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Research Article

Phosphorus-Enriched Organomineral Fertilizers Affect the Cation Exchange Capacity of the Soil: A Comparative Evaluation

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Abstract: The aim of this study is to determine the effects of phosphorus-enriched cattle manure applications on the exchangeable cations content, cation exchange capacity (CEC), and base saturation rate (BSR) of the lime soil. The research was carried out with four different levels (except control) of dairy cattle manure (M1: 10; M2: 20; M3: 30; M4: 40 t ha^{-1}) and with four different levels (except control) of phosphorus dose (P1: 10; P2: 20; P3: 30; P4: 40 kg P ha^{-1}) in the ecological conditions of Southwest Türkiye during the wheat vegetation period of 2019-2021. The study was carried out in medium calcareous soil (14.8%) with three replications randomized blocks experimental by composing organomineral fertilizer combinations. According to the results of the study, the highest change in exchangeable Ca and K content in soils was obtained from organomineral fertilizer applications by 11.2% and 29.7% respectively, and the highest change in exchangeable Mg and Na content was obtained from dairy cattle manure applications by 25.1% and 18.2%, respectively for M4P2 (40 t ha^{-1} dairy cattle manure + 20 kg P ha^{-1}). Among the fertilization systems, the highest increase in total exchangeable cations was 13.1% and the increase in CEC was 21.3% in organomineral fertilizer applications. The fastest decrease in the BSR was also obtained from the organomineral fertilization system. As a result, it has been determined that M4P2 application is the most economical and the most effective combination in the cation exchange capacity among organomineral fertilizer combinations.

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1. Introduction

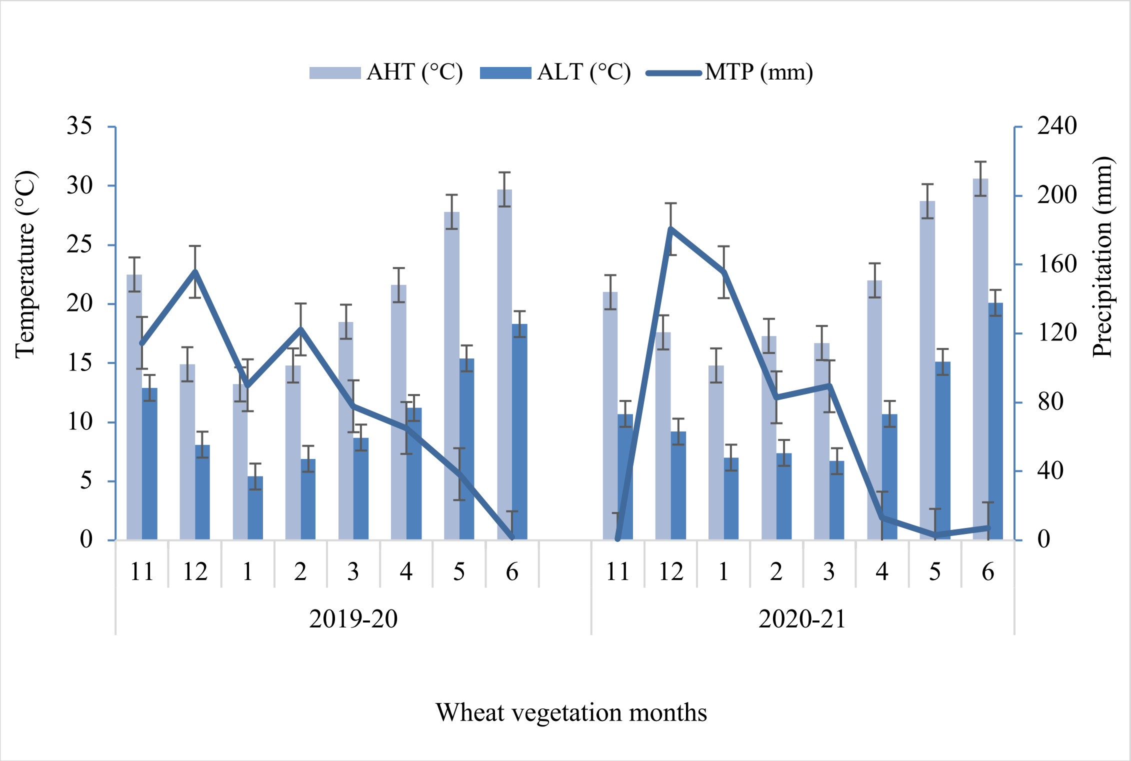
Chemical fertilizers are used intensively at every stage from the beginning of plant production to fruit maturity. However, the problems it creates in the soil are worrisome for the future of sustainable soil fertility (Daneshgar et al., 2018). As a result of the excessive use of fertilizers, the cation exchange capacity (CEC) and the contents of exchangeable cations decrease, especially in soils that are very poor in organic matter (OM) and constantly become barren (Smith et al., 2020). Due to this decrease, there are big problems in the rhizosphere region, and the plants grown cannot complete their development because they cannot be fed adequately resulting in losses in yield and quality (Shen et al., 2011; Alamgir et al., 2012). However, organic fertilizers are the only indispensable key to increasing the CEC of the soil. Regardless of the origin of the organic fertilizer, organic fertilizers added to the soil increase the level of exchangeable cations, and high cation exchange capacities are detected in the rhizosphere region (Fernandez et al., 2016). In the transition to organic agriculture, organomineral fertilizers have created an alternative in plant production. In the last decades, many studies have been reported that detect yield and quality increases in plant production in many countries in the transition to organomineral fertilizers (Namlı et al., 2019; Toprak, 2019; Mounirou et al., 2020; Yossif and Gezgin, 2020). Organomineral fertilizers are composed of both mineral fertilizers and organic fertilizers in certain proportions. With the addition of organomineral fertilizers to the soil, both the mineral-rich chemical fertilizers easily supply the nutrients needed by the plant, while the organic matter in the organomineral fertilizer causes the rhizosphere to be improved and the nutrients offered by the chemical fertilizers to be benefited by the plant much more easily (Süzer and Çulhacı, 2017; Mounirou et al., 2020; Yossif and Gezgin, 2020). Phosphorus fertilizers, on the other hand, are plant nutrients that are highly related to the yield elements in the soil and ultimately to the plant's nutrition (Bai et al., 2017). Even if it is used in high amounts, the presence of high amounts of calcium in the soil transforms phosphorus into forms that plants cannot use (Shen et al., 2011; Malhotra et al., 2018).

