ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Mahmoud Emad MORSY MOHAMED MORSY

ORGANOMINERAL FERTILIZER PHOSPHORUS AVAILABILITY IN A CALCAREOUS SOIL

DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

ADANA-2022

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

ORGANOMINERAL FERTILIZER PHOSPHORUS AVAILABILITY IN A CALCAREOUS SOIL

Mahmoud Emad MORSY MOHAMED MORSY

MSc THESIS

DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on / /2022.

…………………………………………….	……………………………	………………………………
Assoc. Prof. Dr. Emin Bülent ERENOĞLU	Prof. Dr. Hayriye İBRİKÇİ	Prof. Dr. Burçin ÇOKUYSAL
SUPERVISOR	MEMBER	MEMBER

This MSc Thesis is written at the Department of Soil Science and Plant Nutrition and Applied Sciences of Çukurova University.
Registration Number:

Prof. Dr. Sadık DİNÇER
Director
Institute of Natural and Applied Sciences

This study was supported by the Research Projects Unit of Ç.Ü.
Project No: FYL-2021-13478

ABSTRACT

MSc THESIS

ORGANOMINERAL FERTILIZER PHOSPHORUS AVAILABILITY IN A CALCAREOUS SOIL

Mahmoud Emad MORSY MOHAMED MORSY

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

Supervisor : Assoc. Prof. Dr. Emin Bülent ERENOĞLU
Year: 2022, Page: 59
Jury : Assoc.Prof. Dr. Emin Bülent ERENOĞLU
: Prof. Dr. Hayriye İBRİKÇİ
: Prof. Dr. Burçin ÇOKUYSAL

This MSc Thesis aimed to test the role of organomineral fertilizers, which have become widespread in recent years, on the phosphorus (P) use efficiency. For this purpose, an incubation test and a pot experiment were carried out to see the effect of P in organomineral fertilizer (OMF) prepared by mixing the mineral fertilizer (MF) source P with the organic fertilizer (OF) from the biogas plant on the availability of P in soil and on the nutrition of the wheat plant. In both experiments, increasing rates of OMF-P were applied to the same depth (6 cm below the surface) and compared with the triple super phosphate (TSP) fertilizer applied to the same area. In the incubation experiment, the soils were sampled twice, on the 45th and 90th days. Olsen P, an indicator of P availability in calcareous soils, was measured in homogenized soils. In the pot experiment, two samples were made during the tillering and maturation periods. During the tillering period, the whole plant was sampled, and at the maturity harvest, two separate samples were taken plant stubble and grain. Phosphorus, nitrogen (N), and potassium (K) concentrations were measured in plant samples. The content and uptake values per pot were calculated for each nutrient by multiplying these with dry weights. As a result of the incubation experiment, it was observed that the Olsen P contents of the soils treated with the OMF-P were higher at both sampling times than those with the MF-P. In line with this, both the P concentration in the shoots and the P uptake per pot were higher in the plants treated with the OMF-P in the plant samples of the tillering period. A similar trend was observed for P content in grains and total P uptake at maturity harvest. There were no definite results for N and K that the presence of organic fertilizers improved the N and K nutrition of the plants. In general, the P application increased N and K contents in the grain, and when total uptakes were considered, N uptake increased, but no effect on K was observed. However, there is still a need to compare the results with those obtained under field conditions.

Key Words: Biogas plant compost, nutrient uptake, organomineral fertilizer, phosphorus, wheat

ÖZ

YÜKSEK LİSANS TEZİ

KİREÇLİ BİR TOPRAKTA ORGANOMİNERAL GÜBRE FOSFORU YARAYIŞLILIĞI

Mahmoud Emad MORSY MOHAMED MORSY

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
TOPRAK BİLİMİ VE BİTKİ BESLEME ANA BİLİM DALI

Danışman : Doç. Dr. Bülent ERENOĞLU
Yıl: 2022, Sayfa: 59
Jüri : Doç. Dr. Emin Bülent ERENOĞLU
: Prof. Dr. Hayriye İBRİKÇİ
: Prof. Dr. Burçin ÇOKUYSAL

Bu Yüksek Lisans Tezi, son yıllarda kullanımı yaygınlaşan organomineral gübrelerin fosfor(P)un kullanım etkinliği üzerindeki rolünü test etmeyi amaçlamıştır. Bu amaçla, biyogaz tesisi kaynaklı organik gübre (OG) ile karıştırılan mineral gübre (MG) kaynaklı P'un hem topraktaki yarayışlılığı hem de buğday bitkisinin beslenmesine dönük inkübasyon ve saksı denemeleri gerçekleştirilmiştir. Her iki denemede de artan dozlarda OMG-P'u yüzey altına aynı derinliğe uygulanmış ve yine aynı yere uygulanan triple süper fosfat (TSP) gübresi ile karşılaştırılmıştır. İnkübasyon denemesinde topraklar 45 ve 90. günlerde olmak üzere iki defa örneklenmiştir. Homojenize edilen topraklarda yarayışlı P'un bir göstergesi olan Olsen P'u ölçülmüştür. Saksı denemesinde ise kardeşlenme ve olgunlaşma dönemlerinde iki ayrı örnekleme yapılmıştır. Kardeşlenme döneminde tüm bitki örneklenmiş, olgunluk hasadında ise bitki anızı ve dane olmak üzere iki ayrı örnek alınmıştır. Bitki örneklerinde P, azot (N) ve potasyum (K) konsantrasyonları ölçülmüş, bunların kuru ağırlıklar ile çarpılmasıyla da her bir besin elementi için saksı başına içerik ve alım değerleri hesaplanmıştır. İnkübasyon denemesi sonucunda, OMF-P uygulanan toprakların Olsen P'u içeriklerinin MF-P uygulanmış olana göre her iki örnekleme zamanında da daha yüksek olduğu görülmüştür. Bunun ile uyumlu biçimde kardeşlenme döneminde yapılan bitki örneklemesinde hem yeşil aksamdaki P konsantrasyonunun hem de saksı başına P alımı OMF-P uygulanmış bitkilerde daha yüksek olduğu olmuştur. Benzer bir eğilim olgunluk dönemi hasadında danelerdeki P içerikleri ve toplam P alımları için de gözlenmiştir. Azot ve K için ise organik gübre varlığının bitkilerin bu besin elementlerince beslenmelerini iyileştirdiğine dair kesin sonuçlar gözlenmemiştir. Genel olarak, P uygulaması danedeki N ve K içeriklerini artırırken, toplam alımları göz önünde bulundurulduğunda ise N alımını artırırken, K üzerinde herhangi bir etki gözlenmemiştir. Ancak, bu sonuçların tarla koşullarında elde edilecek sonuçlar ile karşılaştırılmalarına da ihtiyaç vardır.

Anahtar Kelimeler: Besin elementi alımı, buğday, fosfor, biyogaz tesisi kompostu, organomineral gübre

EXTENDED SUMMARY

Increasing world population, decrease in rural population, rise in income levels, and changing consumption habits in parallel with improvements in the economic situation are the main socio-economic factors that increase the need for food. In addition, we must achieve this increase in agricultural production areas where we do not have the opportunity to expand further. In addition, this increase must be completed in agricultural production areas where we do not have the chance to increase it further. Apart from increasing the agricultural production areas, these areas are also faced with the risk of losing their productivity/productivity due to reasons such as water shortage, mismanagement activities, and improper use of agricultural chemicals. Crop production also depends on fertilizers, which are carriers of plant nutrients that require energy for their production. Fertilizer means more yield per unit area. However, in addition to the limited and costly mineral fertilizer raw materials, improper use of nutrients such as N and P o also carries environmental risks. Therefore, correctly managing these nutrients in fertilization is crucial for effectively using limited raw materials, more economical plant production, and reducing environmental risks. Thus, an incubation experiment under lab conditions and a pot experiment were planned under greenhouse conditions by using biogas-facility-originated organic material, one of the most critical raw materials of organomineral fertilizers, and a mineral fertilizer source containing P (TSP). While, in the incubation experiment, the changes in available P of the soil were investigated with increasing amounts of organomineral fertilizer-P (OMF-P) and mineral fertilizer-P (MF-P), in the greenhouse experiment, the possible effect of the same fertilizers on the growth and P (N and K as well) uptake of wheat was evaluated.

At the end of 45 and 90 days of incubation of soils in which increasing rates of P were applied with the OMF-P and the MF-P, the available P level, known as Olsen P, in soils treated with the OMF-P was higher than that of the MF-P.

Especially in 90th-day sampling, up to 35% more available P (at a dose of 75 ppm) was measured in soils treated with the OMF-P compared to those treated with MF-P.

A concordance was observed between the shoot dry weights of plants grown with increasing rates of P in the form of OMF-P and MF-P for forty-five days and the available P levels of the incubated soils. Plants to which P was applied in OMF form had more shoot dry mass than those supplied with MF form. In parallel with the increase in shoot growth, P concentrations and total P contents of shoots in pots fertilized with the OMF-P were also higher than those fertilized with the MF-P; and the difference became more apparent when the P rate was decreased; in such a way, reached a level in the field.

At the tillering stage, increasing P application rates caused an increase in N concentration and N uptake of the shoot, independent of the P form. In contrast, it only increased uptake for K. Due to the P fertilizer form, neither the N and K concentrations nor their uptakes showed any positive changes.

The harvest rest and grain samples obtained at the ripening stage showed similar results to the shoot samples of the tillering stage. Phosphorus application increased both harvest residue and grain weight. Phosphorus fertilizer form did not cause significant differences in harvest residues or grain weights. Only at the lowest P rate, the grain yields of the plants supplied with the OMF-P were slightly higher than those treated with the MF-P. In parallel with the samples taken during the tillering stage, the P concentration in the harvest residues of the P-treated plants increased. However, P concentrations in the grain were not affected by P application. In addition, P fertilization increased the P contents of the harvest rest and the grain, and the P uptake was calculated from their sum. While the P application form did not affect the P content of harvest rest, the grains of plants supplied with the OMF-P tended to have more P than those provided with the MF-P. The difference became more pronounced and statistically significant, especially at rates close to the application rates in field conditions and at the lowest P rate, which was 19.7% higher. Regarding P uptake of plants, plants supplied with OMF-P at the lowest P rate, which is close to the application rates in field conditions, had 13.6% higher P uptake values than those treated with the MF-P.

No significant difference was observed between the N and K concentrations of the harvest rest and grain samples at ripening and P applications. While total N uptake of plants increased with phosphorus application, no increase was observed in K. However, plants accumulated more N and K in their grains with P treatment.

In conclusion, the OMF-P application caused an increase in both shoot growth and, to some extent, grain yield compared to the MF-P. Of course, the study needs to be renewed in field conditions where root volume is not limited, and the results should be compared with those obtained there. However, when it comes to P uptake values, the OMF-P effectiveness becomes more pronounced. The OMF-P supply caused an increase in P concentration (accumulation: P uptake greater than plant requirement) and total uptake but did not affect N and K concentrations. Phosphorus application increased the total N uptake, but there was no relationship between application forms of P and K uptake.

GENİŞLETİLMİŞ ÖZET

Artan dünya nüfusu, kırsal nüfusun azalması, gelir düzeylerinin yükselmesi ve ekonomik durumdaki iyileşmelere paralel olarak değişen tüketim alışkanlıkları gıda ihtiyacını artıran başlıca sosyo-ekonomik faktörlerdir. Ayrıca daha fazla genişleme imkânı bulamadığımız tarımsal üretim alanlarında da bu artışı sağlamalıyız. Ayrıca daha fazla artırma şansımızın olmadığı tarımsal üretim alanlarında da bu artışın tamamlanması gerekmektedir. Bu alanlar, tarımsal üretim alanlarının artırılmasının yanı sıra, su sıkıntısı, yanlış yönetim faaliyetleri, tarımsal kimyasalların yanlış kullanımı gibi nedenlerle verimliliklerini/verimliliklerini kaybetme riskiyle de karşı karşıyadır. Mahsul üretimi ayrıca, üretimleri için enerji gerektiren bitki besin maddelerinin taşıyıcıları olan gübrelere de bağlıdır. Gübre, birim alandan daha fazla verim anlamına da gelir. Ancak sınırlı ve maliyetli mineral gübre hammaddelerinin yanı sıra N ve P o gibi besin maddelerinin yanlış kullanımı da çevresel riskler taşımaktadır. Bu nedenle gübrelemede bu besin maddelerinin doğru yönetilmesi, sınırlı hammaddelerin etkin kullanılması, daha ekonomik bitkisel üretim ve çevresel risklerin azaltılması için çok önemlidir. Bu nedenle organomineral gübrelerin en kritik hammaddelerinden biri olan biyogaz-tesis kaynaklı organik madde ve P (TSP) içeren mineral gübre kaynağı kullanılarak laboratuvar koşullarında kuluçka ve sera koşullarında saksı denemesi planlanmıştır. İnkübasyon denemesinde, artan miktarlarda organomineral gübre-P (OMF-P) ve mineral gübre-P (MF-P) ile toprağın yarayışlı P seviyesindeki değişiklikler araştırılırken, sera çalışmasında aynı gübrelerin buğdayın büyümesi ve P (N ve K de) alımı üzerindeki olası etkisi değerlendirilmiştir.

OMF-P ve MF-P ile artan oranlarda P uygulanan toprakların 45 ve 90 günlük inkübasyon süresi sonunda, OMF-P ile muamele edilen topraklarda Olsen P olarak bilinen yarayışlı P seviyesi MF-P'na göre daha yüksek olmuştur.. Özellikle 90. gün örneklemesinde, MF-P ile muamele edilen topraklara kıyasla OMF-P ile muamele edilmiş topraklarda %35'e kadar daha fazla yarayışlı P (75 ppm'lik bir dozda) ölçülmüştür.

Kırk beş gün boyunca OMF-P ve MF-P formunda artan P oranları ile yetiştirilen bitkilerin sürgün kuru ağırlıkları ile inkübasyona tabi tutulmuş toprakların yarayışlı P seviyeleri arasında bir uyum gözlenmiştir. Fosforun OMF formunda uygulandığı bitkiler, MF formunda verilenlere göre daha fazla sürgün kuru maddesine sahip olmuştur. Sürgün büyümesindeki artışa paralel olarak, OMF-P ile gübrelenen saksılardaki bitkilerin yeşil aksamlarındaki P konsantrasyonları ve toplam P içerikleri de MF-P ile gübrelenenlere göre daha yüksek olmuş, P dozu arazi koşullarındaki uygulama dozlarına düşürüldüğünde fark daha belirgin hale gelmiştir.

