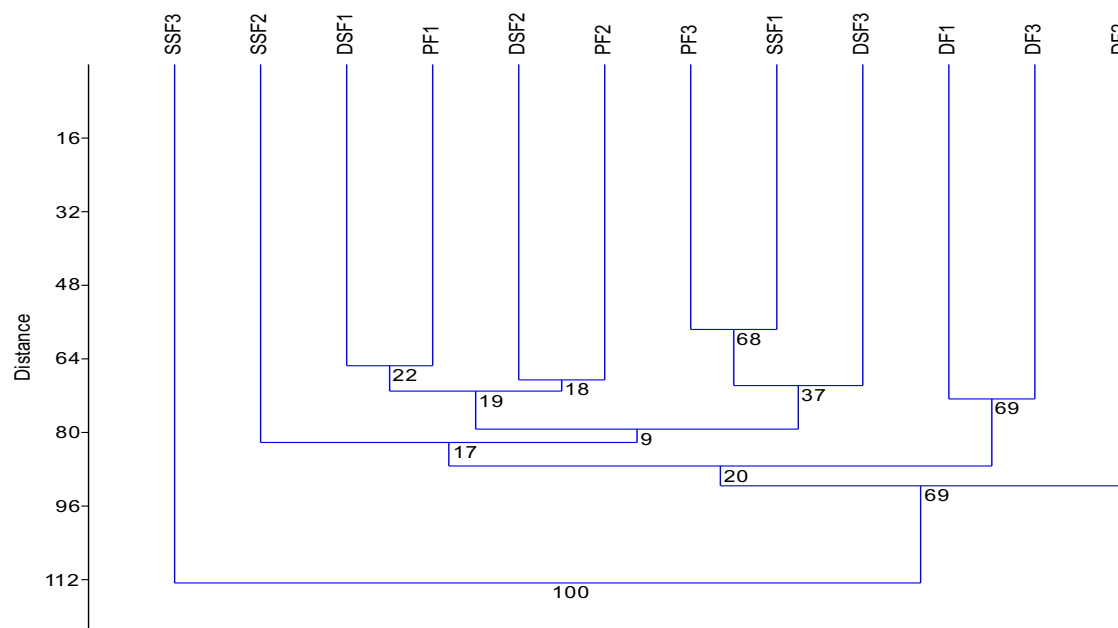


Figure 7. Cluster dendrogram based on PH parameter

For the LN parameter, the cluster analysis led to the dendrogram in Figure 8 (Coph. corr. = 0.859). The highest value for the number of leaves (LN) was recorded for the DSF3 variant, and the other variants were positioned, based on similarity, in two clusters with several subclusters.

