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Original article

Effects of Organomineral Fertilizers on Micronutrient Uptake of Maize (*Zea mays*)

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Abstract

This study was conducted to investigate the effects of different organomineral fertilizer treatments (granular and liquid) on the micronutrient concentration of maize (*Zea mays* L. var. Karadeniz yıldızı) plants grown in soils collected from the Ağrı/Eleşkirt region of Türkiye. Maize plants were grown in pots filled with soil (2 kg). Two granular (G) and liquid (L) organomineral fertilizers were applied at rates of 100 of the technical recommendation and plant micronutrient (iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), and boron (B)) contents were analyzed. The harvested plant samples were digested in concentrated nitric perchloric acid mixture, and the concentrations of Fe, Cu, Zn, Mn in the extraction solution was determined by atomic absorption spectrophotometry device, and the concentration of B was measured by spectrophotometry device.There were significant differences among the organomineral fertilizers in terms of their effects. Plant (Fe) concentrationswere varied from 65.50 to 73.78 mg kg-1, Cu concentrations from 10.10 to 10.90 mg kg-1, Zn concentrations from 22.10 to 23.90 mg kg-1, Mn concentrations from 19.67 to22.25 mg kg-1 and B concentrationsfrom11.12 to12.77. The highest values were obtained from the liquid organomineral fertilizer treatments and the lowest values (except for Mn) were obtained from the control treatments.

Further research is recommended with the same organomineral fertilizers and soil types, but this time with different doses and under field conditions to investigate plant reactions to two organomineral fertilizers (solid/granular and liquid) and to identify optimum doses.

Keywords: Organomineral Fertilizer, Micronutrient, Availability, Plant Analyses, Maize.

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INTRODUCTION

Many factors contribute to soil quality or health (soil fertility and productivity). A key property of soil health is the ability of the soil to provide all essential nutrients in adequate amounts and ratios for plant growth. Balanced nutrient management of organic and/or mineral fertilizers is a prerequisite relevant to sustainable agriculture, end hunger, achieve food security and climate-smart agriculture (appropriate soil management practices and crop variety selection, and on the "4Rs" of nutrient stewardship, (right source of fertilizer, the right rate, the right time and the right place efficient and effective crop nutrition by agricultural practitioners). On the other word, proper crop nutrition practices will help build resilience in agricultural crops, a prerequisite for climate change adaptation. The key factor for soil health and quality is the soil organic matter; (although relatively small) has a beneficial function. Worldwide, farmers apply an average of 180 million tons of nutrients (fertilizers) annually. Analysis of long-term experiments from around the world shows that appropriate and balanced use of mineral fertilizers results in an increase in SOM as compared to unfertilized plots (there is some debate for tropical soil conditions). Nutrient or fertilizer inputs and outputs must be balanced to optimize crop yield, sustainable productivity and minimize environmental losses.. The four areas of nutrient management (source, rate, time and place) provides the basis of best management practices (BMPs). Because nutrients interact between each other, (recognize interactions between nutrient elements and sources must be known), enhanced nutrient use efficiency can be achieved by better managing the nutrient in question, as well as by better managing the nutrients with which it interacts Examples include: the P x Zn, Fe x Cu, Zn x Mn interaction etc. (Anonymous 2016).

Although soil organic matter constitutes a very low percentage of soils, it is an extremely important factor affecting soil fertility and structure in agricultural terms. Humus covers the clay minerals in the soil, prevents the clay minerals from binding to each other and increases the exchange capacity of these molecules. With its high cation exchange capacity, it ensures a better use of chemical fertilizers by the plant and prevents them from moving away from the root zone, forms chelates by combining with high valence cations such as Fe^{+3}, Cu^{+3}, Zn^{+3} and neutralizes the charges of these cations, facilitating their uptake by plants (Aşık and Katkat 2018).

Soil organic matter plays a key role not only in increasing agricultural productivity, but also in environmental aspects. Sustainable agricultural practices protect soil microorganisms and increase soil organic matter content. In general, organomineral fertilizers can improve plant growth parameters such as yield and nutrient uptake more than the sole use of chemical fertilizers (Yıldız and Dizikısa 2022).

High yield and quality largely rely on appropriate supply of macro and microelements to plants. Even though plant requirements for microelements are considerably lower than for macro elements, microelements are essential nutrients needed for proper plant growth and development. Microelement deficiencies first reduce plant's resistance to adverse environmental conditions, then and then reduce yield and quality accordingly (Alloway 2008).