Kardeşlenme aşamasında artan P uygulama dozları, P formundan bağımsız olarak yeşil aksamın N konsantrasyonunda ve N alımında artışa neden olmuştur. Buna karşılık, K'da sadece toplam alımda artışa neden olmuştur. Fosforlu gübre formuna bağlı olarak ne N ve K konsantrasyonları ne de alımları herhangi bir pozitif değişiklik göstermemiştir.

Olgunlaşma aşamasında örneklenen hasat artıkları ve dane örnekleri kardeşlenme aşamasındaki sürgün örneklerine benzer sonuçlar göstermiştir. Fosfor uygulaması hem hasat artığı hem de dane ağırlığını artırmıştır. Fosforlu gübre formu, hasat artıklarında veya dane ağırlıklarında önemli farklılıklara neden olmamıştır. Sadece en düşük P oranında, OMF-P ile beslenen bitkilerin dane verimleri, MF-P ile muamele edilenlerden biraz daha yüksek bulunmuştur. Kardeşlenme döneminde alınan örneklere paralel olarak P uygulanan bitkilerin hasat artıklarındaki P konsantrasyonu da artmıştır. Ancak tanedeki P konsantrasyonları P uygulamasından etkilenmemiştir. Ek olarak, P gübrelemesi, hasat artığının ve danenin P içeriğini arttırmış ve bunların toplamından da P alımı hesaplanmıştır. Fosfor uygulama formu, hasat artığının P içeriğini etkilemezken, OMF-P ile gübrelenen bitkilerin daneleri, MF-P ile beslenenlerden daha fazla P'ye sahip olma eğilimi göstermiştir. Özellikle tarla koşullarındaki uygulama dozlarına yakın durumda ve en düşük P oranında %19,7 daha yüksek olan fark daha belirgin ve istatistiksel olarak anlamlı hale gelmiştir. Bitkilerin P alımı ile ilgili olarak, tarla koşullarındaki uygulama dozlarına yakın olan en düşük P dozunda OMF-P verilen bitkiler, MF-P uygulananlara göre %13,6 daha yüksek P alım değerine sahip olmuştur.

Hasat artığı ve dane örneklerinin N ve K konsantrasyonları ve P uygulamaları arasında önemli bir fark gözlenmemiştir. Fosfor uygulaması ile bitkilerin toplam N alımı artarken, K'da herhangi bir artış gözlenmemiştir. Ancak P uygulaması ile bitkiler danelerinde daha fazla N ve K biriktirmiştir.

Sonuç olarak, OMF-P uygulaması, MF-P'ye kıyasla hem sürgün büyümesinde hem de bir dereceye kadar dane veriminde artışa neden olmuştur. Elbette kök hacminin sınırlı olmadığı tarla koşullarında çalışmanın yenilenmesi ve sonuçların orada elde edilenlerle karşılaştırılması gerekmektedir. Ancak konu P alım değerlerine geldiğinde OMF-P etkinliği daha belirgin hale gelmiştir. OMF-P uygulaması, P konsantrasyonunda (birikim: P alımı bitki ihtiyacından daha fazla) ve toplam alımda bir artışa neden olmuştur, ancak N ve K konsantrasyonlarında herhangi bir değişikliğe yol açmamıştır. Fosfor uygulaması toplam N alımını arttırmış, ancak K alımı ve P uygulaması arasında bir ilişki bulunamamıştır.

ACKNOWLEDGEMENTS

First of all, I would like to thank my esteemed advisor, Assoc. Prof. Dr. Emin Bülent ERENOĞLU, who supported and paved my way during my MSc study. I would also like Prof. Dr. Hayriye İBRİKÇİ and Prof. Dr. Burçin ÇOKUYSAL who were the jury members in my thesis defense.

I would like to thank all my professors and colleagues in the Department of Soil Science and Plant Nutrition at Çukurova University, who supported me with their help, knowledge, and experience throughout my education life. Special thanks to YTP which supported me with Türkiye Scholarship during my study.

I want to express my gratitude to my beloved wife for everything she has done for me. At the same time, I would like to express my sincere thanks to my family, who shared all my responsibilities during my thesis work, encouraged me, and always stood by me.

TABLE OF CONTENTS **PAGE**

ABSTRACT....I
ÖZ II
EXTENDED SUMMARY.... III
GENİŞLETİLMİŞ ÖZET VII
ACKNOWLEDGEMENTS....XI
TABLE OF CONTENTS.... XII
LIST OF TABLE XIV
LIST OF FIGURES XVI
1. INTRODUCTION 1
2. LITERATURE REVIEW 5
2.1. Nutrient Balance and Sustainable Management in Soil 5
2.2. Plant Nutrition Materials (Fertilizers).... 6
2.3. Soil Organic Matter and Fertilization 9
2.4. Organomineral Fertilizers and Their Role in Crop Production.... 11
2.5. Organic matter and P relations in soils and plants 14
3. MATERIALS AND METHODS.... 19
3.1. Materials 19
3.1.1. Experimental Soil and Plant Material 19
3.1.2. Fertilizers 19
3.2. Methods.... 20
3.2.1. Organomineral Fertilizers and $NaHCO_3$-Extractable P in Soil (*Experiment I*) 20
3.2.2. Organomineral Fertilizers and Phosphorus Nutrition (*Experiment II*).... 20
3.3. Statistical Analyses 23
4. RESULTS AND DISCUSSION 25

4.1. Organomineral Fertilizers and $NaHCO_3$-Extractable P in Soil (*Experiment I*) 25
4.2. Organomineral Fertilizers and P Nutrition (*Experiment II*) 25
4.2.1. Plant Growth and Grain Yield 25
4.2.2. Nutritional Status of Plants 29
4.2.2.1. Phosphorus Nutrition 29
4.2.2.2. Nitrogen and Potassium Nutrition 32
4.3. Discussion 37
5. CONCLUSIONS AND RECOMMENDATIONS 43
REFERENCES 45
CURRICULUM VITAE 59

LIST OF TABLE **PAGE**

Table 2.1. The annual amount of organic waste produced in Turkey 9
Table 2.2. OM and HA+FA amounts per unit area calculated from the recommended application rates of a fluid HA+FA and granule 15.20.0+OM 17
Table 2.3. Costs calculated from the recommended application rates of fluid HA+FA, granule 20.20.0 and granule 15.20.0+OM 17
Table 3.1. Some of the chemical and physical properties of the Arık Series 19
Table 3.2. Fertilizer types and P levels used in *Experiment I* and their required amounts 21
Table 3.3. Fertilizer types and P levels used in *Experiment II* and their required amounts 22

LIST OF FIGURES **PAGE**

Figure 2.1. The cycle of organic matter and nutrients in the soil-plant system 10

Figure 2.2. Soil organic matter and its relationships with physical, biological, and chemical processes in soil 10

Figure 2.3. The relationship between humic acid, a large organic molecule, and phosphorus fixation induced by hydroxy iron is the leading cause of phosphorus fixation. The phosphorus fixation level of the surface covered with organic molecules decreases 16

Figure 4.1. Sodium bicarbonate extractable P levels of the experimental soil incubated with increasing rates of P applied either as OMF or MF for 45- and 90-days. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test 26

Figure 4.2. Shoot dry weights of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different at P < 5% according to ANOVA followed by Duncan's test. 27

Figure 4.3. Harvest rests (A) and grains (B) dry weights of wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test. 28

Figure 4.4. Shoot P concentration (A) and P uptake (B) of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test. 30
Figure 4.5. Phosphorus concentration of harvest rests (A) and grains (B) of plants grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test. 31
Figure 4.6. Phosphorus content of harvest rests (A) and grains (B) and total P uptake (C) of plants grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at P < 5%, according to ANOVA followed by Duncan's test. 33
Figure 4.7. Nitrogen and potassium concentrations in shoots (A-B) and uptakes (C-D) of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait, at P < 5% according to ANOVA followed by Duncan's test. 34
Figure 4.8. Nitrogen and potassium concentrations of harvest rests (A-B) and grains (C-D) of wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait, at P < 5% according to ANOVA followed by Duncan's test. 35

Figure 4.9. Nitrogen and potassium contents of harvest rest (A-B) and grains (C-D) and total nitrogen and phosphorus uptake (E-F) in wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test. 36

XIX

1. INTRODUCTION

Considering future world food consumption due to increasing population, declining rural population, increases in income level, and changes in the rate of poverty in the population over time constitute the main socio-economic factors that lead to increased food demand (FAO, 2009; Msangi and Rosegrant, 2009). In addition to all these, when the production contractions and fluctuations that we will face because of global warming are added, it is seen that an overly complex ball of problems awaits human beings. It is estimated that the world population will be around 9.3 billion by 2050 (UN, 2011). Taking the year 2010, when the population was 6.3 billion, as a starting point, this corresponds to an increase of approximately 35%. This increase means that more people's need for food security and healthy nutrition must be met. It is estimated that the demand for food will increase by 70% with today's consumption habits (Bruinsma, 2009). This increase means more agricultural production. And we must achieve all these increases in limited production areas under the threat of global climate change and variability, the adverse effects of which are already being seen.

Using chemical fertilizers in crop production supports the fertility of soils chemically. Still, it falls short of improving its physical and biological properties, especially in areas where organic matter is shallow. For this reason, mainly, these soils should be supported by organic matter.

Soil organic matter, consisting of plant and animal wastes, is widely used as a crucial indicator of productivity in sustainable soil management. The hummus is formed because of the breakdown of these wastes; It is a very stable and homogeneous substance whose color can vary from brown to black, created because of the decomposition of plant and animal wastes by microorganisms' activity. In soil science, organic matter is called humus (Brady and Weil, 2017).

Although soil organic matter constitutes a meager percentage of soils, it is a crucial soil component that affects soil fertility and structure in agriculture. Humus covers the clay minerals in the soil, thus preventing the clay minerals from bonding to each other and increasing the exchange capacity of these molecules. Its high cation exchange capacity provides better use of chemical fertilizers by the plant. It prevents them from moving away from the root zone, combining with high-valent cations such as iron (Fe^{+3}), copper (Cu^{+2}), and zinc (Zn^{+2}) to form chelates and load these cations. It neutralizes them and facilitates their uptake by plants. It increases the activities of microorganisms in the soil. For these reasons, research on applying organic matter to the soil in recent years, especially in areas with low organic matter, and the effects of humus resources on plant growth and soil properties have gained momentum.

The low organic matter content of Turkey's soils (Sönmez et al., 2018) and the decreasing raw material resources (Cordell et al., 2009) increase the need for organic and organomineral fertilizer production, and studies on these issues in Turkey as well as all over the world. The need to utilize organic wastes, which increase due to population growth and consumption in parallel with this, to keep the environmental risks to a minimum, also increases the importance of these research activities.

Using natural organic fertilizers (OFs) and organomineral fertilizers (OMFs) is one of the most critical issues of sustainable agricultural practices. Organic fertilizers can differ since natural fertilizers have different degrees of decomposition and decomposition; they break down and decompose slowly. The distribution of nutrients they contain is variable depending on the source material. On the other hand, OMFs contain plant nutrients found in chemical fertilizers and organic matter together so that nutrients can be presented in a more standardized form in terms of content. In organomineral fertilizers, plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and organic matter originating from humic-fulvic acid, compost, or leonardite are used together as a base fertilizer. It is thought that OMFs produced as "organic matter + mineral fertilizer" by utilizing the positive effects of organic materials on soil fertility, on the one hand, reduce the loss of nutrients by leaching, on the other hand, increase the efficiency of the mineral nutrients used by improving the fertility of the soil in the rhizosphere.

The thesis was planned in two parts: i) an incubation experiment under laboratory conditions and ii) a pot experiment under greenhouse conditions. In the incubation experiment, available P change was observed in a calcareous soil incubated with varying OMF-P and MF-P rates for 45 and 90 days. The effects of OMF-P and MF-P applications at different rates on wheat plants' growth and P uptake were investigated in the pot experiment conducted under greenhouse conditions.

2. LITERATURE REVIEW

Increases in population, urbanization and income level, and changes in the poverty rate over time, constitute the main socio-economic factors leading to increased food demand (FAO, 2009; Msangi and Rosegrant, 2009). With all this, when production contractions and fluctuations that will occur because of global warming are included, it is seen that an extraordinarily complex equation awaits us. By 2050, the world population will be around 9.3 billion (UN, 2011). The world population was 6.9 billion in 2010, corresponding to a 35% increase. This increase means that more people must meet the need for food safety and healthy nutrition. During this time, it is estimated that the demand for food will increase by 70% (Bruinsma, 2009). This increase means more plant production. And we must achieve all these increases in limited production areas under the threat of global climate change and variability, the effects of which are already being seen.

2.1. Nutrient Balance and Sustainable Management in Soil

Considering the limited land resources in agricultural production, more fertilizers are necessary to balance nutrients in the soil and respond to increased food demand (Grote et al., 2005). According to the calculations, while the amount of nutrients removed from the soil on a global scale was 230 million tons in 1997, the fertilizer used in the same year was 130 million tons (Vlek et al., 1997). Since the amount of nutrients currently removed from the field is higher than the total amount of fertilizer used, the fertility of the soils will inevitably decrease over time. For this reason, using more nutrients is an absolute necessity both to protect the fertility of the soils and to be prepared for the possible increase in food requirements in the future.

Of course, when using these nutrients for plant production, the approach of applying the right nutrient source at the right rate, at the right time, to the right place should be adopted. So, the nutrient use must be sustainable for the environment, the economies, and the social lives of farmers and related sectors (IPNI, 2017). This approach refers to a set of scientific practices that are accepted on a global scale, known as 4R's Nutrient Stewardship. The right source of nutrients here includes mineral (chemical) fertilizers and all farm and urban organic wastes (IPNI, 2017).