Besides, the study primarily determines the effect of the surface electrostatic bond, which is formed by phosphorus mostly with carbon-bound cations in the soil, on the exchange capacity under different fertilization systems. As it is known, in recent years, soil and water pollution have reached dangerous levels due to the neglect of sustainable agriculture and soil management with the excessive use of mineral fertilizers in conventional agriculture. Since the use of organomineral fertilizers in the transition to organic agriculture reflects a positive perspective on both economic and environmental sensitivity, their use should be encouraged. In the future, the effect of studies carried out under different fertilization systems on soil properties should be considered comparatively. From this point of view, it is hoped that the conscious and effective use of phosphorus in addition to organic fertilization within the framework of different phosphorus fertilization systems will shed light on such fertilization programs in the future in terms of sustainable agriculture. In addition, P fertilization, which can be created with organic fertilizer combinations, can be a good alternative to mineral fertilization in the future, especially against P eutrophication caused by excessive P fertilizer consumption. This study targets to evaluate the effect of organomineral fertilization systems consisting of conventional phosphorus fertilization, organic fertilization, phosphorus, and organic fertilizer combinations on the exchangeable cations content and cation exchange capacity of the soil.

2. Materials and Methods

2.1. Test location and climatic properties

The experiment was established in the plant production areas with alluvial soil type and silty clay soil texture in the Agricultural Production and Training Center (TAYEM) located at an altitude of 38 m in Söke district of Aydın province (37.705309 North, 27.379727 East) in southwestern Türkiye. The experiment started in November 2019 and was completed in June 2021. Söke County has a warm and temperate climate with much more precipitation in winter than in summer. According to Köppen-Geiger climate classification, it is defined with the definition of Csa (temperate winter, hot and dry summer/Mediterranean climate) (MGM, 2016). According to the meteorological data, in the 2019-2020 wheat growing season, the annual average highest temperature was 20.4 °C, the annual average lowest temperature was 10.9 °C, and the annual average precipitation was 666 mm. On the other hand, the annual average highest temperature was 21.1 °C, the annual average lowest temperature was 10.9 °C, and the annual average precipitation was 532.8 mm (Fig. 1).



AHT: Average highest temperature, ALT: Average lowest temperature, MTP: Monthly total precipitation; The lines above the bars show the standard deviation.

Figure 1. Meteorological data of the research area during the wheat growth periods.

2.2. Fertilizer resources

In the experiment, dairy manures taken from the dairy farm of TAYEM were used as an organic fertilizer source. This organic fertilizer was taken from the dairy and separated for one year in a different area and free of weed seeds. DAP (Diamonniumphosphate: 18% N and 46% P_2O_5) fertilizer was used as a phosphorus source. In the study, organomineral fertilizers were created from different combinations of these two fertilizers. Also, the wheat plant was grown for two years in the experimental area, and Urea (46% N) 160 kg N ha^{-1} and Potassium Nitrate (13% N and 45% K_2O) 75 kg K ha^{-1} were applied as nitrogen sources for optimum growth and support (Kara, 2014).

2.3. Study design and application of fertilizers

The research was set up in a randomized block design with three replications. Block sizes are 2 x 6 m. In the experiment, chemical phosphorus (conventional fertilization-CF) doses (P_1: 10, P_2: 20, P_3:30, and P_4: 40 kg P ha^{-1}), dairy manure (organic fertilization-OF) doses (DM_1: 10, DM_2: 20, DM_3: 30, and DM_4: 40 t ha^{-1}), four different organomineral fertilization systems (P-OMFS) consisting of these two different fertilizer combinations were prepared and studied. These new organomineral fertilizers, composed of combinations of phosphorus and dairy manures, were incubated for one month before being applied to the soil. After all the fertilizers were laid in a layer on the soil 24 hours before wheat planting, they were mixed with a soil rotavator to a depth of 0-30 cm.

2.4. Soil and organic manure sampling and analysis methods

Before and after the study, 75 soil samples were taken from each block from a depth of 0-30 cm. Soil samples were air-dried ground with a soil crushing machine, passed through a 2 mm sieve, and prepared for physical and chemical analysis. Organic manure samples were randomly collected from 10 different places to represent the whole heap and samples were taken as 500 g by mixing. Then passed through a 0.5 mm sieve and prepared for analysis (Kacar and Katkat, 2009). The analysis results of the soil and manure samples taken before the experiment are given in Table 1.