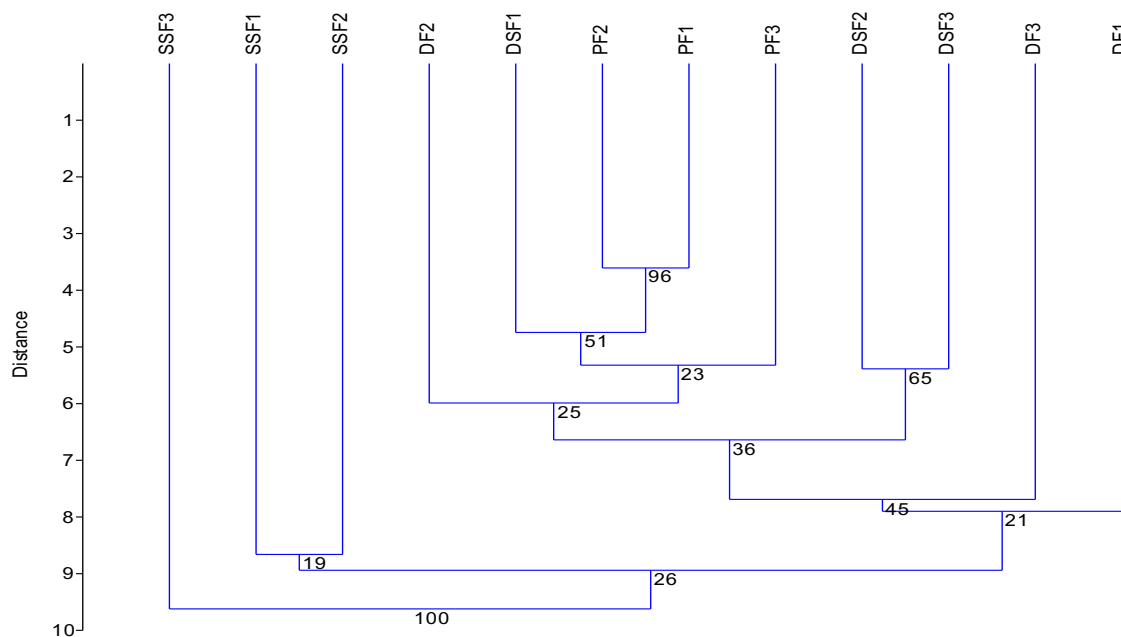


Figure 8. Cluster dendrogram based on LN parameter

For the PL parameter, the cluster analysis led to the dendrogram in Figure 9 (Coph. corr. = 0.871). The highest value for panicle length (PL) was recorded for the DF1 variant, and seven more variants were positioned in the same cluster based on similarity.

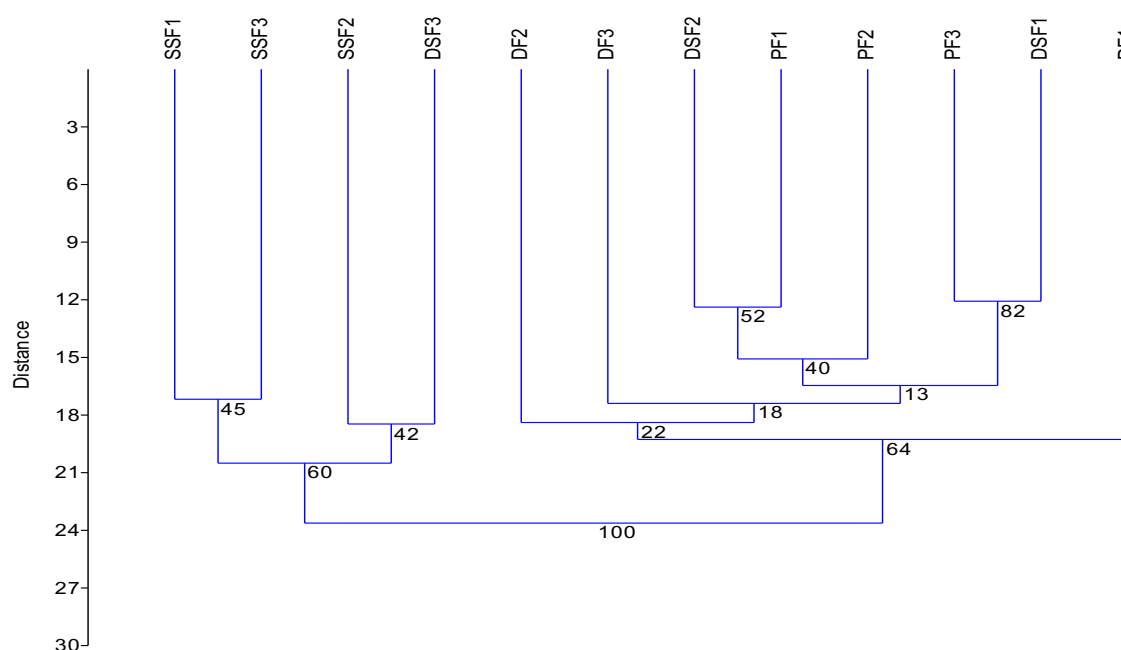


Figure 9. Cluster dendrogram based on PL parameter

For the PGN parameter, the cluster analysis led to the dendrogram in Figure 10 (Coph. corr. = 0.873). With the highest value for the number of grains in the panicle (PGN), the DSF2 variant was independently positioned, and the other variants were grouped into clusters based on similarity.