2.2. Plant Nutrition Materials (Fertilizers)

Fertilizers, which are products that contribute to soil fertility by improving the available levels of plant nutrients and the chemical and physical properties of soils or are applied directly to plants (Wikipedia, 2020), can be natural and processed (Kiiski et al., 2016b). These materials, commonly called fertilizers, can be of chemical and organic origin. However, mineral fertilizers are used more intensively as a source of nutrients than organic fertilizers due to their high nutrient contents and problems in controlling the mineralization processes of organic fertilizers. Due to these properties, fertilizers are one of the most critical components of plant production. In fact, according to an estimation study, 30-50% of the increase in food production between the 1950s and the end of the 1900s was due to the use of fertilizers (Higgs et al., 2000).

A. Mineral (Chemical) Fertilizers

Many nutrients are used in natural or processed fertilizer materials to improve plant production from roots and leaves. However, due to the importance of nitrogen (N) and phosphorus (P) in plant production and the environmental risks of using them at high rates (Guignard et al., 2017), these two nutrients need to be best managed during agronomic studies.

Nitrogen fertilizers are produced using ammonia (NH_3) from the Häber-Bosch process from N_2 gas in the atmosphere, an unlimited resource (Appl, 2006). This ammonia obtained is used as a raw material for all other N fertilizers such as anhydrous ammonium nitrate (NH_4NO_3) and urea ($CO(NH_2)_2$). Nitrogen and its natural cycle are of particular interest to ecologists because N availability can affect the rate of key ecosystem processes, including primary production and decomposition. Human activities such as burning fossil fuels, using artificial N fertilizers, and releasing N with wastewater significantly change the global N cycle (Galloway et al., 2004; Kuypers et al., 2018; Reis et al., 2016). Human intervention in the global N cycle can adversely affect natural environmental systems and human health (Gu et al., 2016; Kim et al., 2017). It is vital to keep the efficiency of N used in fertilizer at the maximum level to meet the needs of plants and all living things taken into the culture, supply the best contribution to the economy of the producers, and manage the mentioned environmental risks in the best way.

As known, P is one of the essential nutrients that may limit plant production in the future with its dependence on non-renewable raw materials (Cordell et al., 2009). However, there are conflicting estimates of when this limited resource will run out. For example, while van Kauwenbergh (2010) thinks this phosphate rock will be depleted in 300-400 years, others state that the raw material will run out in short, like 50-100 years (Cordell et al., 2009). However, current P applications also hold a wide range of environmental risks, from eutrophication in waters to the formation of phosphogypsum piles during the production of phosphoric acid and heavy metal contamination from raw materials in phosphate rock (Oliveira and Machado, 2013). For the reasons mentioned above, it should be the priority of today's agriculture to bring all organic resources having nutrients, especially P, to agricultural lands so as not to harm the environment.

B. Fertilizers of Organic Origin

Kacar and Katkat (2009) define organic fertilizers as the plant- and animal-originated materials used in agriculture. It includes organic fertilizers, animal excreta, plant wastes from agriculture, compost, and treated sewage sludge (biosolids). In addition to animal manure, animal sources may also include materials such as blood meal, bone meal, feather meal, hides, hooves, and horns obtained from slaughterhouses (Kiiski et al., 2016a). The European Consortium of Organic-Based Fertilizer Industry has defined these fertilizers as follows to clarify the boundaries of organic-based fertilizers to end the confusion between the concepts of organic fertilizers (ECOFI, 2020).

- ✓ *Organic fertilizer* is a fertilizer whose main task is to supply nutrients in organic forms from plant and animal origin organic materials.
- ✓ *Organomineral fertilizer* is obtained by formulating inorganic fertilizers with one or more organic fertilizers or organic soil improvers into solid forms (except dry mixes) or liquids.
- ✓ *Organic soil improvers* have carbonaceous plant and animal origin materials whose primary function is to preserve or increase soil organic matter content.

A massive part of organic fertilizers consists of animal excreta, as shown in Table 2.1, prepared from the Turkey Biomass Energy Potential Atlas organized by the Ministry of Energy and Natural Resources (EİGM, 2020). Two-thirds of the total amount of organic waste and potential organic fertilizer in Turkey consists of animal waste. These fertilizers hold organic matter, various amounts of microorganisms, and plant nutrients, albeit at low levels (Kacar and Katkat, 2009). For this reason, they are also known as multi-action fertilizers. These fertilizers are plant nutrition and soil improvement materials that should be used in a particular order to support the fertility of the soil and end the potential waste problems.

Table 2.1. The annual amount of organic waste produced in Turkey

Waste Type	Waste Amount (ton/year)
Animal Waste	193.878.079
Plant Waste	62.206.754
Municipal Waste	32.170.975
TOTAL (tons/year)	**288.255.808**

Organomineral fertilizers, which have become widespread among organic fertilizers in recent years, are fertilizers that have organic fertilizers or organic soil improvers together with mineral nutrients, as stated in the previous definition. It is predicted that there may be significant increases in the future use of organomineral fertilizers (Paré et al., 2009).

2.3. Soil Organic Matter and Fertilization

It is known that soil organic matter (SOM) has complex relationships from soil microorganisms to soil minerals, starting with dead plant or animal residues falling into the soil (Coonan et al., 2020; Figure 2.1). As a natural result of these relationships, organic matter takes part in and is affected by the soil's biological, physical, and chemical processes (Brady and Weil, 2017. Figure 2.2). The organic mass of the soil is a crucial element for the function and quality of the soil. High SOM can increase the nutrient content of the soil (Rochette et al., 1999) and improve the physical and biological properties of the soil (Gong et al., 2009; Guo et al., 2012). Therefore, supporting SOM is vital for maintaining agroecosystems' productivity. Farm practices, such as fertilization or tillage in agriculture, significantly affect soil organic matter (Smith et al., 2005; Ludwig et al., 2011). This situation becomes more critical in areas with low organic matter content (like Turkey). The amount of soil organic matter is estimated by soil organic carbon (SOC) content. Changes in SOC also affect the C and N cycles in terrestrial ecosystems (Malhi et al., 2011; Grandy et al., 2013). Changes in organic C and N fractions in organic matter occur because of the combined effects of soil chemical and biological properties (Zhao et al., 2016).

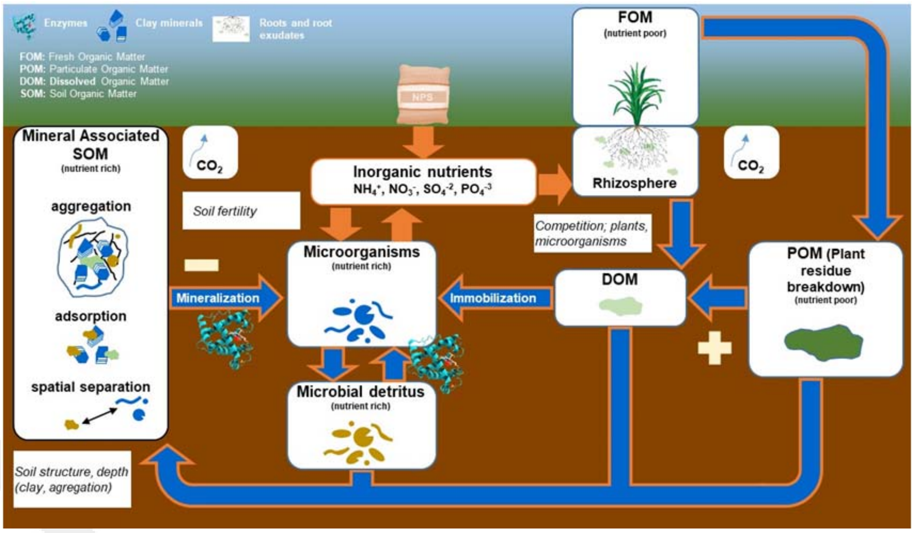

Figure 2.1. The cycle of organic matter and nutrients in the soil-plant system

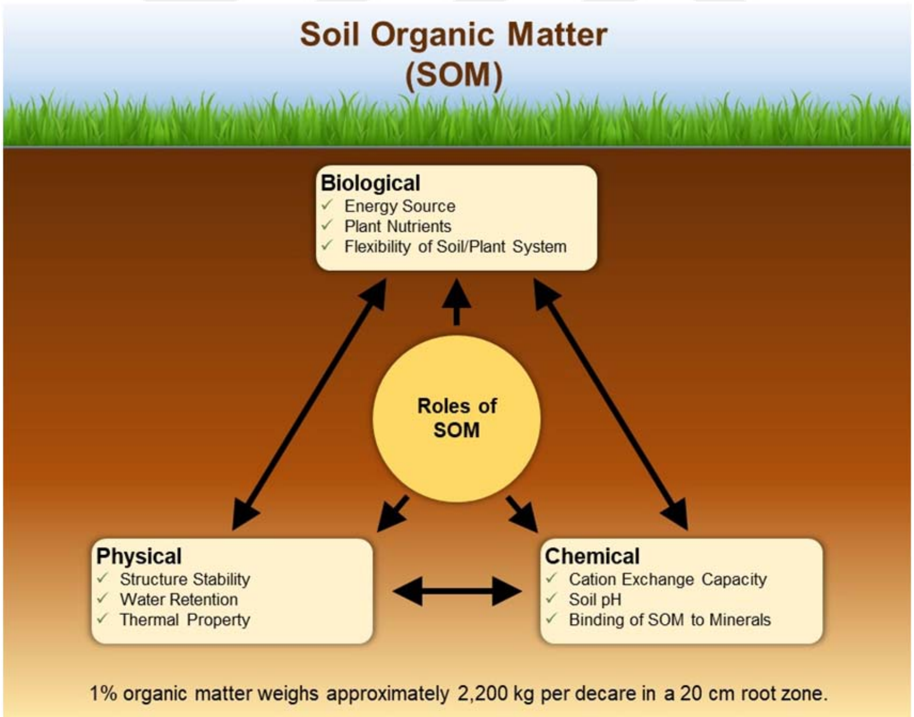

Figure 2.2. Soil organic matter and its relationships with physical, biological, and chemical processes in soil

Fertilization, which improves the nutrition of plants, in addition to achieving high yields, can affect soil microorganisms' activity and diversity (Jangid *et al*., 2008; Ding et al., 2016) and is an essential agricultural application for changes such as C and N chemistry of the soil (Nemergut *et al*., 2008). Earlier studies show that fertilization affects and changes the microbial community in N bacteria (Simonsen et al., 2015), methanotrophs (Hu and Lu, 2015), and cellulosic bacteria (Fan et al., 2012). Microorganisms can respond to changes in soil environmental conditions by adjusting the composition of the microbial community and the total amount of microbial biomass (Tian *et al*., 2015). In addition, diversities in the microbial colony also affect the cycles of C and N in the soil ecosystem (Grandy et al., 2013; Cusack et al., 2011). It is thought that the microbial biomass diversity in the soil is an important indicator of soil quality and soil health (Ding et al., 2016; Romaniuk et al., 2011).

The decomposition of plant residues is a crucial process in the nutrient cycle. After the death of organisms, most organic compounds are released to the soil in the form of insoluble polymers such as cellulose, lignin, protein, and chitin; decomposers cannot take them directly (Allison and Vitousek, 2005). Firstly, extracellular enzymes must convert these polymers into soluble subunits that microorganisms can use. Therefore, extracellular enzyme activity is the limiting phase in microbially treated degradation (Schimel and Weintraub, 2003). For this reason, it is accepted that these exogenous enzymes to be measured in the soil supply indirect information about microbial activities in current conditions (Geisseler and Horwart, 2009).

2.4. Organomineral Fertilizers and Their Role in Crop Production

Animal manure and MFs have been widely used to supply macro-and micronutrients in plant production for a long time. In addition, many materials, such as food, sewage, and other industrial wastes, are used to produce OMFs (Chassapis and Roulia, 2008; Rady, 2012; Kominko et al., 2017). Applying MFs together with organic improvers has a dual effect that enhances crop yield and recycles agricultural waste (Lekfeldt et al., 2017; Yadav et al., 2019). Best nutrient management practices preferably consist of manure, harvest rests, and MF to supply crop nutrient requirements (Ju and Zhang, 2021). That is why; the fertilizer industry has also focused on producing organomineral fertilizers, which are obtained from the mixture of organic residues, such as biogas plants or wastewater sludge treatment plants, with mineral fertilizers.

When applied to the soil, animal manure has another benefit, such as providing organic matter to the soil. When correctly used, it can provide suitable conditions for higher plant yields than when only MF is used (Reddy et al., 2000; Fernandes et al., 2003; Steiner et al., 2007; Ayinla et al., 2018). For instance, it was reported by Steiner et al. (2007) that chicken manure addition provided significantly higher rice (*Oryza sativa* L.) and sorghum (*Sorghum bicolor* L.) yields than MF, rose soil pH and increased extractable P, Ca, and Mg amounts in acidic conditions. However, crop yields were similar in many cases in areas where animal fertilizers or MFs were applied (Eghball and Power, 1999). These results suggest that both fertilizers are excellent nutrient sources. However, a point should not be forgotten using animal fertilizers alone causes nutrient imbalances. In addition, organomineral fertilizers reduce the fixation of phosphorus by minerals (Chaabane, 1994; Parent et al., 2003) and the conversion of P_2O_5 to non-plant available forms (Iyamuremye et al., 1996; Khiari and Parent, 2005) and increase the rooting activity of the younger plants (Lee and Bartlett, 1976) are known.

Although widely used, animal manure and mineral fertilizers may also have disadvantages. Recent research activities have shown that reciprocated overuses of manure and straw in agricultural soils can increase the risk of P losses to waterbodies (Yan et al., 2016; Yang et al., 2017). For example, since animal manure usually has a low N:P ratio, MFs are needed to adjust its nutrients to meet the plant’s nutritional needs. Application of animal manure to meet the N needs of plants will, in most cases, result in excessive P application, leading to environmental problems over time. Organic fertilizers should be subjected to chemical analysis before applying them to the field to apply nutrients in known amounts. Another point related to animal manure management is its higher transport costs over long distances because of its high moisture content. Although MFs have the advantage of being specially blended to meet the nutrient needs of plants, they still have the potential to create environmental problems if they are not applied correctly by the 4D Precision Nutrient Management approach. Due to the depletion of natural resources, the lack of raw materials used for fertilizer production increases. This is a significant problem for phosphorus. Since negative situations are related to these nutrient sources, calls have been made for environmentally and economically healthier options (Ojo et al., 2014; Sakurada et al., 2016; Ayinla et al., 2018).

