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Integrated organic and chemical fertilizer strategies for sustainable corn yield and quality

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Abstract: This study evaluated the effects of different fertilizer applications on yield and quality parameters of the Simpatico (FAO 300) silage maize cultivar, aiming to assess the role of organomineral and foliar fertilizers in sustainable agriculture. The experiment was conducted under field conditions over two years using combinations of granular (DAP, UREA, OMB, OMT) and foliar (Seaweed, Humic Acid, Vermicompost) fertilizers. Granular fertilizers were soil-applied during sowing, while foliar treatments were applied at V4–V6, V11–V13, V14–V16, and tasseling stages. DAP-OMT and OMB-OMT treatments improved yield traits, while DAP-UREA showed the lowest performance. Vermicompost enhanced plant height and crude protein. Humic Acid increased dry matter yield and ratio. Seaweed improved digestible dry matter, intake, and relative feed value. ADF and NDF were highest in plots without foliar application. The best overall performance was observed in OMB-OMT-VC and DAP-OMT-HA combinations. The results confirm the effectiveness of organomineral and foliar fertilizers in improving maize performance and forage quality. The integration of organomineral and foliar fertilizers can reduce reliance on purely chemical fertilization, offering a more sustainable approach to improving forage quality.

Keywords: Corn, Organo-Mineral, Humic acid, Seaweed, Sustainable agriculture, Vermicompost.

Introduction

The rapidly increasing global population has intensified the demand for plant- and animal-based products. In animal production, forage costs account for nearly 70% of total expenses, and the insufficiency of pastures limits access to high-quality feed, leading to productivity losses. Therefore, expanding forage crop cultivation and improving productivity is of critical importance (Xu et al., 2020). Corn, due to its high yield potential and versatile use as grain, green fodder, and silage, is one of the most important feed crops in animal nutrition (Demin & Eremina, 2020). High energy content, easy digestibility, and storage advantages make silage corn particularly valuable in milk and meat production (Heuzé et al., 2017). Among the factors affecting silage yield and quality, fertilization plays a key role (Ahmad et al., 2018). Excessive use of chemical fertilizers may cause salinization and nutrient imbalance over time (Kamaei et al., 2019). Therefore, organic and organomineral fertilizers have gained importance for improving soil properties while sustaining productivity (Aquino et al., 2024; Uddin et al., 2025). In crop production, fertilizer type, dose, timing, and application method are equally important (Ağırağaç & Zorer Çelebi, 2025). When essential nutrients are insufficient or unavailable in soil, foliar fertilizers provide a rapid and effective solution (Veneziano et al., 2022). In recent years, the use of organic-based foliar fertilizers such as vermicompost, seaweed, and humic acid has increased. Vermicompost enhances nutrient uptake and stress tolerance (Garg & Gupta, 2010; Doan et al., 2014). Seaweed extracts support plant growth, particularly under stress conditions (Kumar et al., 2012; El Boukhari et al., 2020). Humic acid improves plant development and soil properties (Selladurai & Purakayastha, 2016). This study evaluated the effects of organomineral and chemical granular fertilizers combined with humic acid, seaweed, and vermicompost foliar applications on yield and quality parameters of silage maize, aiming to contribute to sustainable agricultural practices.

Results

Differences in the yield and quality parameters according to the application of fertilizers from the soil

When examining the effects of soil-applied fertilizers on the corn plant, it was observed that all treatments yielded similar results for the NDF, DMI, and RFV parameters, with no statistically significant differences between them. However, for PH, DM, DMR, CP, and ADF parameters, the DAP-OMT and OMB-OMT treatments had a more pronounced effect, while the DAP-UREA treatment showed the lowest values. In terms of the DDM parameter, the highest result was obtained with the DAP-UREA treatment (71.59%), followed by the DAP-OMT treatment, which was in the same statistical group (70.76%) (Table 1; Fig 1).

Table 1. Comparison of the effects of soil-applied fertilizers on yield and quality parameters of corn (two-year average).