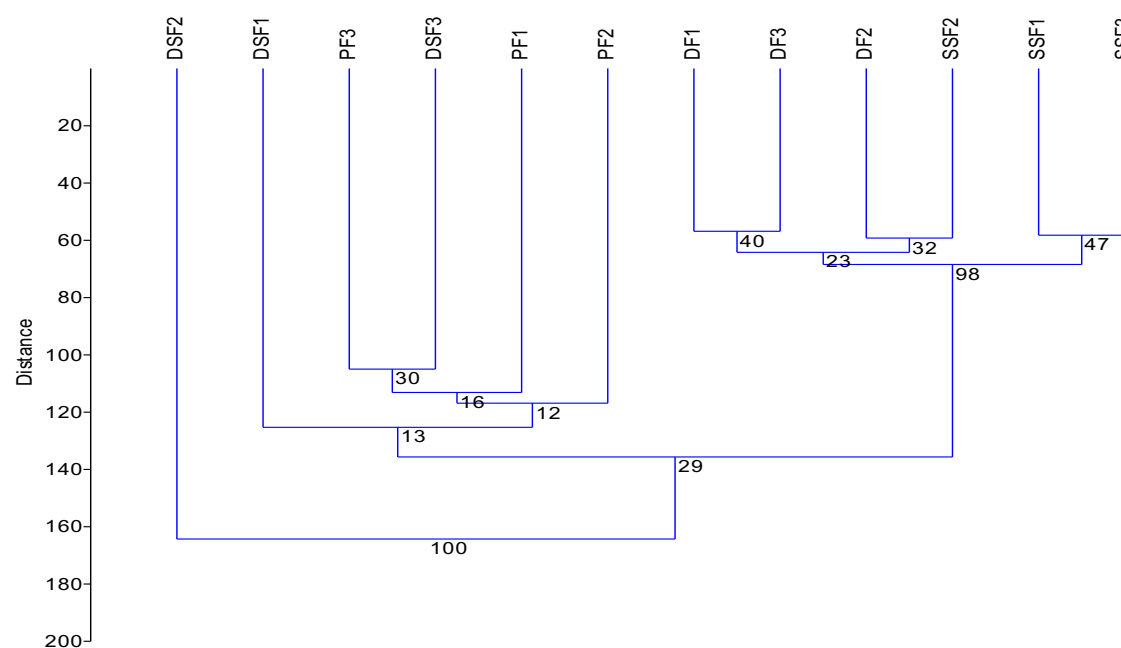


Figure 10. Cluster dendrogram based on PGN parameter

For the PGW parameter, the cluster analysis led to the dendrogram in Figure 11 (Coph. corr. = 0.959). With the highest value for panicle grain weight (PGW), variant DF1 was positioned in an independent cluster associated with variant DF3. Based on similarity, the other variants were grouped.

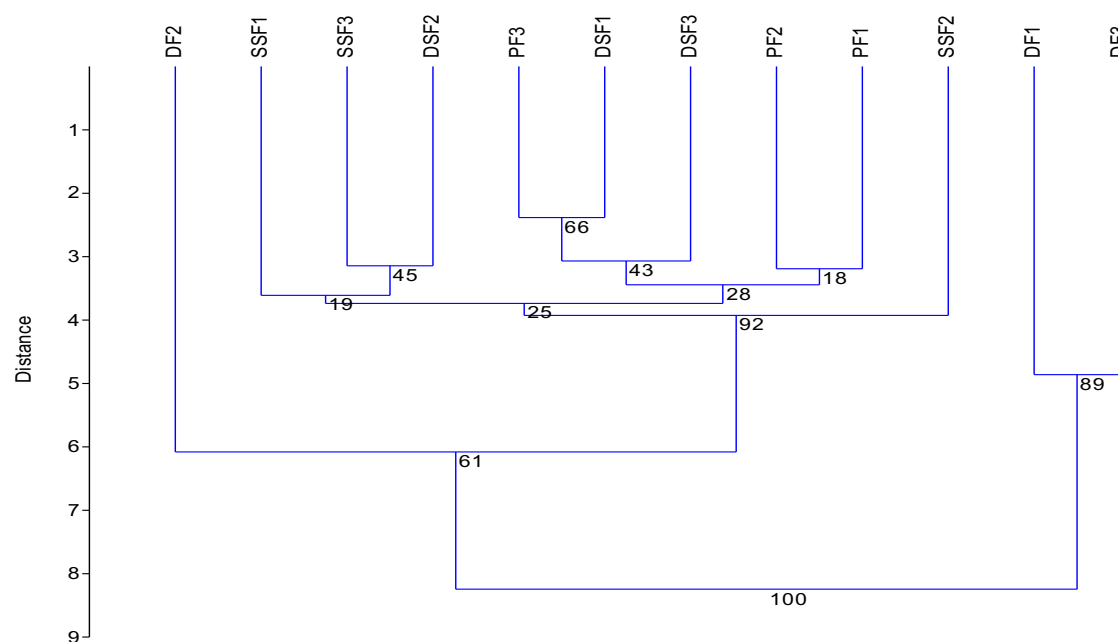


Figure 11. Cluster dendrogram based on PGW parameter

Multivariate analysis (PCA) showed the correlation of experimental variants with morphological parameters and productivity elements as biplot, in oat, 'Ovidiu' variety, Figure 12.