Combining MFs with animal manure or other waste raw materials through industrial processes to produce OMFs as a new product is a promising alternative. As a result of this process, a more stable, balanced, and uniform product can be created by increasing the nutrient concentration in the development, thus enabling lower application rates. These fertilizers obtained from organic residues will become an industrial product source of nutrients. Therefore, it will be packaged and labeled with the nutrient composition clearly written, which can be used to calculate the required amount of nutrients for any product. Similar developments have been seen in our country in recent years. Another vital advantage is that nutrient availability rates can be predicted more easily (Sakurada et al., 2016). Moreover, organomineral fertilizer supplies a range of macro and micronutrients and organic matter. For example, the combination of animal manure and mineral fertilizer offers an excellent opportunity to improve the soil conditions of degraded agricultural soils and, at the same time, keep productivity on undisturbed soils. For example, it has been reported that the joint application of animal manure and chemical fertilizer may have an effect that will result in higher yields than when applied alone (Mandal et al., 2007; Eifediyi and Remison, 2010; Ayinla et al., 2018). It is expected that the organic-mineral fertilizers will increase shortly. In addition to all these, the effect of a solid organic fertilizer originating from a biogas plant applied at rates of 0, 250, 500, and 1000 kg/ha on the growth of the wheat plant was investigated in a pot experiment conducted under greenhouse conditions (Erenoğlu and Hacirüstemoğlu, in press). In the study, the application of fixed rates of nitrogen, phosphorus, and potassium and increasing rates of organic fertilizer 5 cm below the seedbed increased the shoot growth and P concentration; however, it did not affect nitrogen, potassium, magnesium, and calcium concentrations. Moreover, an increase was observed in plants' total nitrogen, phosphorus, and potassium uptakes with organic fertilizers. It was stated that this might be due to the dilution effect.

2.5. Organic matter and P relations in soils and plants

Overuse of P in plant production causes P accumulation in the soil and creates a risk in terms of P losses to the waterbodies (Rowe et al., 2016; Zhou et al., 2021). Since it is bound in the soil as adsorbed or Ca–P and Al/Fe–P precipitates depending on the soil pH and redox condition, most of the P applied in plant production converts to unavailable forms (Barrow et al., 2021; Gu et al., 2020; Zhang et al., 2021b). After that, the changes in soil properties altered by soil management can mobilize fixed P (Nobile et al., 2020). Therefore, understanding the conversion and mobilization of soil P under agricultural practices is very important. Long-term application of organic ameliorates to soils affects organic matter content (Li et al., 2021). In addition, organic matter causes slight and microsite acidification in calcareous soils (Guo et al., 2018; Yan et al., 2018). Soil acidification increases the conversion of Ca–P into Al/Fe–P in different soils (Chen et al., 2018; Liu et al., 2017; Yang et al., 2015). Very recently, Zhang et al. (2022) showed high Ca-P transformation to Al/Fe-P in soils supplied with MF and manure and attributed to the high proportion of humic-like substances in dissolved organic matter, which may have led to a slight/microsite acidification. In well-weathered soils in conditions of flooding or high rainfall, fortified labile OM content also can cause the change in soil P by inducing Fe(III) reduction (Khan et al., 2019; Maranguit et al., 2017) and in the microsites of well-drained oils (Warrinnier et al., 2020). In general, the mobilization of soil P induced by Fe(III) reduction is commonly coupled with decreasing soil Al/Fe–P content (Zhang et al., 2021a, 2021b).

As a result of the change in the rhizosphere, better roots' growth can help use nutrients more effectively, especially those with limited mobility, such as phosphorus. In addition, it has been emphasized that humic substances in the applied organic material can reduce the fixation of phosphorus in the soil, as detailed in Figure 2.3 (Brady and Weil, 2017). In parallel with this, a study conducted in the calcareous soils of the Mediterranean Region showed that the application of humic-fulvic acid plays a vital role in the recovery of phosphorus in the soil (Delgado et al., 2002). Very recently, enhancing effect of the long-term organic amendments' additions on P mobility in calcareous soil was clearly shown (Zhang et al., 2022).

Humin substances were influential not only on the availability/mobility of phosphorus in the soil but also on plant yields and P uptake by plants. Namely, Tahir et al. (2011) stated that humic acid application increased the P content of wheat grown in calcareous soils. Similarly, the applications of mineral P and HA at rising rates increased the agronomic responses of wheat under field conditions (Shafi et al., 2020). In another study conducted with a bread wheat cultivar under greenhouse conditions, the humic-fulvic acid (HA+FA) solution applied in liquid form did not affect wheat development or nutrient uptake (Erenoğlu and Dündar, 2020). However, in the same study, P movement was better in the disturbed soil column incubated with HA+FA than in soils without. In parallel, Erenoğlu and Hacirüstemoğlu (yayına hazırlanıyor) have shown that the organic fertilizer applied in combination with plant nutrients can increase the nutrient use efficiency of plants by improving the uptake of nutrients, especially P.

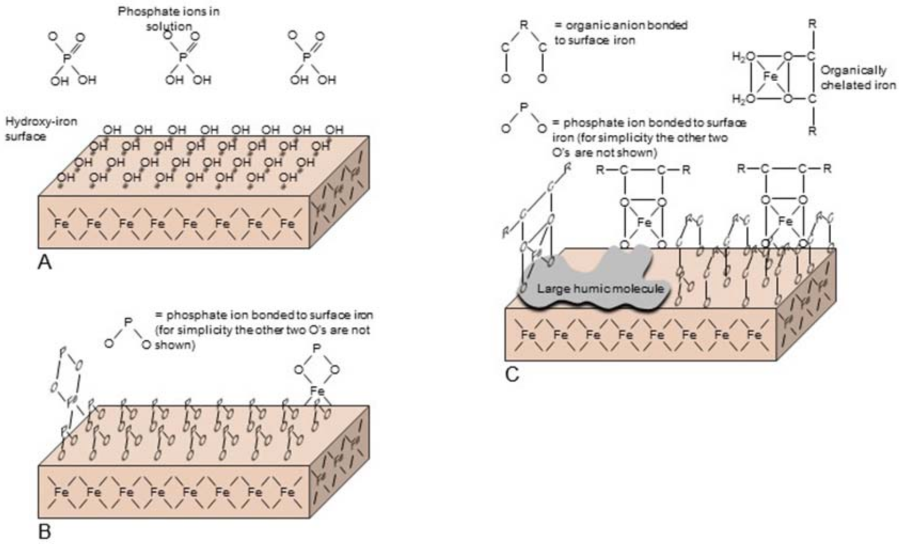

Figure 2.3. The relationship between humic acid, a large organic molecule, and phosphorus fixation induced by hydroxy iron is the leading cause of phosphorus fixation. The phosphorus fixation level of the surface covered with organic molecules decreases (Brady and Weil, 2017).

Although the organic matter and HA+FA content of solid organomineral fertilizers are not higher than the liquid products available in the market, when the application rates to the field are considered, it is seen that organomineral fertilizers are better in terms of those quality parameters. Table 2.2 shows the amounts of organic matter and HA+FA used in a unit area calculated from the possible usage rates of solid 15.20.0+15OM fertilizer and liquid products available in the market. With solid organomineral fertilizer, there is both more organic matter and more HA+FA input per unit area. In addition, since plant nutrients and organic materials are applied together in the solid product, it is likely to be more effective than liquid HA+FA used separately from the nutrients. A comparable situation applies to the costs calculated from the same rates (Table 2.3). It is estimated that the cost of solid organomineral fertilizer, which provides more organic matter and HA+FA input to the soil, is likely to be more effective and affordable than liquid (HA+FA) + mineral fertilizer application.

Table 2.2. OM and HA+FA amounts per unit area calculated from the recommended application rates of a fluid HA+FA and granule 15.20.0+OM

Plant Nutrition Source	Recommended Rate in Cereals (Wheat-Corn)	OM per unit area (kg/da)	HA+FA per unit area (kg/da)
Fluid (HA+FA) 17% OM 12% HA+FA	2-6 L·da^{-1}	0.34-1.02	0.24-0.72
Granule (15.20.0) 15% OM 6% HA+FA	15-60 kg·da^{-1}	2.25-9.00	0.90-3.60

Table 2.3. Costs calculated from the recommended application rates of fluid HA+FA, granule 20.20.0 and granule 15.20.0+OM

Plant Nutrition Source	Recommended Rate in Cereals (Wheat-Corn)	Price	Cost TL/da
Fluid (HA+FA)	2-6 L·da^{-1}	235 TL·[20 L]$^{-1}$	23.5-70.5
20.20.0	15-60 kg·da^{-1}	1.8 TL·kg^{-1}	27-108
Fluid (HA+FA) + 20.20.0			**50.5-178.5**
Granule (15.20.0)	15-60 kg·da^{-1}	2.4 TL·kg^{-1}	**36-144**

3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Experimental Soil and Plant Material

In the study, Arık Series soil with low organic matter content, high pH (7.63), high calcium carbonate, and high clay content was used to stand for the soils of the Çukurova Region. Some of the chemical and physical properties of the soil are given in Table 3.1. The soil was taken from the field after that was dried and sieved.

Table 3.1. Some of the chemical and physical properties of the Arık Series

Parameter	Level	Method
Organic Matter, %	1,2 / low	Schlicting and Blume (1966)
$CaCO_3$, %	27 / very high	Hızalan and Ünal (1966)
pH (1:2.5 soil:water)	7.63 / slightly alkaline	Jackson (1972)
Extractable P, kg $P_2O_5 \cdot da^{-1}$	6.7 / moderate	Olsen et al., (1954)
Extractable K, kg $K_2O \cdot da^{-1}$	119 / high	Carson (1980)
Sand-Silt-Clay Contents, %, and Texture Class	17-28-55 / Clay	Bouyoucos (1951)

A bread wheat (*Triticum aestivum* L. cv. Adana-99) cultivar extensively cultivated in the region was used in the pot experiment.

3.1.2. Fertilizers

In the studies, an organic fertilizer containing and originating from the biogas plant (53% OM, %20 HA+FA, 3% P_2O_5, 2% N, and 1% K_2O), triple superphosphate (TSP; 42% P_2O_5), and urea fertilizers were used. Organomineral fertilizer (OMF) containing 22.4% P_2O_5, total P, and 25% OM was produced under laboratory conditions by mixing organic fertilizer, TSP, and quartz sand in the following amounts: 47.2%, 50%, and 2.8% (total P_2O_5 and OM analysis of prepared OMF - 22.36% and 24.8%, respectively). As a K and S source, K_2SO_4 was used. To ensure the homogeneous application of fertilizers, all fertilizing materials used in the study were ground through a blender.

3.2. Methods

3.2.1. Organomineral Fertilizers and *$NaHCO_3$*-Extractable P in Soil (*Experiment I*)

In this part of the study, conducted as an incubation experiment, 0, 25, 50, and 75 mg $P \cdot kg^{-1}$ soil rates were applied using OMF and MF, as detailed in Table 3.2. The incubation process took place in containers having 250 g of soil as three replicates. The required number of fertilizers given in Table 3.2 was applied for each dose. In addition, the N levels in all incubation containers were kept constant to end the possible effects of N on microorganisms' activities. That is why using urea 150 mg $N \cdot kg^{-1}$ soil was added together with other fertilizers. At the end of the 45- and 90-day incubation periods, the soils in the containers were homogenized, passed through a 2 mm sieve, and then subjected to *$NaHCO_3$*-Extraction (Olsen P analysis).

3.2.2. Organomineral Fertilizers and Phosphorus Nutrition (*Experiment II*)

In this part of the thesis, a pot experiment was conducted under greenhouse conditions. The effects of organomineral and mineral P sources mentioned above on the P uptake of wheat were planned in calcareous soil. In the experiment, visual observations were taken, and two harvests at tillering (45 days after) and ripening (150 days after) stages were done. At the end of the experimental period, the shoots and grains of wheat cultivar Adana-99 were harvested, and biomass, grain yields, and nutrient uptakes were figured out.

The variables to be used in the experiment and the fertilizer forms and rates that should be applied to 3 kg pots are expressed in Table 3.3. The pots were filled after the experimental soil was sieved through 5 mm sieves. The pots were regularly weighed and watered at 50% of the field capacity during the first week after planting, 80% in the following week, and in the next period at 100%. Half of the experiments' pots, designed according to the randomized plot design with six replications, were harvested at the end of tillering stage (Zedoks 29) 45 days after sowing.

Table 3.2. Fertilizer types and P levels used in *Experiment I* and their required amounts

Fertilizer	P Level mg P·kg^{-1} soil	Required Amount of P mg·[250 g]$^{-1}$ soil	Required Amount of Fertilizer mg·[250 g]$^{-1}$ soil
OMF (22.4 P_2O_5+25OM)	0	0	0
	25	6.25	64
	50	12.50	128
	75	18.75	192
MF (TSP) (42 P_2O_5)	0	0	0
	25	6.25	34
	50	12.50	68
	75	18.75	102

The plants will be fertilized with the help of the fertilizers given in Table 3.3 at four different P rates, 0, 25, 50, and 75 mg P·kg^{-1} soil. All the base fertilizer applications were made just before planting, 5 cm below the seedbed. To ensure the homogeneous application of fertilizers, all fertilizing materials used in the study were ground through a blender, as mentioned above. Half of the N, 75 mg N·kg^{-1}

soil (as urea), and all potassium, 100 mg K·kg^{-1} soil (as K_2SO_4), were applied as a starter fertilizer to the same area with P fertilizers. The rest of the N (75 mg N·kg^{-1}) was applied after the harvest at tillering stage.