	TREATMENT		
Parameters	DAP-UREA	DAP-OMT	OMB-OMT
PH (cm)	217.81±6.7^{b}	222.56±6.86^{a}	221.1±5.62^{ab}
DM (kg/da)	1710.17±131.37^{b}	1894.88±189.03^{a}	1885.17±173.79^{a}
DMR (%)	26.73±1.42^{b}	28.53±1.71^{a}	28.54±1.57^{a}
CP (%)	6.5±0.34^{b}	6.76±0.38^{a}	6.86±0.42^{a}
ADF	22.22±2.94^{b}	23.29±2.29^{ab}	23.8±2.07^{a}
NDF	40.52±2.47	40.91±1.93	41.44±1.48
DDM (%)	71.59±2.29^{a}	70.76±1.78^{ab}	70.36±1.61^{b}
DMI (%)	2.97±0.18	2.94±0.14	2.9±0.1
RFV	165.19±14.69	161.32±11.09	158.16±8.38

Different letters in the same line mean significantly differences at P< 0.01.

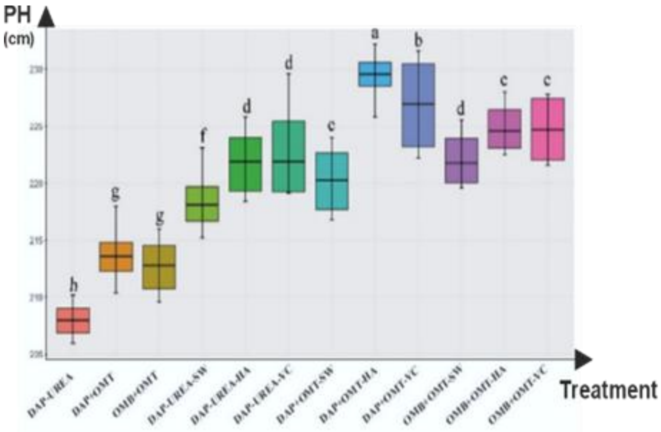

Figure 1. Two-year mean values and grouping results for the effects of fertilizer combinations on PH.

The role of foliar fertilizer addition in yield and quality parameters

The effects of foliar fertilizers are presented in Table 2 and Fig 2, and differences from the control are expressed as percentages. Under DAP-UREA fertilization, VC provided the highest PH and CP increases (7.1% and 13.6%)(Fig 4), while HA was more effective for DM and DMR (21.7% and 14%). SW showed the strongest effect on DDM, DMI, and RFV, increasing them by 8.6%, 15.3%, and 25.5%, respectively. The DAP-UREA treatment without foliar fertilizer generally produced the lowest values, except for ADF and NDF. Under DAP-OMT fertilization, HA and VC yielded the best results for PH, DM, and CP, with average increases of 6.7%, 27.4%, and 14%, respectively. SW significantly improved DDM and DMI (6.4% and 11.5%) and, together with VC, enhanced RFV (18.3% and 8.8%). The highest ADF and NDF values were observed in plots without foliar fertilizer. In OMB-OMT applications, foliar fertilizers showed similar effects on PH and DMR, with average increases of 5.2% and 12%. VC significantly improved DM and CP (26.3% and 17%), whereas SW provided the best DDM, DMI, and RFV results (4.7%, 8.2%, and 13.4%) and produced the lowest ADF (Fig 5) and NDF values (Fig 6).

Differences in yield and quality of fertilizer combinations

The results of the variance analysis are presented in Table 3 and Fig 3. In both years, application and year effects were significant (P<0.01). In the combined analysis, the year × application interaction was significant for PH, DM, and DMR (P<0.01), while it was insignificant for the other parameters. Based on the two-year averages, the highest PH was obtained from DAP-OMT-HA (229.36 cm), followed by DAP-OMT-VC (226.86 cm). For DM, the highest values were recorded from OMB-OMT-VC, DAP-OMT-VC, and DAP-OMT-HA (approximately 2035–2040 kg/da), while the lowest value was observed in DAP-UREA (1514.00 kg/da). Similar trends were observed for DMR and CP, with OMB-OMT-VC and DAP-OMT-HA among the top-performing treatments and DAP-UREA producing the lowest values. Regarding fiber fractions, the highest ADF and NDF values were generally recorded in DAP-UREA and other treatments without foliar fertilizer, whereas the lowest values were obtained from DAP-UREA-SW. Consistently, DAP-UREA-SW provided the highest DDM (Fig 7), DMI (Fig 8), and RFV (Fig 9) values, while DAP-UREA showed the lowest results for these quality indices. Overall, DAP-OMT-HA and OMB-OMT-VC stood out in terms of PH, DM, DMR, and CP, whereas DAP-UREA generally resulted in the lowest performance except for ADF and NDF, highlighting the positive effects of organomineral and foliar fertilizer combinations on yield and quality parameters.