If organic materials are used 1 - without maturing; 2 - in high doses for long periods of time, micronutrient (Fe, Zn, Cu) deficiencies and toxicity (Mn) disadvantages/negativities may occur (Wolf 2000). Therefore, mineral fertilizers combined with composted organic material do not cause such disadvantages. Organomineral fertilizers contain the plant nutrients present in mineral fertilizers and organic matter together in their structures. Organic matter and humic-fulvic acids in organomineral fertilizers have significant positive effects on soil physical, chemical and biological properties. Organic matter increases soil water and nutrient holding capacity, aeration and trace element levels and provides a balanced pH and microbial levels. Previous studies have shown that organic matter from organomineral fertilizers regulates soil negativities and positively affects the yield per unit area (Kacar and Katkat 1999; Olaniyi et al., 2010; Makinde et al., 2011). It has been reported in previous studies conducted in the world and in Türkiye that organomineral fertilizers have various positive effects on the soil properties, the growth and development of plants and the level of yield (Sancakbeyi 2019). Therefore, the demand for organic and organomineral fertilizers is continuously increasing both in the world and in Türkiye. Then, organomineral fertilizers are considered the best alternative to chemical fertilizers in terms of providing plant nutrients and improving soil properties (Yıldız and Dizikısa 2022).

New technologies must be developed to improve soil properties and achieve high yields. Such efficient technologies will also ensure sustainable agriculture. Despite improvements and new techniques in modern agricultural practices, most of the world's agricultural sectors still use conventional methods. Then, sustainability and fertility issues are encountered. Since yield-limiting problems seriously hamper global agriculture, urgent action is needed to rehabilitate soils. Therefore, both organic and synthetic fertilizers have been reduced and organomineral fertilizers (OMFs) have been increased. Compared to inorganic fertilizers, OMF better improved soil physical properties, reduced bulk density and conserved soil moisture (Abdulraheem et al., 2023). The organic fraction of biofertilizers improves root development and water retention, recovers microbial flora, reduces soil erosion, and decreases soil acidification (Levrero 2009; Gonçalves et al., 2007).

According to Herencia et al. (2008), organic amendments can affect the distribution of metals in different soil fractions, which in turn can affect the availability of micronutrients to plants. Mineral and organic fertilization applied over an extended period can drastically alter soil properties including pH and organic matter concentration. Soil pH is lowered by mineral fertilization, especially nitrogen fertilization, which increases the mobility of Cu, Fe, Mn, and Zn (Fan et al., 2012). According to several research (Li et al., 2007; Fan et al., 2012), fertilizing with phosphorus reduced the amount of Zn available to plants. Soil organic matter content increases when farmyard manure is applied consistently over a long period of time (Singh et al., 2010; Fan et al., 2012).

The basic components of soil organic matter are humic substances. They have a direct impact on plant physiology and growth, particularly on root growth and development, in addition to the favorable impacts on soil quality (Rima et al., 2011; Canellas and Olivares 2014). According to Botero et al. (2010), HSs could create stable complexes with divalent cations including Cu, Mn, and Zn, facilitating their availability to plants and facilitating their transportation. The conversion of Fe^{3+} to Fe^{2+} in medium-containing HSs, the latter of which is more accessible to plants, may have promoted the increase in Fe levels (Adani et al., 1998). According to Stevenson (1994), humic substances with more carboxyl groups and a lower molecular weight are more effective in making micronutrients available to plants.

Micronutrients are needed for plant growth and development in smaller amounts than macronutrients. The most common micronutrients needed for plant growth are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo) and chlorine (Cl). These nutrients are important in several aspects of plant growth. Micronutrient deficiencies are difficult to detect in maize farming. Soil testing and plant tissue analysis should be used to detect potential micronutrient deficiencies. Among the above-mentioned micronutrients, maize is highly sensitive to Zn deficiency (Oldham 2019).

Micronutrient levels may be sufficient in majority of the soils for maize plants. However, the total concentration of a micronutrient is not a good indicator of the availability of that micronutrient. Some soil parameters (soil acidity or alkalinity, temperature, moisture) and plant genetics can reduce the availability of micronutrients. Thus, management of micronutrients for high maize yields should take conditions affecting the availability of micronutrients into consideration (Mallarino et al., 2014).

Soil pH has a significantl effects on micronutrients availability.. Micronutrients, with exceptionof Cl and Mo, are mostly available at low pH values.The availability of B, Cu, Fe, Mn, and Zn decreases and the availability of Cl and Mo increases with increasing soil pH levels. Therefore, soil pH should be maintained near to neutral or slightly acidic (6.0-7.0) for optimal availability of micronutrients to maize plants (Johnston 2018).

The effects of different phosphorus concentrations, chemical fertilizers, and organomineral fertilizers (leonardite and animal origin) on silage maize yield, nutrient content, and phosphorus uptake efficiency under field conditions were investigated by Korkmaz et al. (2022). The experiment was set up in a field that was slightly alkaline, low in organic matter, and deficient in phosphorus. At the time of sowing, chemical fertilizer, leonardite-derived organomineral fertilizer, and animal-derived organomineral fertilizer were all applied separately along with controls (no fertilizer application). With respect to P application rates and fertilizers used, the yield, nutritional content, and phosphorus absorption efficiency differed. The application of an organomineral fertilizer of animal origin with a P application rate of 60% (6.6 kg P_2O_5 da $^{-1}$) produced the highest yield (4208 kg da $^{-1}$). The 80% P rate (8.8 kg P_2O_5 da^{-1}) treated with the most chemical fertilizer resulted in the maximum dry matter content.