Table 3.3. Fertilizer types and P levels used in *Experiment II* and their required amounts

Fertilizer	P Level mg P·kg^{-1} soil	Required Amount of	
		P	Fertilizer
		mg·[3 kg]$^{-1}$ soil	
OMF (22.4 P_2O_5+25OM)	0	0	0
	25	75	767
	50	150	1,534
	75	225	2,300
TSP (42 P_2O_5)	0	0	0
	25	75	409
	50	150	818
	75	225	1,227

The experiment was continued until the end of the harvest; 45 days after sowing at the end of the tillering period, the plants in half of the six pots were harvested and dried in an oven at 65 °C for two days. After that, the dry weights of samples were taken and homogenized using a grinder. The homogenized samples were wet-ashed in a microwave oven, and their P, K, Ca, Mg, Fe, Zn, Mn, and Cu concentrations were determined using AAS (Since there were no meaningful results for Ca, Mg, Fe, Zn, Mn, and Cu, those are not given in the text of the present study). Nitrogen concentrations in samples were measured using the Kjeldahl.

The grains and stovers were sampled 150 days after sowing, and grain yields, dry weights, and nutrient concentrations were determined as described for the shoot samples in the previous paragraph.

3.3. Statistical Analyses

At the end of the study, all values obtained from the experiment were subjected to one-way ANOVA using the "SPSS STATISTICS 20" statistical package program. The significance levels of the treatments were determined. The averages of different applications in the measured parameters were compared with the Duncan Test at the probability level of $P \leq 0.05$. The averages that differed from each other are shown with different letters.

4. RESULTS AND DISCUSSION

4.1. Organomineral Fertilizers and $NaHCO_3$-Extractable P in Soil (*Experiment I*)

Sodium bicarbonate extractable P levels of the experimental soil incubated with increasing rates of P applied either as OMF or MF for 45- and 90-days are given in Figure 4.1. As seen, at the end of the incubation period of 45 or 90 days, $NaHCO_3$-extractable P (Olsen P) levels in the soil increased linearly due to increasing P application in OMF or MF forms. At the end of the 45-day incubation period, there was a tendency that 25 and 50 $mg \cdot kg^{-1}$ soil P rates of OMF application caused higher $NaHCO_3$-extractable P than MF, but this result was not statistically significant. In contrast, at the end of the 90 days, P supplies in the form of OMF at all P rates resulted in statistically significant increases in $NaHCO_3$-extractable P levels compared to MF.

4.2. Organomineral Fertilizers and P Nutrition (*Experiment II*)

4.2.1. Plant Growth and Grain Yield

Tillering stage: Figure 4.2 shows the shoot dry weights of wheat plants harvested at the end of the tillering stage, 45 days after sowing. The P application increased the shoot dry weight irrespective of fertilizer type. In addition, the plants supplied with OMF-P had better shoot growth at all three P rates than those fertilized with MF (Figure 4.2). And those differences were statistically significant and increased when the P rate decreased.

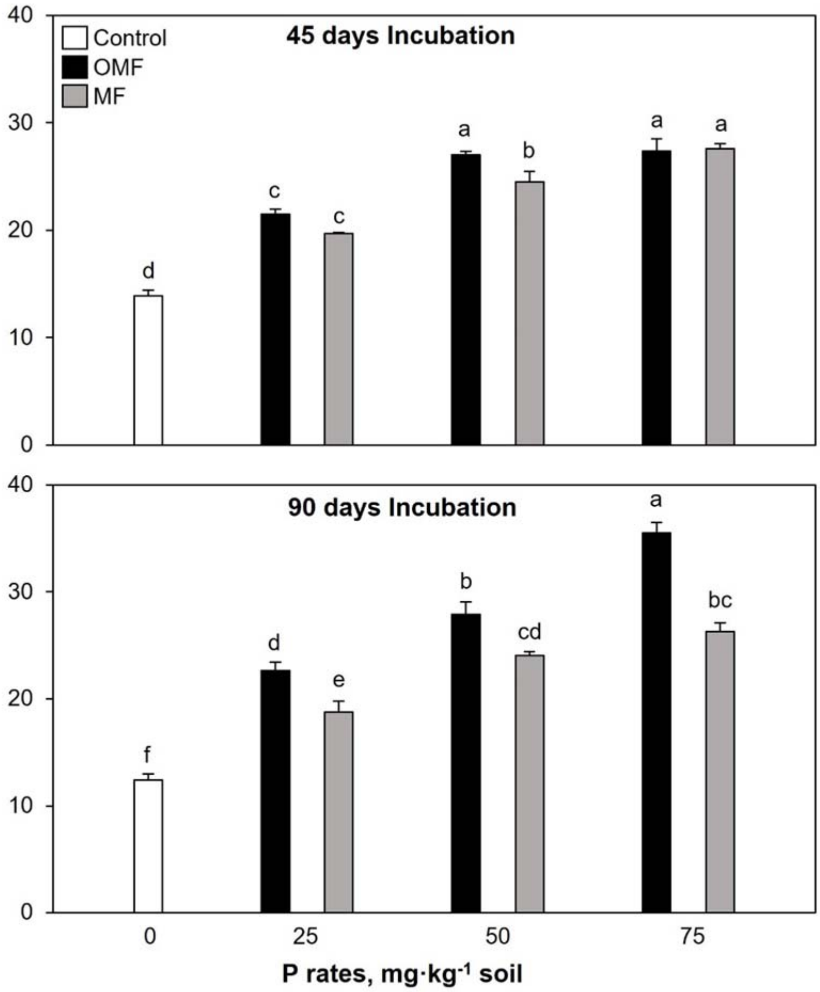

Figure 4.1. Sodium bicarbonate extractable P levels of the experimental soil incubated with increasing rates of P applied either as OMF or MF for 45- and 90-days. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test.

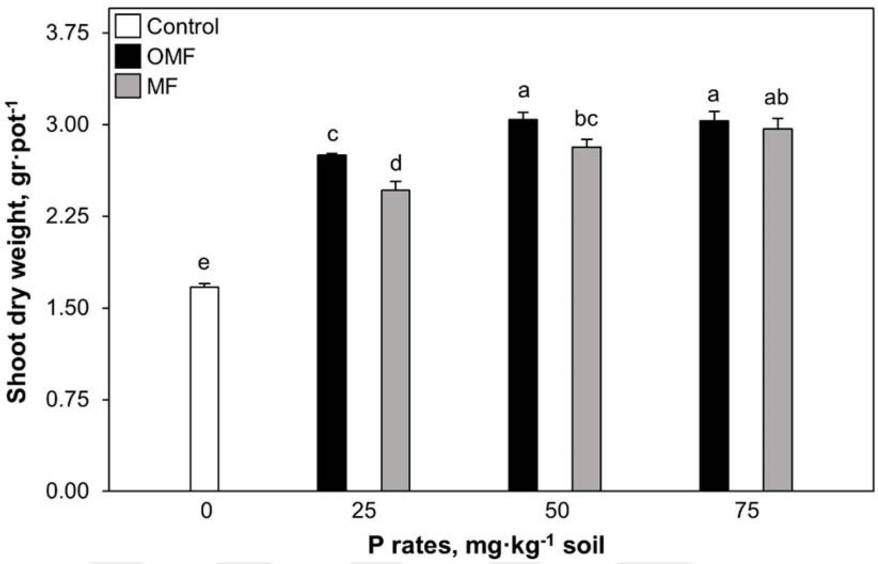

Figure 4.2. Shoot dry weights of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different at P < 5% according to ANOVA followed by Duncan's test.

Ripening Stage: Figure 4.3 presents the dry weights of stovers (shoot + husks - A) and grains (B) of wheat plants harvested 150 days after sowing. As can be seen, when the dry weights of the stover were considered, it was seen that the shoot dry weights of plants increased with the P application compared to the control plants. However, the difference became smaller (Figure 4.3A) compared to 45 days old plants (Figure 4.2).

On the other hand, it was observed that the difference enhanced even more in the case of grain dry weights (Figure 4.3B). There was still a boosting effect of OMF-P on the grain dry weight of the plants supplied with 25 or 50 mg P $\cdot kg^{-1}$ soil in parallel with the shoot dry weights noted for the plants harvested 45 days after sowing. However, the difference was statistically not significant.

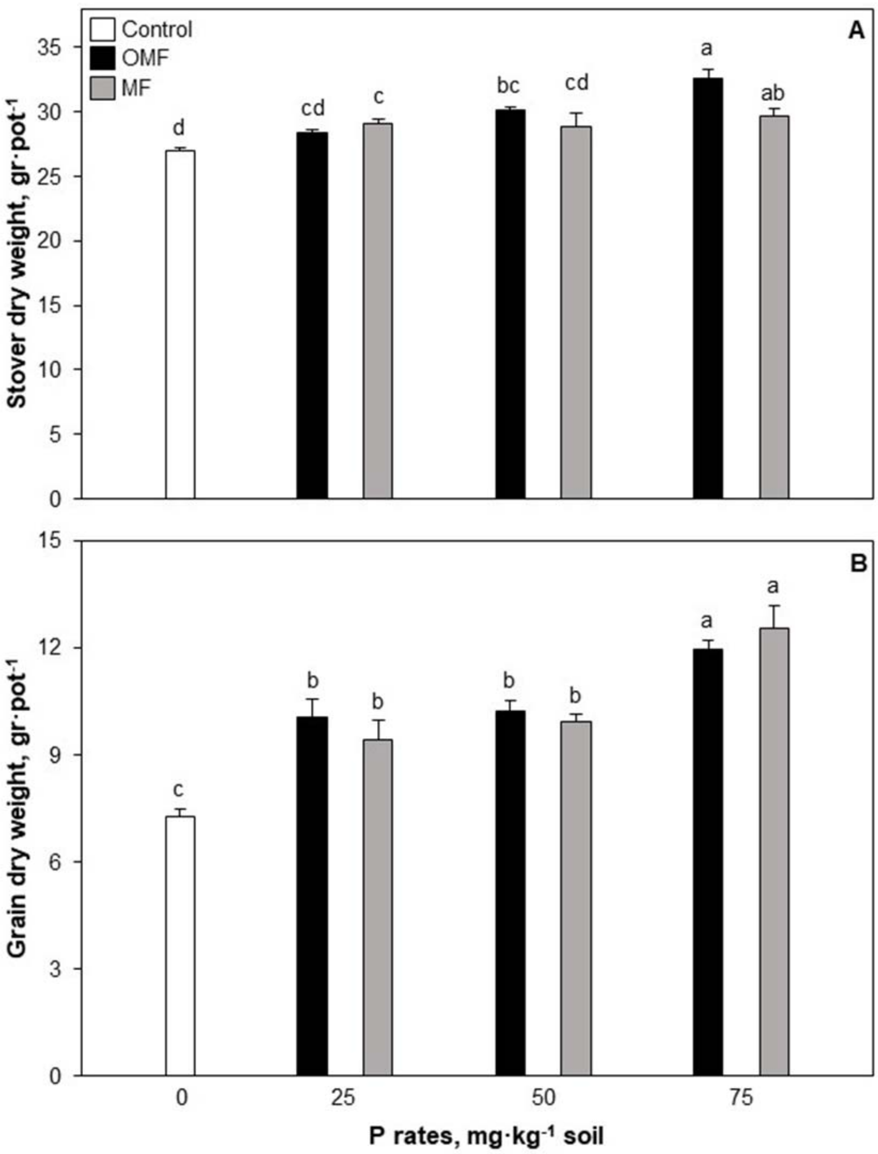

Figure 4.3. Dry weights of stover (A) and grains (B) of wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test.

4.2.2. Nutritional Status of Plants

4.2.2.1. Phosphorus Nutrition

Tillering: Figure 4.4 poses the P concentrations in shoots (A) and P uptake (B) of 45 days old wheat plants. As can be seen, irrespective of the fertilizer types, P application increased the P concentrations in the shoot. The OMF-P applied plants showed higher P concentrations at all P levels than the MF-P used plants (Figure 4.4A). Also, these differences were statistically significant and became more apparent as the P concentration decreased.

When the P uptake values calculated by multiplying the P concentrations in the shoots with the dry weights were evaluated, it was seen that the OMF-P applications increased the total P uptake compared to the MF-P (Figure 4.4B). Parallel to the P concentrations, these relations were statistically significant, and the power of importance was enhanced with the decrease in the level of applied P (Figure 4.4B).

Ripening: As shown in Figure 4.5A, P concentration in stover increased with rising P application rates. However, different fertilizer application forms did not cause any difference in P concentrations of the harvest rests (Figure 4.5A). However, unlike P concentrations in shoots and stover, P application did not significantly affect P concentrations of grains (Figure 4.5B).

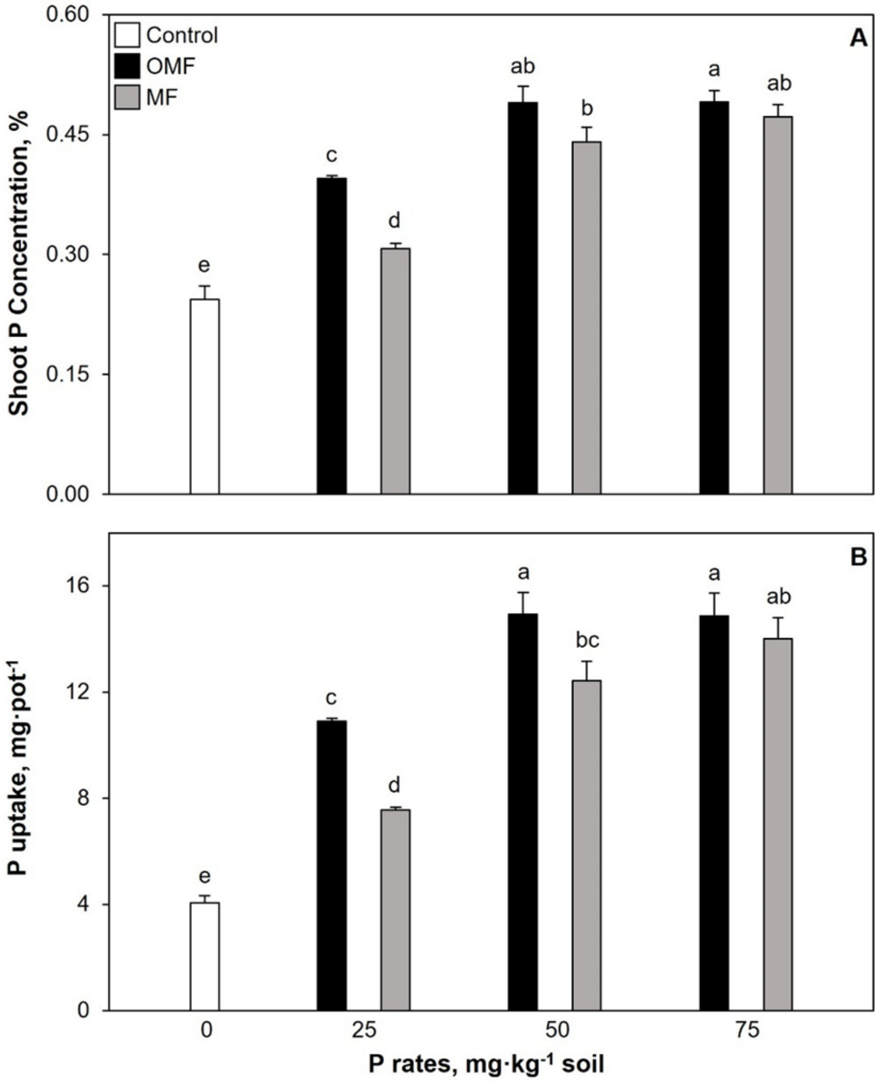

Figure 4.4. Shoot P concentration (A) and P uptake (B) of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Values are the means of three independent replicates ± SE. Columns with different letters are significantly different for each trait at $P < 5\%$ according to ANOVA followed by Duncan's test.