Materials and Methods

Study area, soil sampling, and climate data

The research was conducted in Van, Turkey, located at 38°34'18.8" N latitude and 43°17'17.5" E longitude, with the main crop corn planted on May 10, 2022, and May 5, 2023. During the study period, the impacts of global climate change were

Table 2. Differences in yield and quality parameters of foliar fertilizers used in combination with soilbased fertilizers (two-year average).

	DAP+UREA			
Parameters	DAP-UREA	DAP-UREA-SW	DAP-UREA-HA	DAP-UREA-VC
PH (cm)	208±1.58^{c}	218.48±2.87^{b}	221.85±3.11^{ab}	222.9±4.37^{a}
DM (kg/da)	1513.83±52.11^{c}	1723±30.52^{b}	1842.83±38.46^{a}	1761±59.9^{b}
DMR (%)	24.76±0.76^{c}	27.04±0.65^{b}	28.25±0.39^{a}	26.87±0.73^{b}
CP (%)	5.99±0.08^{c}	6.57±0.24^{b}	6.64±0.07^{b}	6.81±0.12^{a}
ADF	26.59±0.84^{a}	19.03±0.71^{c}	21.54±0.82^{b}	21.71±1.4^{b}
NDF	44.03±1.1^{a}	38.08±0.75^{c}	39.62±1.57^{b}	40.33±0.98^{b}
DDM (%)	68.18±0.65^{c}	74.08±0.55^{a}	72.12±0.64^{b}	71.99±1.09^{b}
DMI (%)	2.73±0.07^{c}	3.15±0.06^{a}	3.03±0.12^{b}	2.98±0.07^{b}
RFV	144.1±4.37^{c}	180.97±4.74^{a}	169.58±8.2^{b}	166.1±5.23^{b}
	DAP+OMT			
	DAP+OMT	DAP+OMT-SW	DAP+OMT-HA	DAP+OMT-VC
PH (cm)	213.77±2.63^{c}	220.25±3.03^{b}	229.37±2.22^{a}	226.87±4.3^{a}
DM (kg/da)	1598.33±57.57^{c}	1905.83±43.62^{b}	2034.83±37.54^{a}	2040.5±55.93^{a}
DMR (%)	25.85±0.74^{b}	28.97±0.56^{a}	29.72±0.62^{a}	29.6±0.6^{a}
CP (%)	6.17±0.07^{c}	6.82±0.05^{b}	6.99±0.13^{a}	7.08±0.13^{a}
ADF	25.77±0.63^{a}	20.1±0.73^{c}	23.5±1.42^{b}	23.78±1.12^{b}
NDF	43.13±0.93^{a}	38.81±1.42^{c}	41.23±1.62^{b}	40.49±0.34^{b}
DDM (%)	68.82±0.49^{c}	73.24±0.57^{a}	70.59±1.1^{b}	70.38±0.88^{b}
DMI (%)	2.78±0.06^{c}	3.1±0.12^{a}	2.91±0.11^{b}	2.96±0.03^{b}
RFV	148.47±3.08^{c}	175.75±7.48^{a}	159.41±6.52^{b}	161.65±2.37^{a}
	OMB+OMT			
	OMB+OMT	OMB+OMT-SW	OMB+OMT-HA	OMB+OMT-VC
PH (cm)	212.73±2.54^{b}	222.12±2.49^{a}	224.87±2.27^{a}	224.7±3.11^{a}
DM (kg/da)	1611±52.43^{c}	1924.5±32^{b}	1969.83±55.1^{b}	2035.33±66.4^{a}
DMR (%)	26.17±0.81^{b}	29.27±0.45^{a}	28.98±0.71^{a}	29.74±0.79^{a}
CP (%)	6.2±0.08^{d}	6.91±0.08^{c}	7.07±0.09^{b}	7.26±0.2^{a}
ADF	25.03±1.03^{a}	20.75±0.94^{b}	24.63±0.8^{a}	24.78±1.47^{a}
NDF	43.05±1.09^{a}	39.76±0.62^{c}	41.8±0.99^{b}	41.17±0.88^{b}
DDM (%)	69.4±0.8^{b}	72.73±0.73^{a}	69.71±0.63^{b}	69.6±1.14^{b}
DMI (%)	2.79±0.07^{c}	3.02±0.05^{a}	2.87±0.07^{b}	2.92±0.06^{b}
RFV	150.02±4.66^{c}	170.17±2.53^{a}	155.17±3.16^{b}	157.29±4.53^{b}