Organomineral fertilizer of animal origin can be used instead of other sources to increase the yield and phosphorus absorption efficiency of silage maize.

Throughout the crop cycle, organomineral fertilizers can slowly and progressively supply macro- and micronutrients found in organic matter. The lasting impact of this gradual release is still unknown, and it has to be assessed more thoroughly. To measure the residual effects of organomineral fertilizers on the P, B, and Zn of the soil, Vieira et al. (2023) carried out a study. The highest doses of organomineral fertilizers enhanced the availability of P and Zn in the soil and accelerated nutrient absorption, which had a positive lasting influence on lettuce output.

Karaca et al. (2006) investigated the effects of gidya as a humic substance on soil chemical and microbiological properties and heavy metal availability. They found that the application of gidya (G) alone and combined application of gidya and mineral fertilizer (G+NP) significantly increased the organic matter content in the soil, and G+NP application gave higher values in microbial properties compared to G alone and NP alone application. They found that extractable Cd, Pb, Ni, Cu, and Zn increased with NP application, but G+NP application gave decreasing results in the amount of extractable metals during the incubation period ($P<0.05$).

Rutkowska et al. (2014) investigated the effects of mineral and organic fertilizers on soil Fe, Cu, Zn, Mn, B, and Mo contents and availability of these nutrients for crops. The highest Zn, Fe, Mn and Cu contents were observed in the treatment with the lowest pH (NPK). This combination also had the lowest levels of B and Mo contents.

This study was conducted to investigate the effects of different organomineral fertilizer treatments on the micronutrient content of maize plants grown in soils collected from Ağrı/Eleşkirt region of Türkiye.

MATERIALS and METHODS

Soil samples were taken before and after sowing from the fields on which sugar beet, barley (forage), wheat, sainfoin, vetch, alfalfa, and meadow grass are cultivated widely in Ağrı/Eleşkirt region. Samplings were initiated in March 2019. Soil maps scaled to 1/25000 and current land use information were used. A grid sampling (2.5 × 2.5 km) method was used and samples were taken from the effective root zones of 20 different locations. Air-dried samples were passed through a 4 mm sieve and for each treatment, three pots (replicates) were used and each pot was filled with 2 kg of soil. Soil samples were supplemented with two different organomineral (granular and liquid) fertilizers when the pots reached field capacity. Maize seeds (*Zea mays* L. var. Karadeniz yıldızı) were sown into the pots on the 4^{th} of March, 2021 and plants were grown under greenhouse conditions. Following the measurement of parameters, plants were harvested on the 19^{th} of June 2021 when the plants reached tasseling (VT) stage and plant samples were prepared for relevant analyses. Effects of organominerals on maize plant characteristics and macronutrient contents were investigated. The following organomineral fertilizers provided from a fertilizer industry (Toros Fertilizer Company, Gönen/Türkiye) were used and were applied at rates of 100 of the technical recommendation in the present experiments.

The organomineral fertilizers sources used in the study were;

Granular Organomineral Fertilizer (G) "12-12-12+(23 SO_3)+10 OM". It is a four-nutrient compound fertilizer containing 12% N (Nitrogen), 12% phosphorus (P_2O_5), 12% potassium (K_2O), 23% sulfur (SO_3) and 10% organic matter (OM). While the organic matter increases soil fertility, humic and fulvic acids turn unavailable macronutrients into available forms and provide high yield and quality of maize crop. Organomineral Granular Organomineral Fertilizer were applied to the depth of 5 cm below soil surface.

Liquid Organomineral Fertilizer (L): Organomineral Liquid Fertilizer is produced by passing the liquid phase of the biogas production process through a specially developed production process. The product is formulated by adding plant-animal-originated additives to increase trace elements and dry matter content is adjusted to be around 35%. It has a stable pH value of 5-7. Fertilizers were applied as 6.4 mg pot $^{-1}$ equivelant to 8 kg liquid organomineral fertilizer per hectare. Liquid organomineral fertilizer was partially diluted and applied to the soil surface in the root zone. Since the pot experiment was conducted for 1.5 months (6 weeks), liquid organomineral fertilizer was not sprayed on the leaves to determine the plant response during the growing period. After planting, the pots were regularly weighed and watered at 50% of the field capacity for the first week and 75% for the ongoing weeks

Experiments were conducted in a completely randomized design with three replications in greenhouses conditions of the Organic Agriculture Program of Ağrı İbrahim Çeçen University, Vocational Collage in Ağrı.