Cation Exchange Capacities (me 100 g^{-1}): The cation exchange capacities of the soils were determined by the ICP OES spectrophotometer (Perkin Elmer 8000) in solutions extracted with ammonium acetate (1 N, pH: 7.0) after sodium adsorption with sodium acetate (1 N, pH: 8.2) in the samples (Rhoades, 1982a). Exchangeable Cations (me 100 g^{-1}): The exchangeable cations (Na and K, Ca, Mg) of the soils were determined in the sieve after extraction with Ammonium Acetate (1 N, pH: 7.0) by ICP OES spectrophotometer (Perkin Elmer 8000) (Rhoades, 1982b).

The base saturation ratio was calculated as the ratio of the total exchangeable cations (Ca, Mg, K, and Na) to the cation exchange capacity and is given in equation 1 below (Doetterl et al., 2018).

$$\text{Base saturation rate: [Total cations / Cation exchange capacity] x 100} \qquad (1)$$

The soils of the study area have silty-loam texture and slightly alkaline character; It has been determined that soils without salinity problems contain insufficient organic matter and moderate lime. It was determined that total nitrogen and available potassium were insufficient, available phosphorus was sufficient, exchangeable calcium was moderate, and available magnesium was high in the soils. However, according to the micro plant nutrients analysis in the soil, it was determined that all of them, except for the available manganese, were in sufficient amounts in the soil (Kacar and Katkat, 2010).

Table 1. Some physical and chemical properties of experiment field soils and organic manure before research

Properties	**Soil**	**Analysis method**	**Manure**	**Analysis method**
Texture class	Silty-Loam	Bouyoucos Hydrometer	-	
pH (1:2.5)	7.95	pH meter	6.92	pH meter
EC (dS m^{-1})	0.32	EC meter	3.40	EC meter
OM (%)	1.81	Walkley-Black	67.9	AOAC
N (%)	0.06	Mikrokjheldahl	1.98	Mikrokjheldahl
P (%)	0.001	MBC	0.45	AOAC
K (%)	0.011	AA	2.16	AOAC
Ca (%)	0.216	AA	0.85	AOAC
Mg (%)	0.077	AA	0.12	AOAC
Fe (mg kg^{-1})	10.9	DTPA	386.7	AOAC
Zn (mg kg^{-1})	1.75	DTPA	92.4	AOAC
Mn (mg kg^{-1})	7.84	DTPA	142.0	AOAC
Cu (mg kg^{-1})	2.86	DTPA	83.3	AOAC
B (mg kg^{-1})	1.82	Azomethine-H	5.60	Azomethine-H

EC: Electrical conductivity, MBC: Molybdophosphoric blue color, AA: Ammonium acetate, DTPA: Diethylene triamine penta acetic acid, AOAC: Association of Official Analytical Chemists.

2.5. Statistical analysis

Evaluation of all the findings obtained in the study was determined according to the randomized blocks experiment design with the Jump statistical program (JMP) ver.7 (JMP, 2007). In the analysis of variance, the significance of the differences between the means was determined by the Duncan's multiple range test in the same package programs. The variance analysis was created by determining the least significant difference according to the importance levels of the factors $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$ probability values.

3. Results and Discussions

3.1. Organic fertilization system

In the organic fertilization system, an increase was observed in exchangeable cations with the increase in the amount of organic manure in the soil. As it is known, the increase in the content of exchangeable cations is closely related to the increase in organic matter (OM) in the soil. Regardless of its origin, OM added to the soil increases the amount of exchangeable cations in the soil (Fernandez et al., 2016). The exchangeable Ca contents of the soil increased also for two years. However, the effect of applied organic manures on the exchangeable Ca content of the soil was not statistically significant in the first year, but significant in the second year ($p \leq 0.05$). With the addition of organic manure to the soil, the exchangeable Ca content increased by 6.6% in the first year and by 9.6% in the second year (Table 2). According to the data of both years, the highest exchangeable Ca content was obtained from the M4 application (8.71 me 100 g^{-1}). The greater increase in the second year may be due to the accumulation of OM in the soil and the mineralization of Ca. Ca bound in the soil is desorption by the effect of OM and can pass into the soil solution (Shen et al., 2011).

Table 2. Exchangeable cations of the soil as affected by manure applications

Manure	**Ca (me 100 g^{-1})**		**Mg (me 100 g^{-1})**		**K (me 100 g^{-1})**		**Na (me 100 g^{-1})**	
doses	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
M0	8.14a	7.95c	1.30e (ef)	1.27c (f)	0.58c (d)	0.65b (c)	0.042a	0.038a
M1	8.27a	8.08bc	1.46d (c)	1.34bc (de)	0.66b (c)	0.66b (c)	0.044a	0.039a
M2	8.26a	8.07bc	1.35c (de)	1.36b (d)	0.71a (bc)	0.66b (c)	0.046a	0.039a
M3	8.68a	8.52ab	1.50b (bc)	1.46a (c)	0.68b (bc)	0.70a (bc)	0.047a	0.043a
M4	8.67a	8.71a	1.68a (a)	1.53a (b)	0.79a (a)	0.72a (b)	0.051a	0.043a
Means	8.41A	8.27A	1.46A	1.39B	0.69A	0.68A	0.046A	0.040B
F-values								
M	2.74 ns	4.98*	211.9**	18.28***	9.62**	9.91**	1.07ns	0.65ns
Y	2.11 ns		31.28***		0.11 ns		7.51*	
M x Y	0.11 ns		7.05**		4.13*		0.20 ns	

M0 to M4: No manure, and 10, 20, 30,40 t ha^{-1} dairy manure applications, respectively; Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Letters in parentheses indicate manure x year interaction. Capital letters indicate the results of the Duncan's test between years.