Different letters in the same line mean significantly differences at P< 0.01.

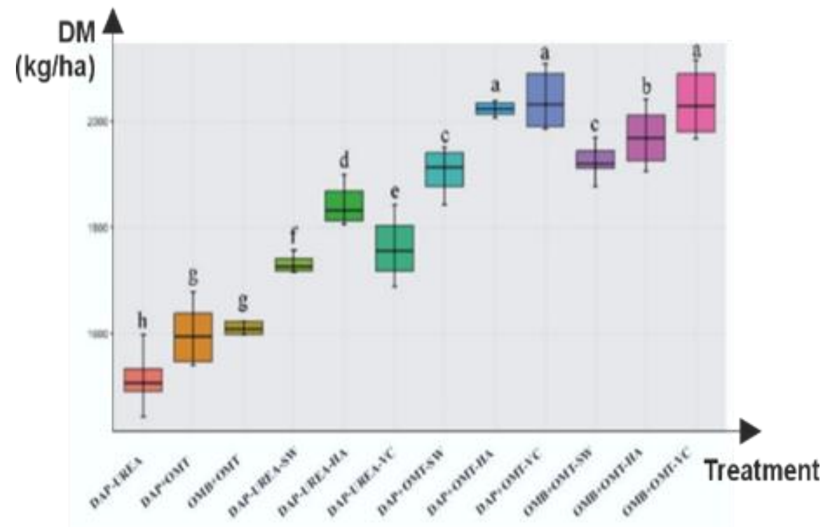

Figure 2. Two-year mean values and grouping results for the effects of fertilizer combinations on DM.

also observed in the region, with an increase in temperature and a decrease in precipitation and humidity compared to the long-term averages. The sowing was performed using a six-row maize planter, with a row spacing of 70 cm and an intra-row spacing of 12 cm. Each plot was arranged as 21 m² (6 rows × 70 cm × 5 m), with 250 cm between plots and 300 cm between blocks. According to the soil analysis results from TOB (2021), the soil in the experimental area is slightly alkaline with a sandy-loam texture. It has a low organic matter content and is classified as slightly calcareous.

Table 3. Analysis of variance table explaining the effect of fertilizer combinations on yield and quality parameters of corn.