Harvested samples were analyzed to micronutrients (Fe, Cu, Zn, Mn and B). Leaf samples were acid-digested in concentrated nitric-perchloric acid mixture and Fe, Cu, Zn, Mn contrations were determined by AAS (Atomic Absorption Spectrophotometer, SensAA, Dual GBC) and B concentration was determined spectrophotometrically (Kalra 1998).

Experimental data were subjected statistical analysis system (SAS) package for the analysis of variance and mean values were compared with the use of Duncan multiple's comparison test (P=0.05).

RESULTS and DISCUSSION

In Soils previously sampled and analyzed for the purpose of serial studies were also used in this study (Dizikısa et al., 2022). The soil samples were loamy 55%, clay-loam 40% and sandy-loam 5% in texture. The soil pH values were between 6.50-7.57 with an average value of 7.14. Soil lime contents were between 3.95-12.10% with an average value of 7.11%; 30% limey and 70% moderately limey.

Organic matter (OM) contents varied between 1.20-2.59% with an average value of 2%; 45% had low and 55% had moderate OM levels. Plant-available Fe levels varied between 2.78 - 6.90 mg kg^{-1}, 60% were sufficient and 40% were insufficient in available Fe. Soil samples were all sufficient in available copper (Cu) levels, available zinc (Zn) contents varied between 0.29 - 0.78 mg kg^{-1}, 10% were sufficient and 90% were low in available zinc content. Available manganese (Mn) levels were insufficient in all soil samples. Present analyses revealed that soils of the research area needed microelement fertilizations, especially for Zn and Mn (Dizikısa et al., 2022; Jones 2018).

Effects of different organomineral fertilizers on micronutrient (Fe, Cu, Zn, Mn and B) content of maize plants are presented in Table 1. There were significant differences among the organomineral fertilizers in terms of micronutrients. Iron (Fe) contents varied between 65.50-73.78 mg kg^{-1}, Cu contents between 10.10 -10.90 mg kg^{-1}, Zn contents between 22.10-23.90 mg kg^{-1}, Mn contents between 19.67- 22.25 mg kg^{-1} and B contents between 11.12 - 12.77. The highest contents of the micronutrient elements (Fe, Cu, Zn, and B) were obtained from the liquid organomineral fertilizer (L) treatments accept for the Mn which was determined from granular organomineral fertilizer, while the lowest values were observed in control treatments in all the organomineral fertilizer treatments In other words, higher values were obtained for Fe, Cu, Zn and B in liquid organomineral fertilizer application compared to the control. Plant Mn content was higher in granular organomineral fertilizer application than the control and liquid application. However, while the control group obtained results around the critical value, the organomineral fertilizer application obtained results in the critical value range . (Table 1).

Table 9. Effects of organomineral fertilizers on plant micronutrients (mg kg-1) 1

Fertilizer	Fe	Cu	Zn	Mn	B
C	65.50^b	10.10^b	22.10^b	19.67^c	11.12^c
G	73.45^a	10.55^a	23.75^a	22.25^a	12.22^b
L	73.78^a	10.90^a	23.90^a	21.77^b	12.77^a
Mean	70.91	10.52	23.25	21.23	12.03
F. value	96.89***	7.15***	26.67***	102.88***	70.58***
LSD	1.334	0.442	0.542	0.40	0.280
CV%	5.20	11.05	6.44	4.94	6.44

1 The means indicated with the same letter are not significantly different, *** significant at $p<0.001$ level.

Effects of different soil samples on micronutrient (Fe, Cu, Zn, Mn, and B) contents of maize plants are presented in Table 2. The iron contents of soil samples varied between 54.11-86.33 mg kg-1, Cu contents between 8.67-13.33 mg kg-1, Zn contents between 17.89-27.00 mg kg-1, Mn contents between 15.22-29.44 mg kg-1 and B contents between 7.89-19.44 mg kg-1 (Table 2). The highest content of Fe (86.33), Cu (13.33), Zn (27.00), Mn (29.44), and B (19.44) was obtained from soil samples 10, 8, 13, 5, and 6 respectively, whereas the lowest values was obtained from the soil samples 1, (1, 15, 1nd 16), 8, 4, and 18 respectively (Table 2). Cu content from soil sample 8 Zn content from soil sample 13, Mn content from soil sample 5 and B content from soil sample 6. The lowest Fe content was obtained from soil sample 1, Cu contents from soil samples 1, 15 and 16, Zn content from soil sample 8, Mn content from soil sample 4 and B content from soil sample 18 (Table 2). Effects of soil x fertilizer interactions on micronutrient (Fe, Cu, Zn, Mn, and B) contents of maize plants together with reference values for each micronutrient are provided in Table 3 (Kacar, 2019; Jones, 2018).