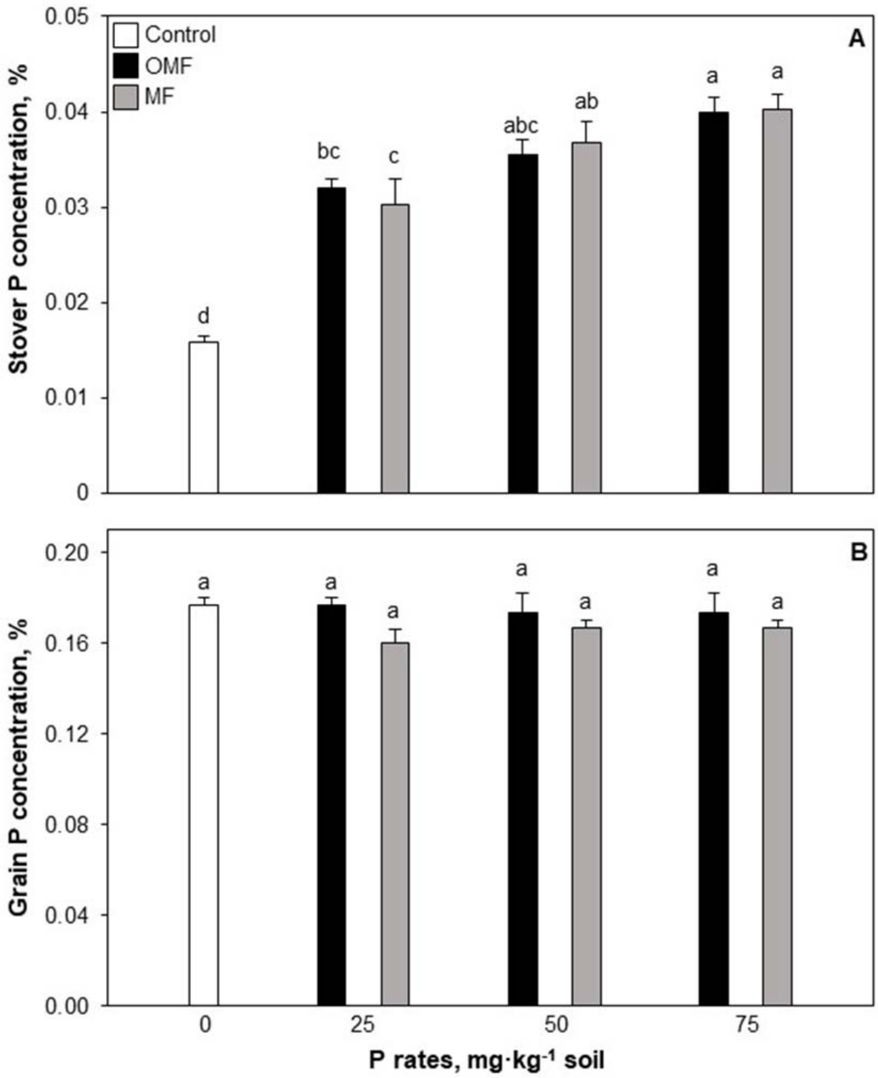

Figure 4.5. Phosphorus concentration in stover (A) and grains (B) of plants grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at $P < 5\%$ according to ANOVA followed by Duncan's test.

Figures 4.6A, B, and C show P contents of harvest rest and grains and total P uptakes obtained by their summing. As can be seen, the P application had an increasing effect on all three traits. Moreover, grains' P contents were higher than that of stovers. Regarding stovers' P content, although OMF-P applied plants tended to have higher P contents than MF-applied ones for all three P rates, differences were statistically insignificant (Figure 4.6A). Regarding the P content of grains, it was clear that the OMF-P application provoked higher P contents than the MF application except for the highest P level; those differences were significant (Figure 4.6B). Consistent with the P content in the grains, there is a substantial relationship between the total P uptake of plants and the forms of P fertilizer, especially in low P applications (Figure 4.6C). In such a way, for all three phosphorus rates, the plants supplied with OMF-P had higher total P uptake than the plants of OF-P application, and when it dropped to 25 mg P $\cdot kg^{-1}$ soil, the difference became statistically significant.

4.2.2.2. Nitrogen and Potassium Nutrition

Tillering: Figures 4.7A and B show the nitrogen and potassium concentrations in the shoots of the 45 d old wheat plants. Increasing P application in OMF and MF forms enhanced N concentrations in the shoot but did not affect K concentrations. The N concentrations in the shoot of wheat plants fertilized with P in the mineral form were higher than those fertilized with P in the OMF-P form, opposite the P concentrations of the same plants.

At the same time, there have been more net increases in the total N uptake; the total N (Figure 4.7C) and K (Figure 4.7D) uptakes of plants broadened with an increment in P rates irrespective of the application form.

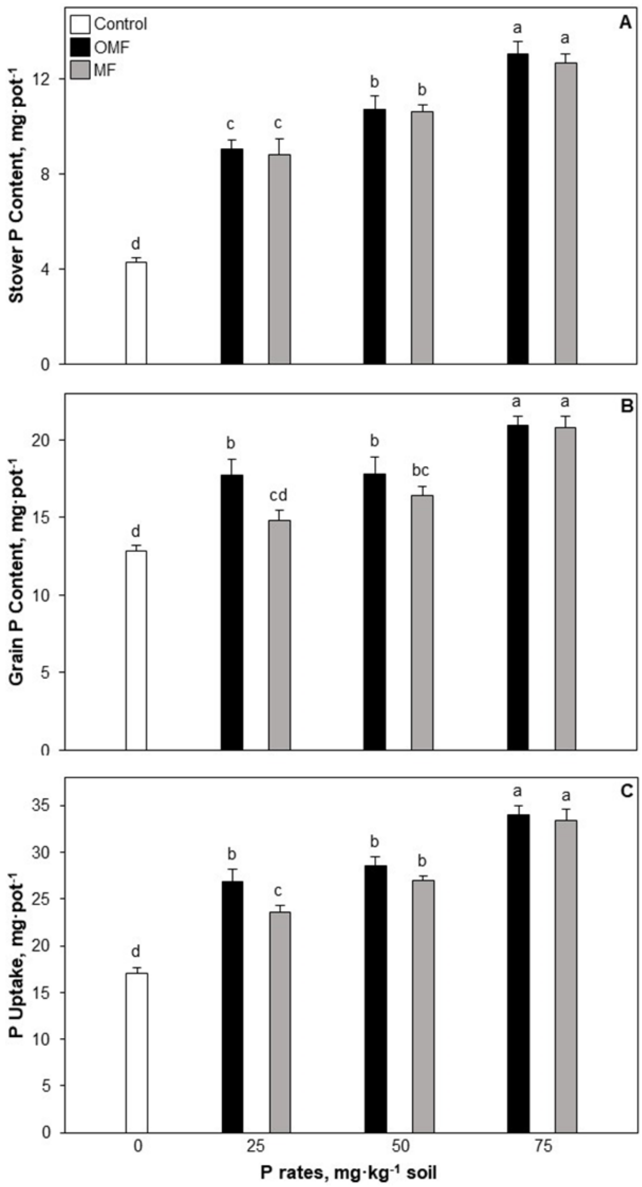

Figure 4.6. Phosphorus content of harvest rests (A) and grains (B) and total P uptake (C) of plants grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at $P < 5\%$, according to ANOVA followed by Duncan's test.

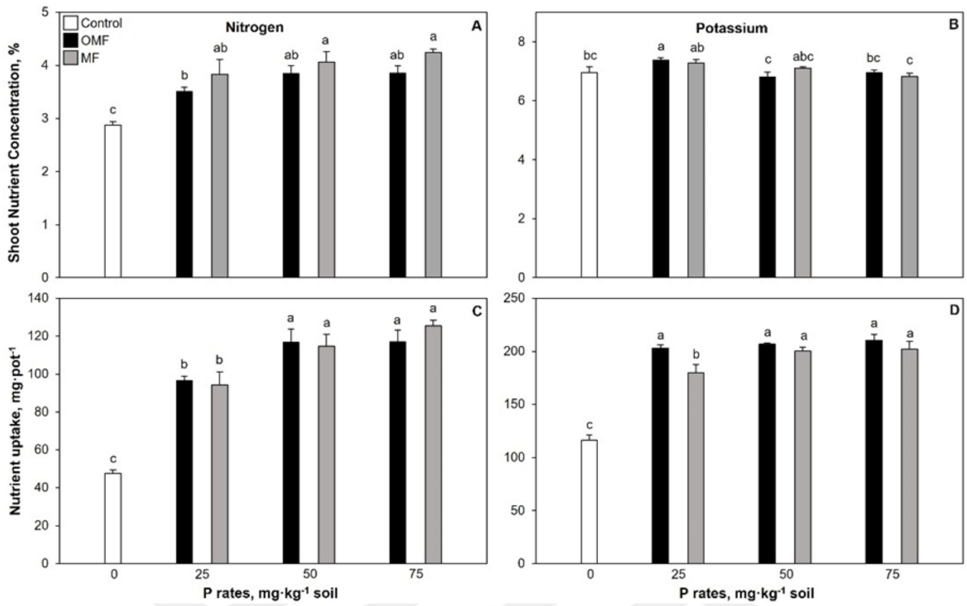

Figure 4.7. Nitrogen and K concentrations in shoots (A-B) and uptakes (C-D) of wheat grown with increasing rates of P applied as either OMF or MF for 45 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait, at $P < 5\%$ according to ANOVA followed by Duncan's test.

Ripening: Figures 4.8A and B present the N and K concentrations in the stover and grains of wheat grown for 150 days. In general, while the N concentrations in the stover were lower than those of the grains, it was the opposite for potassium. None of the N or K concentrations in the stover (Figures 4.8A, B) or grains (Figures 4.8C, D) changed concerning the increased P rate or form of P fertilizer.

Irrespective of application forms, the P application positively affected the total uptakes of both N and K (Figure 4.9E, F). However, it was not so evident in some cases where K was involved (Figure 4.8F). In the case of the N and K contents of grains per pot, the P application had apparent increasing effects; and it was calculated that 58-65% of the total N and 4-7% of total K were localized in the grains. (Figures 4.9C, D). There was no statistically significant relationship between the P fertilizer form and the uptake of these nutrients for neither N nor K (Figure 4.9E, F).

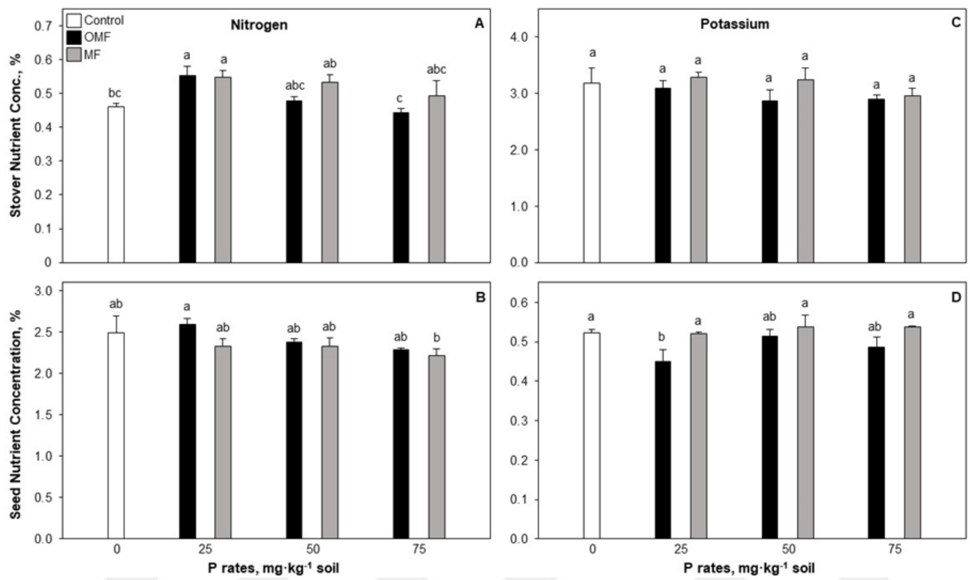

Figure 4.8. Nitrogen and K concentrations of harvest rests (A-B) and grains (C-D) of wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait, at P < 5% according to ANOVA followed by Duncan's test.