Sources of Variation	F value								
	2022								
	PH (cm)	DM (kg/da)	DMR (%)	CP (%)	ADF(%)	NDF(%)	DDM (%)	DMI (%)	RFV
Block	0.02	0.03	0.04	0.20	0.47	1.10	0.478	0.830	0.295
Treatment	100.81**	91.17**	35.03**	48.38**	21.30**	11.42**	21.277**	11.706**	27.258**
CV(%)	0.47	1.81	1.98	1.40	4.30	2.90	1.25	2.40	3.10
2023									
	PH (cm)	DM (kg/da)	DMR (%)	CP (%)	ADF(%)	NDF(%)	DDM (%)	DMI (%)	RFV
Block	4.70	0.54	0.54	0.33	1.64	1.63	2.440	1.936	1.683
Treatment	81.32**	136.22**	41.44**	54.42**	18.17**	12.11**	14.527**	12.232**	23.734**
CV(%)	0.55	1.45	1.90	1.44	4.50	3.00	1.25	2.40	3.00
	Two-Year **Mean** (2022-2023)								
	PH (cm)	DM (kg/da)	DMR (%)	CP (%)	ADF(%)	NDF(%)	DDM (%)	DMI (%)	RFV
Block	3.01	0.17	0.15	0.50	0.62	0.13	0.622	0.260	0.596
Treatment	163.47**	221.98**	74.59**	105.79**	37.96**	20.99**	37.886**	20.986**	48.120**
Year	286.98**	78.53**	29.08**	33.53**	16.97**	18.01**	16.961**	18.398**	34.167**
Year×Treatment	2.75**	3.07**	3.16**	1.63	0.43	1.01	0.435	1.148	1.376
CV(%)	0.51	1.63	1.94	1.42	4.40	2.95	1.25	2.40	3.05

** P< 0.01

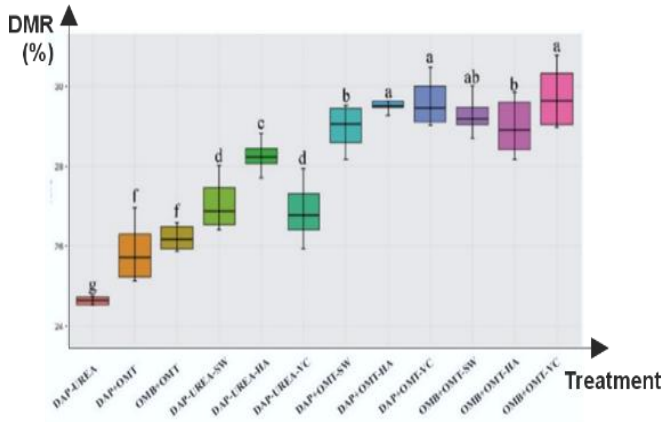

Figure 3. Two-year mean values and grouping results for the effects of fertilizer combinations on DMR.

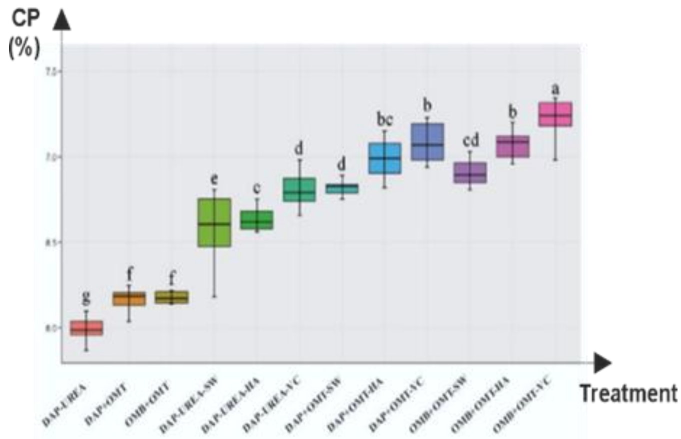

Figure 4. Two-year mean values and grouping results for the effects of fertilizer combinations on CP.

Sources of materials

The corn variety Simpatico (FAO 300) was used in the study. Diammonium phosphate (DAP) and organomineral base (OMB) fertilizers were applied as basal fertilizers, while UREA and organomineral top (OMT) fertilizers were used as topdressings. Seaweed, humic acid, and vermicompost were applied as foliar fertilizers.

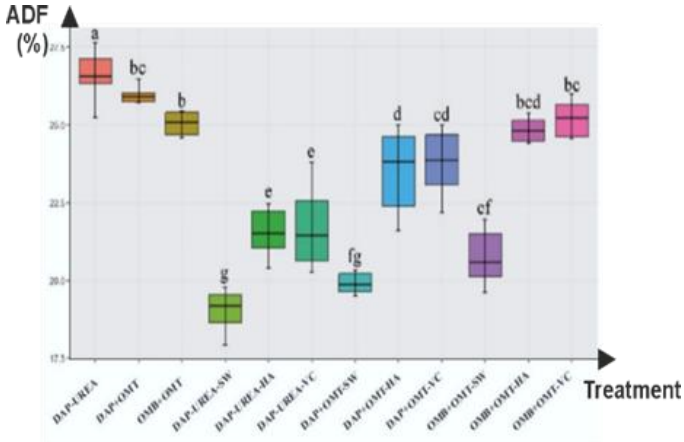

Figure 5. Two-year mean values and grouping results for the effects of fertilizer combinations on ADF.