Table 2. Effects of different soil samples on plant micronutrients contents [1]

Soil sample	Fe	Cu	Zn	Mn	B
1	54.11^{l}	8.67^{j}	24.22^{cde}	25.78^{b}	12.44^{e}
2	58.33^{k}	13.00^{ab}	25.33^{bc}	19.78^{e}	11.22^{f}
3	70.33^{efg}	11.00^{d-g}	24.00^{cde}	18.56^{fg}	10.44^{gh}
4	69.33^{fgh}	9.33^{ghi}	23.89^{c-f}	15.56^{j}	11.33^{f}
5	69.00^{fgh}	12.00^{bcd}	20.33^{i}	29.44^{a}	14.56^{cd}
6	81.00^{b}	11.33^{def}	19.33^{i}	24.22^{c}	19.44^{b}
7	71.56^{ef}	9.33^{hij}	22.00^{gh}	16.78^{i}	16.78^{b}
8	77.33^{c}	13.33^{a}	17.89^{j}	18.22^{fgh}	14.11^{d}
9	63.56^{ij}	12.67^{abc}	26.22^{ab}	15.22^{j}	15.00^{c}
10	86.33^{a}	9.33^{hij}	22.33^{fg}	17.22^{hi}	14.11^{d}
11	75.22^{cd}	10.67^{efg}	22.67^{efg}	17.22^{hi}	9.56^{i}
12	85.00^{a}	8.67^{j}	22.00^{gh}	19.00^{ef}	9.33^{i}
13	63.89^{ij}	10.00^{ghi}	27.00^{a}	29.00^{a}	9.89^{hi}
14	66.33^{hi}	11.67^{cde}	24.89^{bc}	17.89^{gh}	9.89^{hi}
15	66.67^{ghi}	8.67^{j}	22.67^{efg}	26.56^{b}	12.78^{e}
16	61.33^{jk}	8.67^{j}	20.78^{hi}	22.56^{d}	11.56^{f}
17	73.56^{de}	11.00^{d-g}	24.33^{cd}	26.44^{b}	9.33^{i}
18	83.33^{ab}	9.00^{ij}	23.22^{d-g}	18.22^{fgh}	7.89^{j}
19	77.33^{c}	10.33^{fgh}	25.00^{bc}	24.77^{c}	11.00^{fg}
20	64.67^{ij}	11.67^{def}	26.89^{a}	22.11^{d}	10.00^{hi}
Mean	70.91	10.52	23.25	21.23	12.03
F. value	52.91***	15.87***	23.78***	168.76***	124.86***
LSD	4.13	1.31	1.68	0.98	0.87
CV%	5.20	11.05	6.44	4.94	6.44

[1] The means indicated with the same letter are not significantly different, *** significant at p<0.001 level.

In terms of the interactions between the two factors, maize plant showed different performance on the micronutrients uptake. The best performance of the plant was from (fertilizer L × soil sample 10), (fertilizer G × soil sample 8), (fertilizer L × soil sample 13), (fertilizer G × soil sample 5), and (fertilizer L × soil sample 6) interactions. While the minimum uptake of the micronutrients Fe (49.33±1.53), Cu (6.00±0.00), Zn (17.67±0.58), Mn (12.67±0.58), and B (6.67±0.58) by the plant from (C fertilizer × soil sample 1), (fertilizer L × soil sample 8), (C fertilizer × soil sample 11), (fertilizer G × soil sample 18), and interactions respectively (Table 3).

Table 3. Effects of soil x fertilizer interactions on plant micronutrients (mg kg^{-1})