In the experiment, the exchangeable magnesium contents increased in both years with the effect of organic manure. This increase was statistically significant in both years ($p \leq 0.01$; $p \leq 0.001$). While the increase in the exchangeable Mg content in the soil was 29.2% in the first year, it was recorded as 20.5% in the second year (Table 2). However, the manure x year interaction was found to be statistically significant ($p \leq 0.01$). In both years, the highest exchangeable Mg content in the soil was determined in the M4 application in the first year of the experiment (1.68 me 100 g^{-1}). The differences in exchangeable Mg contents between years were also found to be statistically significant ($p \leq 0.001$). In the preliminary manure analysis, the Mg content in the organic fertilizer was already high. However, with the addition of OM, it became inevitable to increase the exchangeable Mg content in the soil when combined with the Mg existing in the soil (Angelova et al., 2013).

The exchangeable K contents in the soil increased with the increase of organic manure applied. Statistically significant relationships were found between the organic manure applied and the exchangeable K content of the soil ($p \leq 0.01$). However, organic manure x year interaction was also found to be statistically significant ($p \leq 0.05$). According to the data obtained at the end of both years, the highest exchangeable K content in the soil was obtained from M4 application in the first year (0.79 me 100 g^{-1}). Besides, organic fertilizers increased the exchangeable K content of the soil by 36.2% in the first year and by 10.8% in the second year (Table 2). The decrease in the rate in the second year compared to the first year may be related to the saturation of the potential K content in the soil. The amount of K in organic manures can increase the exchangeable K amount in the soil (Siregar et al., 2005; Shen et al., 2011; Whittinghill and Hobbie, 2012).

However, it increased the exchangeable sodium content of the soil by being affected by the existing salt ratio in the amount of organic manure applied. In addition, this increase was not statistically significant (Table 2). The exchangeable Na content of the soil increased by 21.4% in the first year and by 13.2% in the second year. However, the exchangeable Na content of the soil decreased in the second year compared to the first year, and this was statistically significant ($p \leq 0.05$). Depending on the types of organic manures, the Na content may also vary due to the amount of salt in them. Organic manures added to the soil can also increase the salt content of the soil (Demirtaş et al., 2012; Erdal et al., 2018).

According to the results of the experiment, it was determined that the organic manure added to the soil increased the cation exchange capacity (CEC) of the soil. However, organic manure's effect on the soil's CEC was found to be statistically significant in both years ($p \leq 0.001$). While the increase in the first CEC was 19.6% in the experiment, it was recorded as 22.9% in the second year. In both years, the highest CEC was obtained from the M4 application (12.8 and 12.9 me 100 g^{-1}, respectively). However, no statistically significant difference was found between the years (Table 3). The CEC of the soil increased stably in both years. It is directly related to the amount of organic matter in the soil. Many studies have also reported that the organic matter added to the soil increases the CEC (Francou et al., 2005; Kasongo et al., 2011; Whittinghill and Hobbie, 2012; Gayathri et al., 2019).

Table 3. Cation exchange capacity and base saturation rate of the soil as affected by manure applications

Manure doses	**CEC (me 100 g$^{-1)}$**		**BSR (%)**	
	2019-20	**2020-21**	**2019-20**	**2020-21**
M0	10.7c	10.5d	94.4a	94.1a
M1	11.5b	11.2c	90.6bc	90.3b
M2	11.3bc	11.3c	91.7ab	89.9b
M3	12.4a	12.2b	88.2c	87.8c
M4	12.8a	12.9a	87.5c	85.6d
Means	11.7A	11.6A	90.5A	89.6A
F-values				
M	11.64***	28.24***	7.79**	80.15***
Y	0.76 ns		3.72 ns	
M x Y	0.20 ns		0.58 ns	

CEC: Cation Exchange capacity, BSR: Base saturation rate; M0 to M4: No manure, and 10, 20, 30,40 t ha^{-1} dairy manure applications, respectively; Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Capital letters indicate the results of the Duncan's test between years.

On the contrary, the base saturation ratio (BSR) decreased as the amount of organic manure applied increased. Meanwhile, by 7.3% decrease was recorded in the first year of the study, and by 9.0% decrease was detected in the second year (Table 3). The BSR is the ratio of the total exchangeable cations in the soil to the cation exchange capacity, and this ratio increases with the increase in the amount of the total exchangeable cations in the soil, on the contrary, it decreases with the increase of the cation exchange capacity. This situation is closely related to the desorption of saturated cations and the exchange capacity of the cations separated from the solid phase increases and is offered to the plant in the forms that the plant can take, so the BSR in the soil decreases (Dengiz et al, 2007; Wuddivira and Camps-Roach, 2007; Osman, 2013).

3.2. Conventional phosphorus fertilization system

In the conventional phosphorus fertilization system, increasing doses of mineral P were applied and the effect on the content of exchangeable cations in the soil was not found statistically significant (Table 4). Although an increase in the exchangeable Ca content was noted up to the P2 application, decreases were detected at subsequent doses. Meanwhile, the effect of P doses on exchangeable Mg content was statistically significant in the first year of the study, it was insignificant in the second year ($p \leq 0.01$).

Exchangeable Mg content increased by 6.2% in the first year and increased by 3.1% in the second year. In addition, the difference in exchangeable Mg content between years was found to be statistically significant ($p \leq 0.01$). Compared to the first year, the exchangeable Mg content in the soil decreased in the second year. The effect of mineral P doses on the exchangeable K contents of the soil was not statistically significant for two years. However, the exchangeable K content of the soil increased in the second year of the study and this was statistically significant ($p \leq 0.01$). Moreover, the highest exchangeable K content was recorded at the P2 dose (0.69 me 100 g^{-1}).