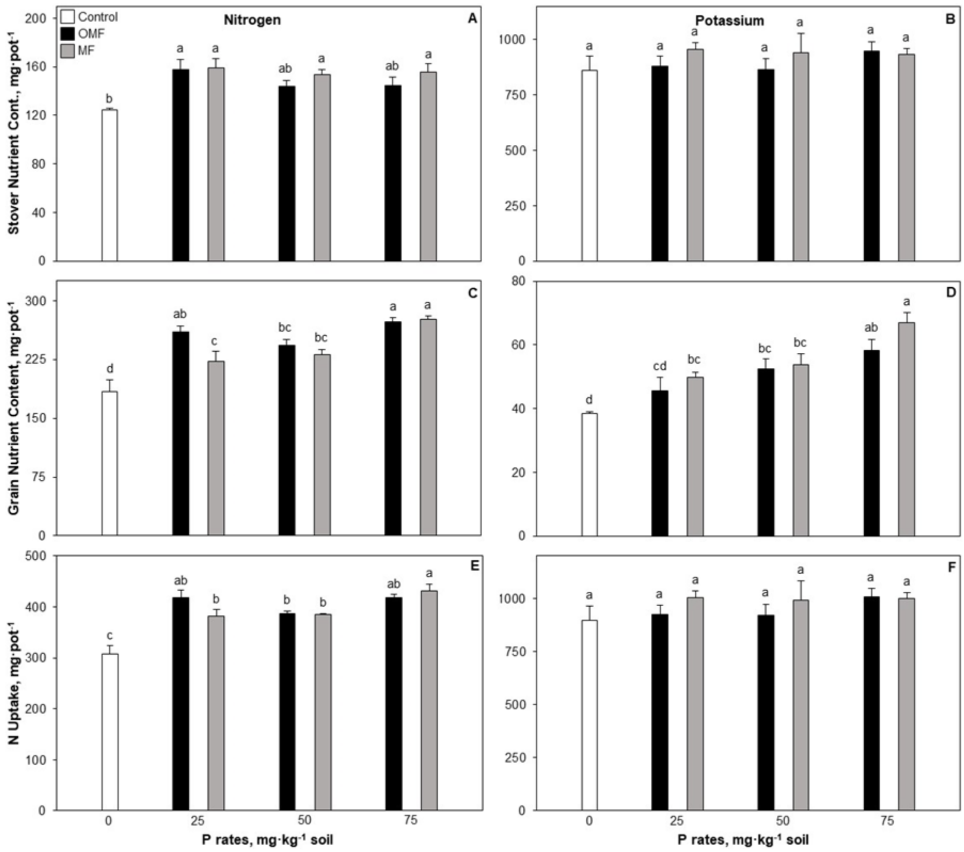

Figure 4.9. Nitrogen and K contents of harvest rest (A-B) and grains (C-D) and total N and K uptake (E-F) in wheat grown with increasing rates of P applied as either OMF or MF for 150 days in the experimental soil under greenhouse conditions. Columns with different letters are significantly different for each trait at P < 5% according to ANOVA followed by Duncan's test.

4.3. Discussion

Effect of organomineral P on P availability/mobility in soils

Application of manure-based organic fertilizer or humic substances can affect plant P uptake in two ways: i) increasing its mobility and recovery (Delgado et el., 2002; Shafi et al., 2020; Zhang et al., 2022) and ii) allowing it to be transported to longer distances (Du et al., 2013; Erenoğlu and Dündar, 2020).

In the current MSc Thesis, it was found that compared to mineral P, the incubation of organomineral P caused higher $NaHCO_3$ extractable in such a way that plant-available P in the experimental soil at the end of the 45- and 90-day incubation period (Figure 4.1). It was recently shown that long-term organic amendments enhanced P mobility and reduced P adsorption in calcareous (Farid et al., 2021; Zhang et al., 2022) and non-calcareous soil (Farid et al., 2021). These results agree with the results found by Delgado et al. (2002). In that study, they revealed that the application of humic-fulvic acid plays a significant role in the recovery of P in the calcareous soils of the Mediterranean Region (Delgado et al., 2002). In the current study, the reason for the higher plant-available Olsen P in the soil incubated with organomineral fertilizer P than the mineral fertilizer may also be the humic substances from the organic raw material (Figure xx). Slight and microsite acidification in calcareous soils (Guo et al., 2018; Yan et al., 2018) due to humic-like substances (Zhang et al., 2022) around mineral P sources might be one of the possible reasons for enhanced Olsen P levels (Figure 4.1). An additional reason may be the increased mobilization of soil P due to Fe(III) reduction in micro-sites, coupled with the decrease in soil Al/Fe-P contents (Zhang et al., 2021a, 2021b). Moreover, humic substances can enhance P availability by increasing the distance of P movement (Du et al., 2013; Erenoğlu and Dündar, 2020) and the concentration of extractable P in soil (Du et al., 2013; Shafi et al., 2020). While Du et al. (2013) showed increased P movement in the nearby soil volume surrounding the fertilizer granule, Erenoğlu and Dündar (2020) were also able to detect P in soil solution samples taken at a vertical distance of 15 cm from the application point when P was applied in the liquid form. However, P was not found even in soil solution samples taken 5 cm away from the application point (Erenoğlu and Dündar, 2020).

Effect of organomineral P on shoot growth and grain yield of wheat

Forty-five days after sowing, application of OMF-P caused significantly higher shoot growth than MF-P application at each P level from 25 to 75 mg P·kg^{-1} soil (Figure 4.2). There was good accordance between shoot growth (Figure 4.2) and $NaHCO_3$ extractable P in soils incubated with OMF-P or MF-P for 45 days (Figure 4.1). When we look over stover dry weights for the final harvest, it is seen that the plants fertilized with OMF at higher P rates had more stover than those fertilized with MF (Figure 4.3A). In terms of grain dry weight, although the grain yields in the pots fertilized with OMF in the lowest two P treatments were higher than those treated with MF, this difference was not statistically significant (Figure 4.3B). The current study was conducted in a limited volume in the pot, and the significant differences in favor of plants fertilized with OMF in the initial period may have disappeared in the later periods as the roots reached the entire pot. Therefore, it is essential to compare the subjects in this study in larger pots and field conditions. These results are consistent with previous studies stating that using organic fertilizers will result in better plant growth than when only mineral fertilizers are used, apart from the additional organic matter input to the soil (Steiner et al., 2007; Ayinla et al., 2018). However, the soils of both experimental sites were low in soil fertility and cation exchange capacity (CEC); they were highly weathered clayey and sandy soil, respectively. In a study conducted with sweet corn in clayey loam soil, Canatoy and Daquiado (2021) demonstrated that vermicompost application and mineral NPK increased the canopy and grain yields. In a recent study conducted in greenhouse conditions, the application of fixed rates of N, P, and K, together with increasing rates of organic fertilizer originating from a biogas plant, increased the shoot growth of wheat grown in pots for 45 days up to

15% compared to plants supplied with only mineral N, P, and K (Erenoğlu and Hacirüstemoğlu, in press). Consistent with these results, Tahir et al. (2011) and Shafi et al. (2020) stated that the application of humic substances boosted the agronomic responses of wheat under field conditions. However, Erenoğlu and Dündar (2020), in a short-term pot experiment (45 days) under greenhouse conditions, could not find any stimulating effect of humic substances on wheat growth. In a field trial conducted with wheat, in which compound fertilizers containing different NPs were compared, it was shown that although it was statistically not significant, 12.12.0+12S+OM fertilizer at a 25 kg·da^{-1} rate resulted in more grain yield than the same amount of mineral fertilizer with 20.20.0+Zn content (Süzer and Çulhacı, 2017). However, as seen in the grades of both fertilizers, organomineral fertilizer contained 12% SO3, while mineral 20.20.0+Zn fertilizer did not besides the combination of green manure with increased maize yield compared to the control (Mukuralinda et al., 2010). Moreover, the combined application of inorganic fertilizer and organic amendment might be a suitable approach for sustainable production systems under no-tillage which potentially causes hardening in the soil. For example, applying vermicompost with inorganic fertilizer enhanced stover and grain yields in sweet corn (Canatoy and Daquiado, 2021).

Effect of organomineral P on P, N, and K uptake of wheat

Some of the well-known characteristics of the P are high fixation, slow diffusion, and low availability, making P one of the major limiting factors for average plant growth in arid climates (Shen et al., 2011). As shown in Figure 4.1, the presence or addition of humic substances can effectively increase the availability of P in the soil (Xing et al., 2020; Farid et al., 2021). In addition, although organomineral fertilizers are effective only in the root zone of a plant known as the rhizosphere and not the entire soil in a field due to their low application rates, this can result in better root development. Thus, it may also increase the use efficiency of nutrients, especially for those with limited mobility, such as phosphorus. These improvements in root development, together with the advances in the mobility of elements such as P, can positively affect the growth of plants. In such a way, adding humic acids from vermicompost to the growth medium of pepper (Arancon et al., 2006), banana, strawberry, and cowpea (Quility and Cattel, 2011) increased root mass. The combined effect of increased P availability in soil and root growth can lead to improved P uptake, increased plant growth, and enhanced nutrient utilization efficiencies.

Although it provides meager organic matter contribution to the soil compared to directly applied animal manure compost, the organomineral P application has also led to increased P use efficiency (Figures 4.4A, B; Figures 4.6B, C), as in plant growth (Figure 4.2; Figures 4.3A, B). At the end of the tillering period, the plants supplied with OMF-P had higher shoot P concentration and P uptake per pot than MF-P-applied plants. It became more pronounced as the application rate decreased and approached the P rates in the field. At 25 mg $P \cdot kg^{-1}$ rate, OMF-P applied plants showed 28% and 44% more P concentration and P uptake in the first harvest than MF-P used ones (Figures 4.4A, B). These results are also consistent with the research of Erenoğlu and Hacırüstemoğlu (in press), which showed that organic fertilizer and N, P, and K application increased both P concentration and uptake compared to mineral N, P, and K applications. Regarding harvesting at maturity, although the P concentrations in the grains of OMF-P treated plants are slightly higher than those of MF-P treated plants, they are statistically insignificant (Figures 4.5B). When the total P uptakes are evaluated, it is seen that the P uptake of OMF-P-treated plants is higher than that of MF-P-treated plants (Figures 4.6C). In such a way, at the lowest P rate, grain P content and total P uptake of OMF-P applied plants were 19.7 and 13.6% higher, respectively than those of MF-P used. While these differences were statistically insignificant at high P rates, the difference was statistically significant at the lowest P dose (like practical applications) (Figure 4.6C). In accordance, the combined application of animal manure with half-reduced inorganic P fertilizer (DAP) increased the P concentration in the shoot of chickpeas (Khan et al., 2022). In line with this, under no-till conditions, parallel to yield increases in sweet corn grown with complete NPK and vermicompost, vermicompost application boosted total N, P, and K uptakes. Very recently, it has been shown that DAP fertilizer coated with humic acid increases phosphorus availability in soil and photosynthesis activity and yield of maize (Chen et al., 2021). In addition, it has been found that while the coated-DAP fertilizer increases the efficiency of phosphorus use by 8.4% compared to the non-coated, this application also produces economically profitable results.

Opposite to the P, the OMF-P application did not stimulate either the concentration (Figures 4.7A, B) or the uptake (Figures 4.7C, D) of N and K compared to MF-P. However, in a very recent study by Erenoğlu and Hacırüstemoğlu (in press), it was shown that although the application of N, P, and K with organic fertilizer did not cause an increase in N and K concentrations compared to those with mineral N, P, and K, it increased the total uptake of the plant.

5. CONCLUSIONS AND RECOMMENDATIONS

The current MSc thesis aims to reveal the effects of P applied as an organomineral fertilizer on both the availability of P in the soil and the development and P uptake of wheat grown under greenhouse conditions.

As it is known, the use efficiency of P used in plant production is low, which causes negative results both in terms of the farmers' economy and the environment. In addition, it is crucial to evaluate the urban and agricultural residues, which increase in parallel with the increasing world population in agriculture. Using organic residues in agriculture is essential to increase or at least not lose soil fertility in areas with low organic matter content. Therefore, it is necessary to consider each agricultural practice that will at least protect the soil fertility and increase P use efficiency by evaluating the organic residues. That is why this study, which aimed to increase the efficiency of using P and organic residues correctly, is critical.

With these thoughts, the conclusions of the current MSc thesis and the recommendations related to them are given below:

- Organomineral fertilizers produced using an organic fertilizer containing and originating from a biogas facility may positively affect plant growth and yield.
- Particularly, it is possible that the efficiency/availability of P applied as OMF-P increases in the presence of organic fertilizer due to the difficulty of binding P to the soil.
- At P rates close to the application rates under field conditions, the P accumulation in grains of OMF-P applied plants is higher than that of MF-P used plants (19.7%). The total P uptake of OMF-P supplied plants is 13.6% higher as well.

- However, the current study should also be carried out under field conditions, and the actual effects of the OMF-P application should be revealed.

REFERENCES

Allison, S. D., Vitousek, P. M., 2005. Responses of extracellular enzymes to simple and complex nutrient inputs Soil Biology and Biochemistry, 37: 937-944.

Appl, M., 2006. Ammonia. Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH, Weinheim. doi: 10.100 2/14356007.a02_143.pub2.

Arancon, N. Q., Edwards, C. A., Lee, S., Byrne, R., 2006. Effects of humic acids from vermicomposts on plant growth. European Journal of Soil Biology, 42: S65-S69. doi: 10.1016/j.ejsobi.2006.06.004.

Ayinla, A., Alagbe, I. A., Olayinka, B. U., Lawal, A. R., Aboyeji, O. O., Etejere, E. O., 2018. Effects of organic, inorganic and organo-mineral fertilizer on the growth, yield and nutrient composition of corchorus olitorious (L). Ceylon J. Sci, Biol. Sci. 47: 13-19. doi: 4038/cjs.v47i1.7482.

Barrow, N. J., Sen, A., Roy, N., Debnath, A., 2021. The soil phosphate fractionation fallacy. Plant and Soil, 459: 1-11, https://doi.org/10.1007/s11104-020-04476-6.

Brady, N. C. and Weil, R. W., 2017. The Nature and Properties of Soils. Pearson Education Limited, England.

Bruinsma, J., 2009. The Resource Outlook to 2050 - By how much do land, water and crop yields need to increase by 2050?. FAO Expert Meeting on How to Feed the World in 2050. Rome 24-26 June 2009.