Fertilizer	Soil	Fe	Cu	Zn	Mn	B
C	1	49.33±1.53	6.00±0.00	22.00±0.00	23.00±1.00	13.00±0.00
C	2	55.00±3.00	13.00±1.00	23.00±1.00	18.67±0.58	8.67±0.58
C	3	70.00±2.00	11.00±2.00	24.00±2.00	17.00±1.00	9.67±1.53
C	4	59.00±0.00	9.00±0.00	22.00±0.00	14.00±0.00	10.67±0.58
C	5	59.00±1.00	12.00±2.00	21.00±2.00	20.67±0.58	12.00±1.00
C	6	79.00±0.00	10.00±0.00	18.00±0.00	27.67±0.58	18.00±0.00
C	7	66.67±1.53	9.00±1.00	20.00±1.00	20.00±1.00	15.67±0.58
C	8	71.00±1.00	13.00±0.00	19.00±0.00	16.00±1.00	13.67±0.58
C	9	58.00±5.00	11.00±0.00	24.00±0.00	13.00±0.00	12.67±0.58
C	10	79.00±4.00	9.00±1.00	21.00±1.00	16.00±1.00	14.00±2.00
C	11	69.00±1.00	11.00±1.00	20.00±0.00	12.67±0.58	10.00±0.00
C	12	78.00±4.00	9.00±1.00	19.00±1.00	18.00±1.00	7.67±0.58
C	13	59.00±2.00	10.00±2.00	27.00±4.00	27.67±0.58	8.67±1.53
C	14	61.00±0.00	11.00±0.00	24.00±0.00	17.00±0.00	10.00±0.00
C	15	60.00±0.00	9.00±1.00	23.00±1.00	23.67±0.58	11.67±0.58
C	16	58.00±2.00	7.00±0.00	19.00±2.00	21.00±1.00	10.00±0.00
C	17	70.00±3.00	11.00±1.00	22.00±0.00	20.67±1.53	8.67±0.58
C	18	81.00±0.00	8.00±0.00	23.00±1.00	18.00±0.00	8.00±0.00
C	19	71.00±0.00	11.00±0.00	25.00±0.00	25.67±0.58	10.67±0.58
C	20	57.00±1.00	12.00±1.00	26.00±0.00	23.00±0.00	9.00±0.00
G	1	58.00±2.00	9.00±1.00	26.00±2.00	27.67±1.53	13.67±0.58
G	2	58.00±1.00	12.00±1.00	27.00±1.00	21.00±1.00	12.00±0.00
G	3	72.00±2.00	12.00±1.00	23.00±1.00	17.67±1.53	9.00±0.00
G	4	71.00±0.00	10.00±0.00	26.00±0.00	14.67±0.58	10.67±0.58
G	5	75.00±5.00	11.00±3.00	20.00±3.00	35.00±0.00	17.00±2.00
G	6	83.00±2.00	11.00±0.00	19.00±0.00	24.00±1.00	19.67±0.58
G	7	72.00±2.00	9.00±0.00	23.00±1.00	16.67±0.58	17.00±0.00
G	8	81.00±3.00	14.00±4.00	17.00±2.00	18.00±1.00	15.00±2.00
G	9	66.67±0.58	14.00±1.00	28.00±0.00	15.67±0.58	15.67±0.58
G	10	89.00±1.00	9.00±1.00	22.00±0.00	16.67±0.58	14.67±0.58
G	11	76.00±3.00	10.00±1.00	23.00±2.00	20.33±1.15	8.67±0.58
G	12	87.00±3.00	8.00±1.00	24.00±2.00	20.00±2.00	10.67±0.58
G	13	66.67±1.53	9.00±0.00	26.00±0.00	30.67±0.58	11.00±0.00
G	14	70.00±1.00	12.00±0.00	26.00±0.00	1767±0.58	9.00±0.00
G	15	71.00±0.00	8.00±1.00	21.00±2.00	27.00±2.00	12.67±0.58
G	16	61.00±3.00	9.00±2.00	21.00±3.00	23.00±3.00	11.00±2.00
G	17	74.67±4.51	12.00±2.00	26.00±2.00	29.00±2.00	9.67±0.58
G	18	89.00±3.00	10.00±2.00	23.00±2.00	19.00±3.00	6.67±0.58
G	19	81.00±8.00	10.00±1.00	26.00±1.00	27.67±0.58	9.67±0.58
G	20	67.00±2.00	12.00±2.00	28.00±2.00	23.67±1.53	11.00±1.00
L	1	55.00±3.00	11.00±1.00	24.00±0.58	26.67±0.58	10.67±0.58
L	2	62.00±0.00	14.00±0.00	26.00±0.00	19.67±0.58	13.00±0.00
L	3	69.00±1.00	10.00±1.00	25.00±2.00	21.00±1.00	12.67±0.58
L	4	78.00±3.00	9.00±1.00	23.00±0.58	18.00±0.00	12.67±0.58
L	5	73.00±3.00	13.00±1.00	20.00±1.00	32.67±0.58	14.67±1.53

L	6	81.00±1.00	13.00±0.00	21.00±0.00	21.00±0.00	20.67±0.58
L	7	76.00±2.00	10.00±1.00	23.00±1.00	13.67±0.58	17.67±0.58
L	8	80.00±1.00	13.00±0.00	17.67±0.58	20.67±0.58	13.67±0.58
L	9	66.00±2.00	13.00±1.00	26.67±0.58	17.00±0.00	16.67±0.58
L	10	91.00±1.00	10.00±0.00	24.00±1.00	19.00±1.00	13.67±0.58
L	11	80.67±0.58	11.00±0.00	25.00±0.00	18.67±0.58	10.00±0.00
L	12	90.00±2.00	9.00±1.00	23.00±2.00	19.00±1.00	9.67±0.58
L	13	66.00±1.00	11.00±1.00	28.00±5.00	28.67±1.53	10.00±0.00
L	14	68.00±2.00	12.00±0.00	24.67±0.58	19.00±0.00	10.67±0.58
L	15	69.00±1.00	9.00±0.00	24.00±0.00	29.00±0.00	14.00±0.00
L	16	65.00±1.00	10.00±1.00	22.33±2.08	23.67±0.58	13.67±0.58
L	17	76.00±1.00	10.00±0.00	25.00±0.00	29.67±0.58	9.67±0.58
L	18	80.00±0.00	9.00±0.00	23.67±0.58	17.67±0.58	9.00±0.00
L	19	80.00±2.00	10.00±1.00	24.00±0.00	21.00±0.00	12.67±0.58
L	20	70.00±2.00	11.00±1.00	26.67±0.58	19.67±0.58	10.00±0.00