Table 4. Exchangeable cations of the soil as affected by phosphorus applications

Phosphorus doses	**Ca (me 100 g^{-1})**		**Mg (me 100 g^{-1})**		**K (me 100 g^{-1})**		**Na (me 100 g^{-1})**	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
P0	8.14a	7.95a	1.30a	1.27a	0.58a	0.65a	0.042a	0.038a
P1	8.45a	8.26a	1.34a	1.31a	0.64a	0.68a	0.042a	0.040a
P2	8.53a	8.37a	1.30a	1.30a	0.69a	0.69a	0.042a	0.041a
P3	8.42a	8.32a	1.33a	1.31a	0.59a	0.68a	0.042a	0.041a
P4	8.08a	8.23a	1.38a	1.30a	0.64a	0.67a	0.040a	0.041a
Means	8.32A	8.23A	1.33A	1.30B	0.63B	0.67A	0.042A	0.040A
F-values								
P	1.89 ns	2.06 ns	2.84 ns	1.36 ns	2.03 ns	2.01 ns	0.11 ns	1.85 ns
Y	1.38 ns		13.39**		11.43**		1.81 ns	
P x Y	0.67 ns		2.41 ns		1.26 ns		0.34 ns	

P0 to P4: No phosphorus, and 10, 20, 30,40 kg ha^{-1} phosphorus fertilizer applications, respectively; Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Capital letters indicate the results of the Duncan's test between years.

Table 5. Cation exchange capacity and base saturation rate of the soil as affected by phosphorus applications

Phosphorus doses	**CEC (me 100 g^{-1})**		**BSR (%)**	
	2019-20	**2020-21**	**2019-20**	**2020-21**
P0	10.7a	10.5a	94.4a	94.1a
P1	10.9a	10.9a	95.7a	94.4a
P2	11.2a	10.9a	94.7a	95.1a
P3	10.8a	10.9a	96.2a	94.9a
P4	10.6a	10.8a	96.2a	94.7a
Means	10.8A	10.8A	95.4A	94.6A
F-values				
P	1.81 ns	1.93 ns	0.60 ns	0.23 ns
Y	0.001 ns		1.50 ns	
P x Y	0.86 ns		0.34 ns	

CEC: Cation Exchange capacity, BSR: Base saturation rate; P0 to P4: No phosphorus, and 10, 20, 30,40 kg ha^{-1} phosphorus fertilizer applications, respectively; Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Capital letters indicate the results of the Duncan's test between years.

Also, the effect of mineral P doses on the exchangeable Na content of the soil was not statistically significant. The CEC and BSR of soils were not affected by mineral P applications. According to the results obtained, the effect of mineral P doses on the CEC and BSR were not statistically significant during both study years (Table 5). The highest CEC was recorded at the P2 dose (11.2 me 100 g^{-1}) in the first year of the study. Cations dissolved from carbonate minerals (Ca, Mg, Na, and K) may tend to change by forming electrostatic bonds, especially with phosphorus at superficial levels, and/or cause precipitation of phosphates (Zhang et al., 2021). This depends on the alkaline potential of the soil. At high pHs, precipitation occurs by forming Ca and Mg-P phases. In some studies conducted in recent years, it has come to the fore that phosphorus applied in soils rich in Ca and Mg at high pH precipitates with electrostatic bonding rather than the change of these elements in the soil (Naveed et al., 2020; Geng et al., 2022). Therefore, it is reported that the effect of the phosphorus-to-cation exchange capacity is not alone but under some environmental factors (Zhu and Dittrich, 2016).

3.3. Organomineral phosphorus fertilization system

The effects of sixteen different organomineral fertilizer combinations comprised of dairy cattle manure and mineral P doses on the content of exchangeable cations, cation exchange capacity, and base saturation rate during the study period were examined. Its statistical evaluation is given in Tables 6 and 7. According to the results, although the effect of organomineral fertilizer combinations on the exchangeable Ca content of the soil was not statistically significant in both years, it was determined that the exchangeable Ca content of the soil increased. It was noted that organomineral fertilizers increased the exchangeable Ca content of the soil by 13.3% in the first year and by 12.3% in the second year. Among the combinations, the highest exchangeable Ca content in the soil was determined in the first year in M4P3, and in the second year in M4P2 application. However, it was determined that the increase in the exchangeable Ca content increased with the increase in the organic fertilizer content of the organomineral fertilizers. Mainly, the exchange of Ca, a base cation, is due to the electrostatic interaction between the clay minerals and/or the negative charge on the organic matter, so the adsorption depends on variables such as pH and ionic strength (Rytwo et al., 2002). Decreased pH and increasing OM amount in the soil increased the exchange capacity of Ca and provided its adsorbent on the colloid surface. The amount of exchangeable Ca increasing in line with the increasing organic matter content supports the results obtained from the experiment, as in many studies (Gustafsson and Van Schaik, 2003; Meier et al., 2004; Whittinghill and Hobbie, 2012). The effect of organomineral fertilizer combinations on the exchangeable Mg content of the soil was found to be statistically significant ($p \leq 0.001$). It was determined that the exchangeable Mg content of the soil increased with the increase in the doses of organomineral fertilizers (especially the organic fertilizer content). The highest exchangeable Mg content was recorded in the combination of M4P3 in the first year and M4P1 in the second year (Table 6). However, it was determined that organomineral fertilizer combinations increased the exchangeable Mg content of the soil by 26.2% in the first year and 25.2% in the second year. The study also obtained statistically significant differences between the years ($p \leq 0.001$).