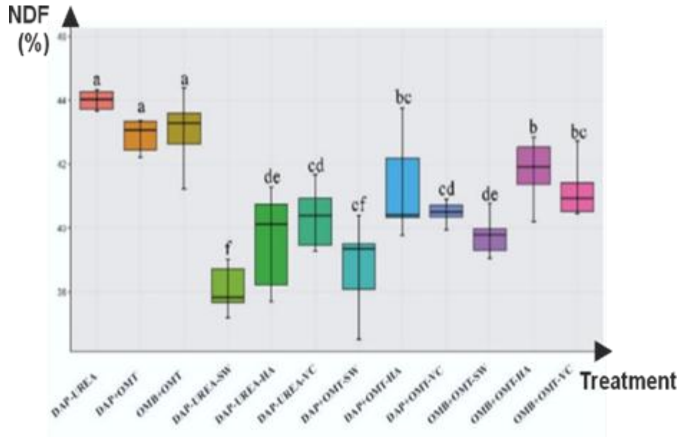

Figure 6. Two-year mean values and grouping results for the effects of fertilizer combinations on NDF.

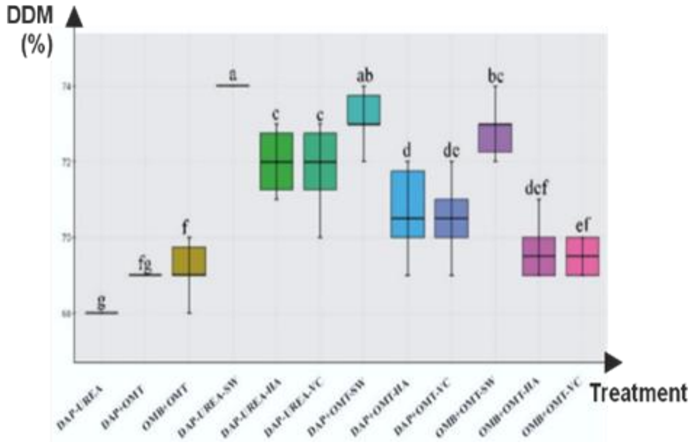

Figure 7. Two-year mean values and grouping results for the effects of fertilizer combinations on DDM.

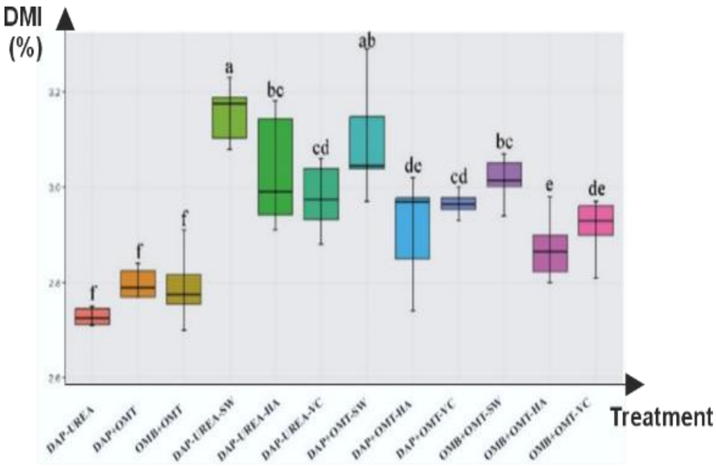

Figure 8. Two-year mean values and grouping results for the effects of fertilizer combinations on DMI.