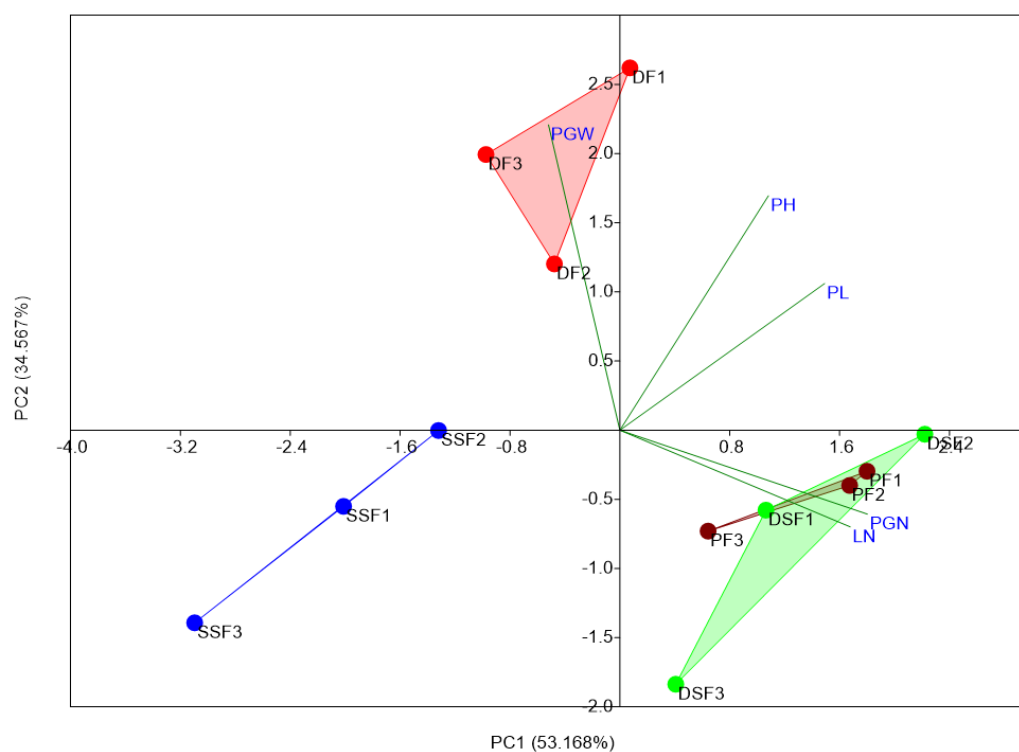


Figure 12. PCA diagram, correlation of variants with parameters of spring oat plants, 'Ovidiu' variety

The score of the variants in relation to the Principal Components is presented in Table 17, and the parameter loadings in the Principal Components are presented in Table 18.

Table 17. Variant score in Principal Components

	PC 1	PC 2	PC 3	PC 4	PC 5
PF1	1.7998	-0.2966	-0.2367	0.0592	-0.0218
PF2	1.6731	-0.3995	0.1383	0.0163	0.0022
PF3	0.6423	-0.7297	-1.0127	-0.3869	-0.0528
DF1	0.0733	2.6196	-0.4451	0.4497	-0.0709
DF2	-0.4766	1.2022	0.5433	0.0452	-0.1187
DF3	-0.9753	1.9933	-0.0075	0.0679	0.0874
SSF1	-2.0120	-0.5509	0.1395	-0.3175	-0.2780
SSF2	-1.3203	-0.0023	1.0883	-0.6310	0.0998
SSF3	-3.0962	-1.3926	-0.8022	0.3086	0.3211
DSF1	1.0640	-0.5778	-0.4826	-0.2576	-0.3185
DSF2	2.2208	-0.0290	0.2414	-0.1852	0.4776
DSF3	0.4072	-1.8367	0.8361	0.8313	-0.1274

Table 18. Parameter loadings in Principal Components

	PC 1	PC 2	PC 3	PC 4	PC 5
PH	0.3468	0.5434	0.5626	-0.5157	-0.0438
LN	0.5380	-0.2242	0.4381	0.6269	-0.2745
PL	0.4780	0.3399	-0.6727	-0.0159	-0.4508
PGN	0.5779	-0.1944	-0.1960	-0.0949	0.7621
PGW	-0.1667	0.7079	-0.0240	0.5760	0.3725

The two main components explained 87.735%% of the total variance. The independent positioning of the variants given by superficial scarification (SS) associated with the three types of fertilization (SSF1, SSF2, SSF3) in relation to plant parameters was observed.

The variants considered on soil preparation with the disk (DF1, DF2, DF3) were correlated with the PGW parameter, and the variants made on soil preparation by plowing (P) and deep scarification (DS) were correlated with the LN and PGN parameters. The PH and PL parameters were positioned intermediate between the variants made with the disk (D) and those by plowing and deep scarification (P, DS).