According to the findings, the amount of organic matter increased in the soil increased the exchangeable Mg amount of the soil in the same direction. This status can be explained due to the high organic matter content and the high electrostatic charge absorbency of Mg on colloid surfaces (Angelova et al., 2013). However, many studies have shown similarities with the findings in the experiment, in which the change of Ca and Mg elements increases with the increase of OM in the soil and the decrease in pH values in the soil (Dijkstra, 2003; Reich et al., 2005; Guckland et al., 2009; Whittinghill and Hobbie, 2012). In addition, it was determined that as the applied P doses increased, the exchangeable Mg capacity first increased and then decreased. P mineralization increased with the increase in OM in the soil, and the retained Mg element in the soil was activated for cation exchange. Therefore, it has been reported in some studies that phosphorus-bound Mg is stored in soil water in water-soluble forms for the benefit of the plant (Neirynck et al., 2000; Reich et al., 2005; Shen et al., 2011; Melenya et al., 2015).

Table 6. Exchangeable cations of the soil as affected by organomineral fertilizer applications

Organomineral fertilizer doses	**Ca (me 100 g^{-1})**		**Mg (me 100 g^{-1})**		**K (me 100 g^{-1})**		**Na (me 100 g^{-1})**	
	2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
M0P0	8.14a	7.95a	1.30j	1.27j	0.58e	0.65f	0.042a	0.038a
M1P1	8.44a	8.25a	1.41gh	1.36hı	0.69d	0.68ef	0.040a	0.040a
M1P2	8.54a	8.35a	1.42gh	1.39gı	0.71d	0.71b-e	0.039a	0.041a
M1P3	8.40a	8.41a	1.38hı	1.35ı	0.73cd	0.69d-f	0.039a	0.040a
M1P4	8.40a	8.34a	1.33ıj	1.34ı	0.69d	0.68ef	0.039a	0.039a
M2P1	9.05a	8.39a	1.45e-g	1.41f-h	0.75cd	0.69d-f	0.043a	0.042a
M2P2	8.63a	8.59a	1.42gh	1.39gı	0.73cd	0.73a-c	0.039a	0.042a
M2P3	8.62a	8.71a	1.43f-h	1.37hı	0.75cd	0.71b-e	0.041a	0.043a
M2P4	8.15a	8.56a	1.38hı	1.35ı	0.75cd	0.70c-e	0.042a	0.042a
M3P1	9.08a	8.87a	1.51c-e	1.48de	0.82bc	0.73a-c	0.043a	0.043a
M3P2	9.08a	8.87a	1.53cd	1.50cd	0.77cd	0.73a-c	0.044a	0.043a
M3P3	8.97a	8.76a	1.48d-f	1.45ef	0.75cd	0.74ab	0.046a	0.042a
M3P4	8.51a	8.65a	1.46e-g	1.42e-g	0.73cd	0.74ab	0.041a	0.041a
M4P1	8.78a	8.78a	1.63a	1.59a	0.93a	0.74ab	0.048a	0.045a
M4P2	8.92a	8.93a	1.60ab	1.57ab	0.88ab	0.76a	0.045a	0.045a
M4P3	9.22a	8.80a	1.64a	1.53bc	0.77cd	0.76a	0.045a	0.044a
M4P4	8.67a	8.58a	1.56bc	1.52b-d	0.75cd	0.72a-d	0.044a	0.043a
Means	8.68A	8.58A	1.47A	1.43B	0.75A	0.72B	0.042A	0.042A
F-values								
OMF	1.20 ns	1.77 ns	23.34***	24.64***	5.19***	3.67***	1.01 ns	0.80 ns
Y	1.45 ns		31.59***		15.84***		0.20 ns	
OMF x Y	0.41 ns		0.72 ns		2.41 ns		0.38 ns	

Phosphorus x manure interactions are organomineral fertilizer combinations (OMF). Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Capital letters indicate the results of the Duncan's test between years.

The effect of organomineral fertilizers applied during the study period on the exchangeable K content of the soil was found to be statistically significant ($p \leq 0.001$). Depending on the doses of organomineral fertilizers, increases were recorded in the exchangeable K contents of the soils. In the study, organomineral fertilizer combinations increased the exchangeable K content of the soil by 60.3% in the first year and by 16.9% in the second year. This rapid increase in the first year compared to the second year may be due to the insufficient K content in the soil and the strong effect of both the K existing in the soil and the K present in the organic fertilizer together with the organomineral fertilizer combinations. In the second year, the situation became more stable, the potential K content in the soil became saturated and the rate of increase slowed down. Also, the highest exchangeable K content was determined in the M4P1 application in the first year, and in the M4P2 and M4P3 applications in the second year (Table 6). According to the findings obtained from the experiment, the increasing amount of OM in the soil increased the exchangeable K contents. It is reported that with the increase of OM and decrease in pH, the exchange of K, a base cation with high absorbance in soil, increases and it can be found in forms that can be taken by the plant (Siregar et al., 2005; Whittinghill and Hobbie, 2012). Many studies have stated that increasing OM in the soil increases the exchangeable K activation (Khoshgoftarmanesh and Kalbasi, 2002; Verma et al., 2005; Yalçın et al., 2018; Çimrin, 2020).