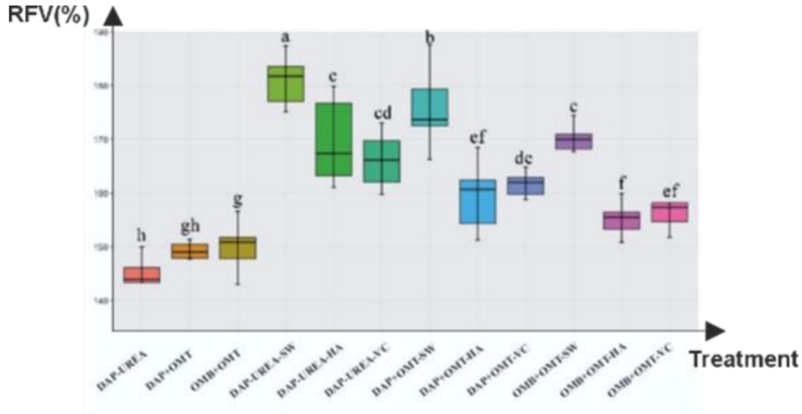

Figure 9. Two-year mean values and grouping results for the effects of fertilizer combinations on RFV.

Experimental design and statistical analysis
The experiment was established using a randomized block design with three replications. Each plot was 5 meters in length, with a spacing of 250 cm between plots and 300 cm between blocks. The planting was done with a row spacing of 70 cm and 12 cm between plants in the row. A total of 90 kg/ha of pure phosphorus and 170 kg/ha of pure nitrogen were applied, with soil fertilizers being administered in two stages (at planting and at the 8-12 leaf stage). Foliar fertilizer applications were carried out on designated plots during the V4-V6 (4-6 leaf), V11-V13 (11-13 leaf), V14-V16 (14-16 leaf), and VT (tasseling) stages. The application doses for foliar fertilizers (over four different periods), as recommended by the respective companies, were 600 cc/ha for seaweed (SW), 400 g/ha for humic acid (HA), and 2500 mL/ha for vermicompost (VC). A total of 12 treatment combinations were created using basal, top, and foliar fertilizers. The harvest was conducted at the R3 stage (August 18 in the first year, August 10 in the second year). In the study, plant height (PH), dry matter yield (DM), dry matter content (DMR), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), digestible dry matter (DDM), dry matter intake (DMI), and relative feed value (RFV) were examined. PH was determined by averaging the measurements of 10 randomly selected plants from each plot. DM was calculated by drying plant samples in an oven at 70°C until constant weight was achieved. CP was calculated by multiplying nitrogen (N) content, measured using a Kjeldahl nitrogen analyzer, by 6.25 (AOAC, 1990). NDF and ADF analyses were performed using the methods of Van Soest et al. (1991). Amylase and sodium sulfite were used in the NDF analysis, and the results were expressed on a dry matter basis, including ash content. The digestible DDM, DMI, and RFV were calculated using the following equations (Rohweder, 1978):

$$DDM\% = 88.9 - (0.779XADF\%)$$

$$DDI\% = \frac{120}{NDF\%}$$

$$RFV = \frac{DDM\%xDMI\%}{1.29}$$

Analysis of variance (ANOVA) was performed to test the significance of treatments, i.e., basal/top fertilizer and foliar fertilizer applications. When treatment effects were significant, means were separated using Duncan's multiple range test. Statistical significance was declared at *P < 0.05 and **P < 0.01, where applicable. The obtained data were analyzed using SPSS 27.0 statistical software according to a randomized complete block design (Mertler et al., 2021).