C: Control, G: Granular organomineral fertilizer, L: Liquid organomineral fertilizer

In terms of plant Fe contents; in control treatments, all soils, except for the soil sample 1, were within the reference values (50-250 mg kg^{-1}), the lowest value was seen in soil 1 and the greatest value in soil 18; in granular organomineral fertilizer treatments, all samples were within the reference values, the lowest values were seen in soil 1 and the greatest values in soils 10 and 18; in liquid organomineral fertilizer treatments, again all samples were within the reference values, the lowest value was seen in soil 1 and the greatest value in soil 10. As a matter of fact, the plant-available iron contents of the soil samples were in the adequacy range. Since the plant Fe content was found to be sufficient between 50-250 mg kg^{-1}, the application of organomineral fertilizer slightly increased the plant Fe content. This is due to the humic acid in the organomineral fertilizer, which increases the microelement availability (releasing).

In terms of plant Cu contents; in control treatments, all samples were within the reference values (2-20 mg kg^{-1}), the lowest value was seen in soil 1 and the greatest values in soils 2 and 8; in granular organomineral fertilizer treatments, all samples were within the reference values, the lowest values were seen in soils 12 and 15 and the greatest values in soils 8 and 9; in liquid organomineral fertilizer treatments, again all samples were within the reference values, the lowest values were seen in soils 4, 12, 15 and 18 and the greatest value in soil 2. As a matter of fact, the plant-available cupper contents of the soil samples were in the adequacy range. The application of organomineral fertilizer slightly increased the plant Cu content.

In terms of plant Zn contents; in control treatments, all samples were within the reference values (14-50 mg kg^{-1}), the lowest value was seen in soil 6 and the greatest value in soil 13; in granular organomineral fertilizer treatments, all samples were within the reference values, the lowest value was seen in soils 8 and the greatest values in soils 9 and 20; in liquid organomineral fertilizer treatments, again all samples were within the reference values, the lowest value was seen in soil 8 and the greatest value in soil 13. As a matter of fact, the plant available zinc contents of the soil samples were also in the adequacy range. Since the plant Zn content was found to be sufficient between 14-50 ppm, the application of organomineral fertilizer increased the plant micro Zn content a little more.

In terms of plant Mn contents; in control treatments, all soils, except for soils 9 and 11, were within the reference values (15-100 mg kg^{-1}), the lowest values were seen in soils 9 and 11 and the greatest values in soils 6 and 15; in granular organomineral fertilizer treatments, all samples were within the reference values, the lowest value was seen in soil 4 and the greatest value in soil 5; in liquid organomineral fertilizer treatments, all samples, except for soil 7, were within the reference values, the lowest value was seen in soil 7 and the greatest value in soil 5. In most of the soil samples, the level of plant available Mn was below the sufficiency limit. This study clearly demonstrated the positive effect of both organomineral fertilizers especially on the manganese availability in the soil. Indeed, plant Manganese contents increased to the sufficiency range in all plant samples except one soil (7). Therefore, the interpretation made for Fe in this regard is also valid for Mn.

In terms of plant B contents; in control treatments, all samples were within the reference values (2-20 mg kg^{-1}), the lowest values were seen in soils 12 and 18 and the greatest value in soil 6; in granular organomineral fertilizer treatments, all samples were within the reference values, the lowest value was seen in soil 18 and the greatest value in soil 6; in liquid organomineral fertilizer treatments, again all samples were within the reference values, the lowest value was seen in soil 18 and the greatest value in soil 6. The boron content of the plant samples was within the adequacy range for each treatment.

Correlations among micronutrients of maize plants are provided in Table 4. Significant ($p<0.05$) and positive correlations were observed between Iron and Boron (r = 0.152^{*}) and highly significant ($p<0.01$) and positive correlations were observed between copper and zinc (r = 0.213^{**}) and between copper and boron (r = 0.209^{**}). There was a significant ($p<0.05$) negative correlation between iron and zinc (r = -0.157^{*}) and highly significant ($p<0.01$) negative correlations were observed between zinc and boron (r = -0.246^{**}) (Table 4). The existence of interactions (antagonistic or synergistic) between nutrients is a constant fact of plant nutrition science. In particular, antagonistic interactions (opposing), which are present in the soil solution but reduce the effect of each other in the plant uptake stage or in the plant body, are frequently encountered. Among these, the interaction of iron and zinc (Fe & Zn), copper and zinc (Cu & Zn) and copper and iron (Cu & Fe) are very common (Rabson 1993).