Table 7. Cation exchange capacity, and base saturation rate of the soil as affected by organomineral fertilizer applications

Organomineral	**CEC (me 100 g^{-1})**		**BSR (%)**	
fertilizer doses	**2019-20**	**2020-21**	**2019-20**	**2020-21**
M0P0	10.7e	10.5g	94.4a	94.1a
M1P1	11.5c-e	11.3f	91.8a-c	91.4b-d
M1P2	11.5c-e	11.4e-f	93.0ab	92.0b
M1P3	11.4de	11.4e-f	92.3a-c	91.8bc
M1P4	11.3de	11.3f	92.3a-c	91.7bc
M2P1	12.6a-c	11.7d-f	89.9c-e	90.3de
M2P2	12.0b-d	11.9c-f	90.4b-d	90.7c-e
M2P3	12.0b-d	12.0b-f	90.4b-d	90.3de
M2P4	11.4de	11.9c-f	90.4b-d	89.5ef
M3P1	13.0ab	12.6a-c	88.0d-f	88.0g
M3P2	12.8ab	12.6a-c	89.6c-e	88.6fg
M3P3	12.7ab	12.4a-d	88.5d-f	88.4fg
M3P4	12.1b-d	12.4a-d	88.5d-f	87.9g
M4P1	13.2ab	12.9a	86.1f	86.4h
M4P2	13.3a	13.1a	86.0f	86.4h
M4P3	13.4a	12.9a	87.2ef	86.0h
M4P4	12.7ab	12.7ab	86.6f	85.7h
Means	12.2A	12.1A	89.7A	89.4A
F-values				
OMF	4.76***	7.87***	5.78***	34.00***
Y	1.96 ns		1.73 ns	
OMF x Y	0.41 ns		0.23 ns	

CEC: Cation Exchange capacity, BSR: Base saturation rate; Phosphorus x manure interactions are organomineral fertilizer combinations (OMF). Statistically significant at (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; ns, not significant). Column means with the same letter are not significantly different by Duncan's multiple range test ($p \leq 0.05$). Capital letters indicate the results of the Duncan's test between years.

The effect of organomineral fertilizers applied during the study period on the exchangeable Na content of the soil was not statistically significant. However, it was determined that the increasing amount of organic fertilizer in organomineral fertilizer combinations increased the exchangeable Na content of the soil (Table 6). In the study, the highest exchangeable Na content was recorded in the M4P1 combination in the first year, and in the M4P1 and M4P2 combination in the second year. It was determined that the exchangeable Na content of the soils increased by 14.3% compared to the control in the first year, and by 18.4 in the second year. According to the findings, organomineral fertilizer combinations applied in both years increased the exchangeable Na content of the soils. Some studies reported that fertilizers of animal origin contain salt in different amounts depending on the type and breed of animals (Demir et al., 2003; Demirtaş et al., 2012; Erdal et al., 2018). The presence of organic matter in the soil helps to disperse Na and can be mobilized in a soluble form, possibly in a colloidal form (Leogrande and Vitti, 2019). It was determined that the application of organomineral fertilizers increased the total exchangeable cation contents of the soil. Many researchers have reported that the increase in the content of exchangeable cations depends on the amount of OM in the soil (Whittinghill and Hobbie, 2011; Boethling, 2019; Timmer et al., 2020). The binding of cations to soil surface components results from the electrostatic interaction of the negative charge on OM, and thus cation adsorption is dependent on variables such as pH and ionic strength (Behera et al., 2010). The electrostatic charge and high surface area allow clay-sized particles to dominate mineral-mineral, mineral-organic, mineral-metal, and mineral-water interactions in soils (Kleber et al., 2021). However, with the increase in phosphorus doses, low-level increases were recorded in the exchangeable cations level. These increases are due to the increase in the saturation of colloid-bound Ca as the amount of water-soluble P in the soil increases, and the increase in the binding strength of Ca and Mg-bound P to the colloid as the soil pH decreases in lime soils (Manimel et al., 2013).