Discussion and Conclusion

Corn is widely used in agriculture, particularly as silage feed. Although chemical fertilizers increase yield, they pose risks to soil sustainability; therefore, organic and organomineral fertilizers have gained importance due to their environmental and soil health benefits. Fertilization timing and method are critical for corn growth, and foliar fertilizers have become a practical alternative (Fernández and Brown, 2013). PH, one of the parameters examined in the study, is directly related to silage yield (Olgun et al., 2012). The DAP-OMT-HA application gave the most favorable PH results, followed by DAP-OMT-VC. The superior performance of DAP compared to OMB as a base fertilizer is related to nitrogen form. De Grazia et al. (2003) reported that phosphorus had no significant effect on plant height, whereas nitrogen increased it. Nitrogen in DAP is in ammonium form, which dissolves and is absorbed faster than urea (Baran and Uygun, 2017). Early nitrogen availability is critical, particularly between V3 and V12 stages (Safdarian et al., 2014; Kaya, 2020). Increased nitrogen promotes rapid early growth and vegetative development (Rhezali and Rabii, 2020; El-Sobky and Abdo, 2020). OMT performed better than UREA in top dressing, likely due to sulfur oxide and humic-fulvic acids. Sulfur enhances nitrogen uptake, and humic substances improve nutrient utilization (Imran and Al Tawaha, 2022; Kouame et al., 2025). Among foliar fertilizers, HA showed the best PH response, followed by VC. Foliar fertilization increases nutrient content and yield (Niu et al., 2020; Veneziano et al., 2021). HA was more effective than VC due to its nitrogen form, as organic nitrogen requires conversion before plant uptake (Tokalak, 2020). Corn accumulates most dry matter during the generative period, especially between

R2 and R3 stages (Bender et al., 2013; Kaya, 2020). Agronomic practices applied up to R3 significantly influence dry matter accumulation. In this study, treatments including foliar fertilizers (OMB-OMT-VC, DAP-OMT-VC, DAP-OMT-HA) showed higher dry matter than non-foliar treatments. This increase is associated with enhanced photosynthetic activity. Nitrogen fertilization increases leaf area and photosynthetic efficiency (Luo et al., 2015; Sieling and Kage, 2021). Zinc, copper, and sulfur also support photosynthesis and protein synthesis (Tsonev and Lidon, 2012; McCauley et al., 2009; Thirunavukkarasu et al., 2023). The OMB-OMT-VC application yielded the best CP results. Although cereals generally contain lower CP than legumes, corn's high energy content compensates for this (McDonald, 1981; Açıkgöz, 1991). NDF and ADF are key indicators of feed quality and are inversely related to nutritional value (Behrouzi et al., 2023; Najaf Abadi et al., 2017). The highest ADF and NDF values were observed in treatments without foliar fertilizers, while the lowest values were obtained from SW applications. Although VC and HA increased CP more than SW, they also showed higher ADF-NDF values, possibly due to earlier maturation. Shortened vegetative period and accelerated maturity increase ADF levels (Cherney et al., 1990; Belyea et al., 1999; Rocateli and Zhang, 2017). Nitrogen and phosphorus in VC may have accelerated development, explaining maturity differences at harvest (Bolat and Kara, 2017). Regarding feed quality indices, the highest DDM, DMI, and RFV values were obtained from DAP-UREA-SW, while the lowest values were associated with DAP-UREA. The inclusion of SW improved these parameters, emphasizing the importance of foliar fertilization. Foliar nutrient supply is considered effective and environmentally favorable (Villares et al., 2013). In soils with high lime and pH, micronutrient uptake may be limited (Fageria and Santos, 2002). SW applications improved DDM, DMI, and RFV by 4–7% compared to HA and VC. SW extracts function as biostimulants that enhance growth, photosynthesis, and product quality (Babilie et al., 2015; Zhang et al., 2023). As a result, the combination of organomineral fertilizers with foliar applications such as humic acid, seaweed, and vermicompost can enhance the growth, yield, and quality of silage corn while improving nutrient use efficiency. Therefore, optimizing these fertilization strategies is essential for supporting sustainable agricultural production and reducing the environmental impacts associated with conventional fertilizer use.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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A few source entries deserve particular attention before publication. **Niu et al. (2020)** contains the apparent source-text error **“tnitrogenadinin”**, which should be checked against the original article rather than guessed. **Najaf Abadi et al. (2017)** has an unusual combination of journal volume/year and should be verified. **Rocateli & Zhang (2017)** gives “PSS-2225” in the supplied citation but its supplied URL points to a PDF labelled **PSS-2117**, so the factsheet number should be checked. The **TOB (2021)** entry is also insufficient as a formal reference because it provides neither a document title nor the full institutional author.