The variability of crop plant response was evaluated and analyzed in relation to different types of fertilizers and bioactive products (Pirvulescu et al., 2015; Blaes et al., 2016; Kihara et al., 2016; Nziguheba et al., 2021; López-Atanacio et al., 2022). Also, different models for optimizing some indicators in agricultural crops in relation to fertilizers were communicated (Boldea and Sala, 2010; Xing and Wang, 2024; Rangaiah et al., 2025).

Mineral fertilization associated with soil works generated differentiated variability in parameters of spring oat plants, 'Ovidiu' variety, under the study conditions. Low variability was recorded in the PH parameter in all experimental variants. In the case of the LN parameter, low variability was recorded in seven variants, and moderate variability in five variants (DF1, DF3, SSF1, SSF2 and SSF3). In the case of the PL parameter, low variability was recorded in nine variables and moderate variability in three variants (SSF1, SSF2 and DSF3). In the case of the PGN parameter, low variability was recorded in one variant (DF1), moderate variability in two variants (SSF2 and SSF3) and variability in the other variants. In the case of the PGW parameter, moderate variability was recorded in three variants (PF3, DF1 and DF3) and variability in the other variants.

Through cluster analysis, the response level of some crop plants in relation to location and different types of fertilization was identified (Kihara et al., 2016; Venugopal et al., 2024; Nagendrachi et al., 2025). The information provided by the cluster dendrograms generated in this study facilitated the identification of those variants that provided similar values for morphological parameters and productivity elements in oat plants, in relation to the established objectives. Thus, the variants (tillage x fertilization) that generated performance in oat cultivation, under non-irrigated cultivation conditions, can be identified.

Multivariate analysis (PCA) explained soil quality indices, physiological indices, agronomic parameters and productivity elements in agricultural crops under different experimental conditions (Zhou et al., 2022; Rangaiah et al., 2025). The results of the multivariate analysis clarified in the present study the correlation of experimental variants with agronomic parameters of oat plants, and the main two principal components (PC1, PC2) explained most of the variation in the experimental data.

CONCLUSIONS

The land preparation systems and applied fertilizations differentially influenced morphological parameters and productivity elements in spring oat, the 'Ovidiu' variety, under the study conditions.

The disc tillage system (D) associated with the three fertilization systems predominantly influenced the PGW parameter, and the DF1 variant generated the highest average value for the PGW parameter ($PGW = 2.69 \pm 0.14$ g), followed by the DF3 variant with $PGW = 2.46 \pm 0.13$ g, respectively by the DF2 variant with $PGW = 2.07 \pm 0.13$ g.

The deep scarification (DS) tillage system associated with F2 fertilization (DSF2 variant) generated the highest value for the PGN parameter ($PGN = 54.60 \pm 3.32$ grains), followed by the PF1 variant with the average PGN value = 49.03 ± 3.08 grains, respectively the PF2 variant, with the average PGN value = 47.87 ± 3.08 grains.

The disc tillage system (D) associated with F1 fertilization (DF1 variant) generated the highest mean value for the PL parameter, with $PL = 15.80 \pm 0.45$ cm. This was followed by PF1 variant with a mean $PL = 15.35 \pm 0.35$ cm, and DSF1 variant with a mean $PL = 15.15 \pm 0.34$ cm.

Regarding plant height, the DF1 variant led to an average value of $PH = 89.03 \pm 1.98$ cm (the highest value), followed by the DSF2 variant, with an average value of $PH = 89.00 \pm 1.70$ cm, and respectively by the DF2 variant, with an average value of $PH = 87.87 \pm 2.06$ cm.

The DSF3 variant strongly influenced the number of leaves per plant, with the average value $LN = 5.70 \pm 0.12$ leaves, followed by the PF2 variants ($LN = 5.47 \pm 0.10$ leaves) and DSF2 ($LN = 5.47 \pm 0.17$ leaves).

By the overall analysis of the results, it was appreciated that under the study conditions, the land preparation variants that mobilized the soil to a greater depth generated positive effects in plant parameters, compared to the superficial soil preparation variants. Regarding fertilization, among the tested variants (F1, F2, F3), associated with land preparation works, the F1 and F2 variants were more frequently associated with high values of the considered parameters, and especially with productivity parameters (PGN, PGW). The F3 fertilization variant was found to be involved in high values only for the LN parameter.

The results recorded are of great importance for agricultural practice, in order to optimize the cultivation technology of spring oats, non-irrigated system, under the conditions of climate change and sustainable use of agricultural land.

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