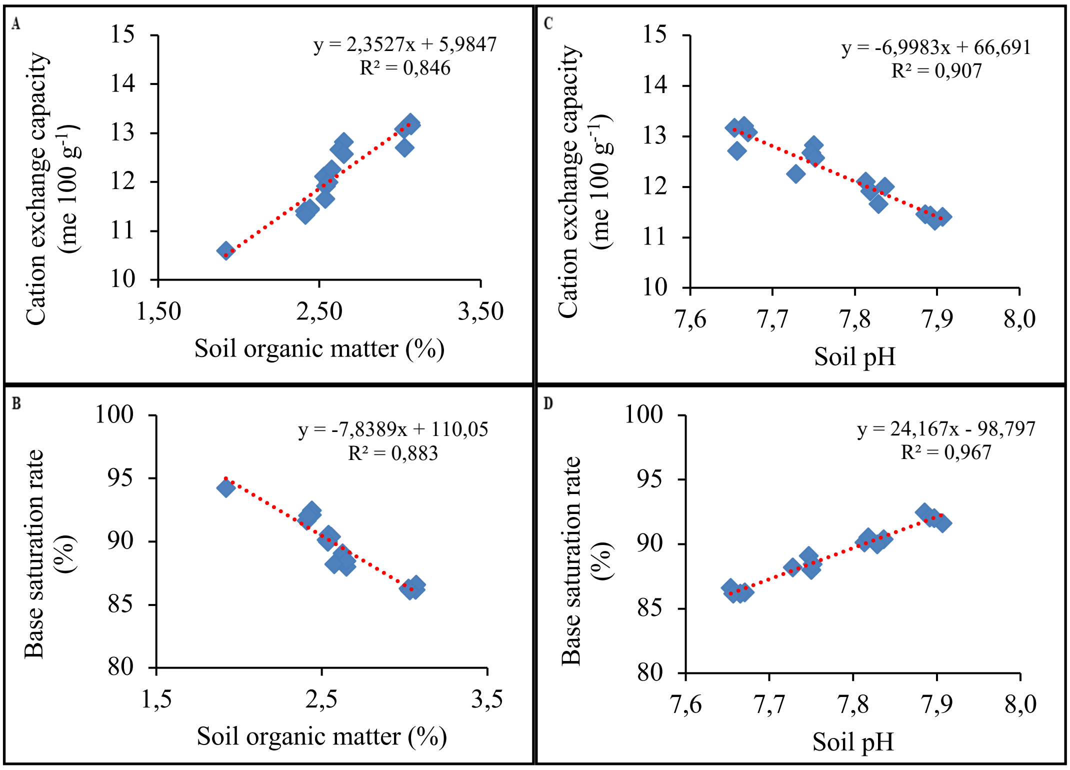


Figure 2. Relationship between cation exchange capacity and soil organic matter and pH (A-C) and the relationship between base saturation rate and soil organic matter and pH (B-D) affected by organomineral fertilizers.

Organomineral fertilizers composed of mineral phosphorus and dairy cattle manure combinations increased the cation exchange capacity of the soil for two years, and this was statistically significant ($p \leq 0.001$). Organomineral fertilizers increased the soil's cation exchange capacity by 25.2% in the first year of the study and by 24.8% in the second year. The highest cation exchange capacity in the soil was recorded in the M4P3 combination in the first year of the study, and in the M4P2 combination in the second year (Table 7). The difference between years was not statistically significant. According to the findings, it was determined that organomineral fertilizer applications in the soil increased the cation exchange capacity depending on the increasing amount of organic matter (Fig. 2A). Organic matter gives significant strength to the soil in terms of increasing cation exchange. As a result of the width of its surface area and its electrostatic state, it is the only substance that has the ability to bind large amounts of cations and increase their exchange activation (Oorts et al., 2003). Many researchers have reported that soils rich in organic matter have high cation exchange capacity (Francou et al., 2005; Kasongo et al., 2011; Gayathri et al., 2019; Demirel and Şenol, 2019; Liu et al., 2020). Base saturation capacity is an important soil chemical property with implications for both soil taxonomic classification and soil fertility. Base saturation is defined as the sum of the four basic cations (Ca, Mg, K, and Na) relative to the total soil cation exchange capacity at pH 7.0 or 8.2 (Foth and Ellis, 2018). According to the results obtained from the experiment, it was determined that organomineral fertilizer applications reduced the base saturation capacity of the soil. The lowest base saturation rate was recorded in the M4P2 application in the first year and in the M4P4 application in the second year (Table 7). In the study, organomineral fertilizer combinations reduced the base saturation rate by 8.9% in both years. The effect of organomineral fertilizers on the base saturation ratio was found to be statistically significant ($p<0.001$). In many studies, it has been reported by researchers that the basic cations in the soil have a high exchange capacity in soils where organic matter is rich and decrease with the increase of organic matter (Fig. 2B) and decrease in pH values (Fig. 2C) in the soil and that basic cations pass into the soil solution in forms that the plant can take (Wuddivira and Camps-Roach, 2007; Osman, 2013; Blanco, 2017; Alkharabsheh et al., 2021).

Conclusion

According to the data obtained as a result of the study, the effects of organic fertilizer (dairy cattle manure), mineral P doses, and P-enriched organic fertilizer combinations (organomineral fertilizers) applied to the soil on the change of total cations, cation exchange capacity, and base saturation ratios in a calcareous soil at different levels as compare were evaluated. These comparative effects, by adding mineral fertilizers and organic fertilizers directly to the soil, or by the combination of these two fertilizers, the effects of the cation exchange capacity in the soil have provided some new ideas. In particular, mineral P doses had little or no effect on the cation exchange capacity in the soil. However, as the doses of organic fertilizer applied with the doses of mineral P were increased, the level of exchangeable cations and as a result, the CEC increased. Besides, cationic changes increased rapidly in organomineral fertilizers prepared by increasing the amount of organic matter.

The exchangeable Ca, Mg, K, and Na contents in organomineral fertilizer combinations were recorded as 8.67, 1.46, 0.74, and 0.042 me 100 g^{-1} on average, respectively. The cation exchange capacity and base saturation ratio were found to be 12.24 me 100 g^{-1} and 89.2% on average, respectively. With organic fertilizer applications, the exchangeable and exchangeable Ca, Mg, K, and Na contents of the soil were recorded as 8.41, 1.46, 0.70, and 0.044 me 100 g^{-1}, respectively. The cation exchange capacity and base saturation ratio were determined as 11.95 me 100 g^{-1} and 88.9% on average. With the addition of mineral P to the soil, the lowest cation changes, the content of total cations, and the highest base saturation rate were achieved compared to the other two fertilization systems. However, the fastest changes in the cation exchange capacity occurred with organomineral fertilizer applications. It was determined that the soil's exchangeable Ca, Mg, K, and Na contents increased by 11.2%, 22.8%, 29.7%, and 15.9%, respectively. In addition, organomineral fertilizer applications increased the cation exchange capacity by %21.3 and the base saturation rate decreased by 9.2%. As a result, it was concluded that M4P2 application (40 t ha^{-1} dairy cattle manure + 20 kg P ha^{-1}) could be the most economical and the most effective combination for CEC among organomineral fertilizer combinations.

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