Korkmaz et al. (2022) reported that different chemical and organomineral fertilizers increased yield levels and nutrient (P, K, Ca, Mg, Fe, Zn, Cu, Mn and B) contents of silage maize as compared to the control. The greatest dry matter content was obtained from chemical fertilizer together with 80% of the recommended phosphorus.

Ayeni et al. (2012) conducted field trials to compare the effects of industrially produced organic fertilizer (OF, 0, 2.5, and 10 t/ha), organomineral fertilizer (OMF) and 300 kg ha^{-1} NPK 15:15:15 fertilizer (NPK) on soil chemical properties, nutrient uptake, growth and yield of maize plants. It was reported that organomineral fertilizer significantly ($P<0.05$) increased plant N, P, K, Ca, Cu, Fe, Zn and Mn contents; organomineral fertilizer (OMF) and NPK (15:15:15) fertilizer significantly increased maize plant height, number of leaves, leaf area, yield, root dry matter and kernel yield ($P<0.05$).

Table 4. Correlations among micronutrients of maize plants

	Iron (Fe)	Copper (Cu)	Zinc (Zn)	Manganese (Mn)	Boron (B)
Iron (Fe)	1				
Copper (Cu)	0.009	1			
Zinc (Zn)	-0.157*	0.213**	1		
Manganese (Mn)	-0.079	-0.019	0.121		
Boron (B)	0.152*	0.209**	-0.246**	0.085	1

* and **:Correlation is significant at 0.05 and 0.01 levels, respectively.

Cardoso et al. (2018) conducted a study to evaluate micronutrient absorption and extraction of Agata potato cultivar. It was reported that organomineral fertilizer treatments yielded greater absorption of micronutrients than the mineral fertilizer treatments; micronutrients were ordered as Fe> Zn> Mn> Cu> B. Toprak (2019) indicated iron deficiency as an important limiting factor for several products grown in calcareous soils with high pH levels It was reported that iron-rich organomineral fertilizers applied in increasing doses increased leaf N, P, K and Fe contents, but decreased leaf Ca, Mn, Zn and Cu contents.

Rodrigues et al. (2021) indicated that organomineral fertilizers combined economy and environment together and thus had increasingly been used worldwide, especially under tropical conditions. Researchers applied mineral fertilizers and organomineral fertilizers to soybean plants grown in clay and sandy-clay soils and reported that organomineral fertilizers increased soil microbial activity as well as nutrient accumulation, number of pods per plant and nodulation, but did not have any significant effects on shoot and root dry mass and enzymatic activities.

Torres et al. (2023) investigated the effects of 5 different organomineral fertilizer doses as a P and micronutrient (boron and zinc) source for curly lettuce cultivation and reported that 225 and 300 mg/dm^3 P_2O_5 doses of organomineral fertilizers provided higher levels of boron and zinc from the soil as compared to other applications.

Conclusion

Organomineral fertilizers have been progressively recognized as a promising technology for nutrient delivery. Organomineral fertilizers have significant effects on plant growth and development by improving soil physical, chemical and biological properties and increased micronutrients supply and uptake.. Therefore, this study was conducted to investigate the effects of different organomineral fertilizer treatments on micronutrient (Fe, Cu, Zn, Mn and B) content of maize plants grown in soils collected from Ağrı/Eleşkirt region of Türkiye. Two types of organomineral fertilizers were used: Granular organomineral fertilizer (G) (12-12-12+ (23 SO_3) + 10 OM) and liquid organomineral fertilizer (L). In terms of plant micronutrients, there were significant differences between organomineral fertilizers. Plant Fe contents varied between 65.50-73.78 mg kg^{-1}, Cu contents between 10.10-10.90 mg kg^{-1}, Zn contents between 22.10-23.90 mg kg^{-1}, Mn contents between 19.67-22.25 mg kg^{-1} and B contents between 11.12-12.77. Thehighest values were obtained from the liquid organomineral fertilizer treatments and the lowest values (except for Mn) were obtained from the control treatments.

The most significant effect of different organomineral fertilizer (granular and liquid) applications made a significant difference in increasing plant manganese content, especially for Mn, which has a low usefulness level in the soil samples used in this study. This study also revealed that the application of granular and liquid mineral fertilizers increased plant uptake of micronutrients that were at critical but borderline adequate levels in the soil. It was concluded that micronutrient availability and deficiency might be significant limiting factors for crop production in calcareous soils (with high pH levels) and organomineral fertilizers may offer important solutions for such problems encountered in calcareous soils. Further research is recommended with the same organomineral fertilizers and soil types, but this time with different doses and under field conditions to investigate plant reactions to organomineral fertilizers and to identify optimum doses.

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