Canatoy, R. C., Daquiado, N. P., 2021. Fertilization influence on biomass yield and nutrient uptake of sweet corn in potentially hard setting soil under no tillage. Bull Natl Res Cent, 45: 61, https://doi.org/10.1186/s42269-021-00526-w.

Chaabane A. (1994). Nitrogen transfert in peat-ammoniac-soil-plant system [Transfert de l'azote dans le syste`me tourbe-ammoniac-sol-plante]. Ph.D. Thesis, Université Laval, Québec, Canada.

Chacon, N., Silver, W. L., Dubinsky, E. A., Cusack, D. F., 2006. Iron reduction and soil phosphorus solubilization in humid tropical forests soils: the roles of labile carbon pools and an electron shuttle compound. Biogeochemistry 78: 67-84. https://doi.org/10.1007/s10533-005-2343-3.

Chassapis, K., Roulia, M., 2008. Evaluation of low-rank coals as raw material for Fe and Ca organomineral fertilizer using a new EDXRF method. International Journal of Coal Geology, 75: 185-188.

Chen, Q., Qu, Z., Li, Z., Zhang, Z., Ma, G., Liu, Z., Wang, Y., Wu, L., Fang, F., Wei, Z., and Zhang, M., 2021. Coated Diammonium Phosphate Combined with Humic Acid Improves Soil Phosphorus Availability and Photosynthesis and the Yield of Maize. Frontiers in Plant Science, 12:759929. https://doi.org/10.3389/fpls.2021.759929.

Chen, H., Chen, M.L., Li, D.J., Mao, Q.G., Zhang, W., Mo, J.M., 2018. Responses of soil phosphorus availability to nitrogen addition in a legume and a non-legume plantation. Geoderma, 322: 12-18. doi: 10.1016/j.geoderma.2018.02.017.

Coonan, E. C., Kirkby, C. A., Kirkegaard, J. A. et al., 2020. Microorganisms and nutrient stoichiometry as mediators of soil organic matter dynamics. Nutr Cycl Agroecosyst 117: 273-298. doi: 10.1007/s10705-020-10076-8.

Cordell, D., Drangert, J.O., White, S., 2009. The story of phosphorus: global food security and food for thought. Global Environmental Change 19: 292-305.

Cusack, D.F., Silver, W.L., Torn, M.S., Burton, S.D., Firestone, M.K., 2011. Changes in microbial community characteristics and soil organic matter with nitrogen additions in two tropical forests. Ecology, 92: 621-632.

Delgado, A., Madrid, A., Kassem, S., Andreu, L., del Carmen del Campillo, M., 2002. Phosphorus fertilizer recovery from calcareous soils amended with humic and fulvic acids. Plant Soil, 245: 277-286.

Ding, J.L., Jiang, X., Ma, M.C., Zhou, B.K., Guan, D.W., Zhao, B.S., Zhou, J., Cao, F.M., Li, L., Li, J., 2016. Effect of 35 years inorganic fertilizer and manure amendment on structure of bacterial and archaeal communities in black soil of northeast China. Appl. Soil Ecol., 105, 187-195.

Du, Z. Y., Wang, Q. H., Liu, F. C., Ma, H. L., Ma, B. Y. and Malhi, S. S. 2013. Movement of phosphorus in a calcareous soil as affected by humic acid. Pedosphere. 23(2): 229-235. https://doi.org/10.1016/S1002-0160(13)60011-9.

ECOFI (European Consortium of the Organic-Based Fertilizer Industry), 2020. www.ecofi.info.

Eghball, B., Power, J.F., 1999. Phosphorus- and nitrogen-based manure and compost applications. Soil Sci. Soc. Am. J. 63(4): 895. doi:10.2136/sssaj1999.634895x

Eifediyi, E.K., Remison, S.U., 2010. Growth and yield of cucumber (Cucumis sativus L.) as influenced by farmyard manure and inorganic fertilizer. J. Plant Breed. Crop Sci. 2(7): 216-220.

Enerji İşleri Genel Müdürlüğü, 2020. Türkiye Biyokütle Enerjisi Potansiyeli Atlası, https://bepa.enerji.gov.tr.

Erenoğlu, E. B. and Dündar S., 2020. Application of liquid phosphorus fertilizer improves the availability of phosphorus in calcareous soils. Applied Ecology and Environmental Research, 18:3615-3626.

Erenoğlu, E. B. and Hacirüstemoğlu, K. D., 2022. Biogas facility-based organic fertilizer and nitrogen, phosphorus, and potassium uptake of wheat. Applied Ecology and Environmental Research (in press).

Fan, F.L., Li, Z.J., Wakelin, S.A., Yu, W.T., Liang, Y.C., 2012. Mineral fertilizer alters cellulolytic community structure and suppresses soil cellobiohydrolase activity in a long-term fertilization experiment. Soil Biol. Biochem., 55: 70-77.

FAO (2009): How to feed the world in 2050. Report on FAO Expert Meeting Rome 24-26 June 2009.

Farid, M.I., El-Ghozoli, M.A., Abbas, M.H.H., El-Atrony, D.S., Abbas, H.H.; Elsadek, M.; Saad, H.A., El Nahhas, N., Mohamed, I., 2021. Organic Materials and Their Chemically Extracted Humic and Fulvic Acids as Potential Soil Amendments for Faba Bean Cultivation in Soils with Varying CaCO3 Contents. Horticulturae, 7: 205. https://doi.org/10.3390/horticulturae7080205.

Fernandes, A.L.T., Rodrigues, G.P., Testezlaf, R., 2003. Mineral and organomineral fertirrigation in relation to quality of greenhouse cultivated melon. Sci. Agric. 60(1):149-154. doi: 10.1590/S0103-90162003000100022.Galloway et al., 2004

Geisseler, D., Horwath, W.R., 2008. Regulation of extracellular protease activity in soil in response to different sources and concentrations of nitrogen and carbon. Soil Biol. Biochem., 40: 3040-3048

Gong, W., Yan, X.Y., Wang, J.Y., Hu, T.X., Gong, Y.B., 2009. Long-term manure and fertilizer effects on soil organic matter fractions and microbes under a wheat-maize cropping system in northern China. Geoderma: 149, 318–324.

Grandy, A.S., Salam, D.S., Wickings, K., McDaniel, M.D., Culman, S.W., Sieglinde S. Snapp, S.S., 2013. Soil respiration and litter decomposition responses to nitrogen fertilization rate in no-till corn systems. Agriculture, Ecosystems & Environment, 179: 35-40. https://doi.org/10.1016/j.agee.2013.04.020.

Grote, U., Craswell, E.T., Vlek, P.L.G., 2005. Nutrient flows in international trade: Ecology and policy issues. Environmental Science and Policy, 8: 439-451.

Gu, B., Ju, X., Wu, Y., Erisman, J.W., Bleeker, A., Reis, S., Sutton, M.A., Lam, S.K., Oenema10, O., Smith, R. and Chen, D., 2016. Turning points of global anthropogenic nitrogen creation and their climate effect. Proceedings of the 2016 International Nitrogen Initiative Conference, "Solutions to improve nitrogen use efficiency for the world", 4-8 December 2016, Melbourne, Australia. www.ini2016.com.

Gu, C., Dam, T., Hart, S.C., Turner, B.L., Chadwick, O.A., Berhe, A.A., Hu, Y., Zhu, M., 2020. Quantifying uncertainties in sequential chemical extraction of soil phosphorus using XANES spectroscopy. Environ. Sci. Technol., 54: 2257-2267, https://doi.org/10.1021/acs.est.9b05278.

Guignard, M.S., Leitch, A.R., Acquisti, C., Eizaguirre, C., Elser, J.J., Hessen, D.O., Jeyasingh, P.D., Neiman, M., Richardson, A.E., Soltis, P.S., Soltis, D.E., Stevens, C.J., Trimmer, M., Weider, L.J., Woodward, G., Leitch, I.J. 2017. Impacts of Nitrogen and Phosphorus: From Genomes to Natural Ecosystems and Agriculture. Front. Ecol. Evol. 5:70. https://10.3389/fevo.2017.00070.

Guo, S.L., Wu, J.S., Coleman, K., Zhu, H.H., Li, Y., Liu, W.Z., 2012. Soil organic carbon dynamics in a dryland cereal cropping system of the Loess Plateau under long-term nitrogen fertilizer applications. Plant Soil, 353: 321-332. https://10.1007/s11104011-1034-1.

Guo, Z.B., Liu, H., Hua, K.K., Wang, D.Z., He, C.L., 2018. Long-term straw incorporation benefits the elevation of soil phosphorus availability and use efficiency in the agroecosystem. Span. J. Agric. Res. 16, e1101 https://doi.org/10.5424/sjar/2018163-12857.

Higgs B, Johnston AE, Salter JL, Dawson CJ, 2000. Some aspects of achieving sustainable phosphorus use in agriculture. Journal of Environmental Quality 29, 80-87.

Hu, A., Lu, Y.H., 2015. The differential effects of ammonium and nitrate on methanotrophs in rice field soil. Soil Biol. Biochem., 85: 31-38.

IPNI, 2017. 4D Bitki Besleme: Bitki Besleme Yönetimini İyileştirme Kılavuzu. Ed., (T.W. Bruulsema, P.E. Fixen, G.D. Sulewski, E.B Erenoğlu, eds.), Uluslararası Bitki Besleme Enstitüsü, Peachtree Corners, GA, ABD.

Iyamuremye, F., Dick, R.P., Baham, J., 1996. Organic amendments and soil phosphorus dynamics: I. Phosphorus chemistry and sorption. Soil Sci 161: 426-435.

Jangid, K., Williams, M.A., Franzluebbers, A.J., Sanderlin, J.S., Reeves, J.H., Jenkins, M.B., Endale, D.M., Coleman, D.C., Whitman, W.B., 2008. Relative impacts of land-use, management intensity and fertilization upon soil microbial community structure in agricultural systems. Soil Biol. Biochem., 40, 2843-2853.

Ju, X., Zhang, C., 2021. The principles and indicators of rational N fertilization. Acta Pedol. Sin. 58, 1-13. https://doi.org/10.11766/trxb202006220322.

Kacar, B., Katkat, A.V., 2009. Fertilizers and Fertilization Techniques (in Turkish). Third Edition. Nobel Publication No: 1119, p. 559, Ankara

Khan, I., Fahad, S., Wu, L., Zhou, W., Xu, P., Sun, Z., Salam, A., Imran, M., Jiang, M., Kuzyakov, Y., Hu, R., 2019. Labile organic matter intensifies phosphorous mobilization in paddy soils by microbial iron (III) reduction. Geoderma 352, 185-196. https://doi.org/10.1016/j.geoderma.2019.06.011.

Khan, M.S.; Naveed, M.; Qadir, M.F.; Bashir, M.A.; Rafique, M.; Siddiqui, M.H.; Alamri, S.; Brtnicky, M.; Holatko, J.; Mustafa, A. Combined Effect of Animal Manures and Di-Ammonium Phosphate (DAP) on Growth, Physiology, Root Nodulation and Yield of Chickpea. Agronomy 2022, 12, 674. https://doi.org/10.3390/agronomy12030674.

Khiari, L., Parent, L.E., 2005. Phosphorus Transformations in Acid Light-Textured Soils Treated Locally with Swine Manure. Canadian Journal of Soil Science, 85: 75-87. doi:10.4141/S03-049.

Kiiski H, Dittmar H, Drach M, Vosskamp R, Trenkel ME, Gutser R, Steffens G (2016). Fertilizers, 2. Types. Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH, Weinheim. doi: 10.1002/14356007.n10_n01.pub2.

Kiiski, H, Scherer HW, Mengel K, Kluge G, Severin K (2016). Fertilizers, 1. General. Ullmann's Encyclopedia of Industrial Chemistry. Wiley-VCH, Weinheim. https://10.1002/14356007.a10_323.pub4.

Kim, K. H., Kabir, E., Jahan, S. A., 2017. Exposure to pesticides and the associated human health effects. Sci Total Environ, 575: 525-535. https://10.1016/j.scitotenv.2016.09.009.

Kominko, H., Gorazda, K., Wzorek, Z., 2017. The possibility of organo-mineral fertilizer production from sewage sludge. Waste and Biomass Valorization, 8(5): 1781-1791.

Kuypers, M., Marchant, H., Kartal, B., 2018. The microbial nitrogen-cycling network. Nat Rev Microbiol 16, 263-276. https://10.1038/nrmicro.2018.9.

Lee, Y.S., Bartlett, R.J. (1976) Stimulation of Plant Growth by Humic Substances. Soil Science Society of America Journal, 40: 876-879.

Lekfeldt, J.D.S., Kjaergaard, C., Magid, J., 2017. Long-term effects of organic waste fertilizers on soil structure, tracer transport, and leaching of colloids. J. Environ. Qual. 46, 862-894. https://doi.org/10.2134/jeq2016.11.0457.

Li, B., Song, H., Cao, W., Wang, Y., Chen, J., Guo, J., 2021. Responses of soil organic carbon stock to animal manure application: a new global synthesis integrating the impacts of agricultural managements and environmental conditions. Global Change Biol. 27, 5356-5367. https://doi.org/10.1111/gcb.15731.

Liu, J., Yang, J.J., Cade-Menun, B.J., Hu, Y.F., Li, J.M., Peng, C., Ma, Y.B., 2017. Molecular speciation and transformation of soil legacy phosphorus with and without long-term phosphorus fertilization: insights from bulk and microprobe spectroscopy. Sci. Rep. 7, 15354. https://doi.org/10.1038/s41598-017-13498-7.

Ludwig, B., Geisseler, D., Michel, K., Joergensen, R.G., Schulz, E., Merbach, I., Raupp, J., Rauber, R., Hu, K., Niu, L., ve ark., 2011. Effects of fertilization and soil management on crop yields and carbon stabilization in soils. A review. Agron. Sustain. Dev., 31: 361-372.

Malhi, Y., Doughty, C., Galbraith, D., 2011. The allocation of ecosystem net primary productivity in tropical forests. Phil. Trans. R. Soc. B 366: 3225-3245. http://doi.org/10.1098/rstb.2011.0062.

Mandal, A., Patra, A.K., Singh, D., Swarup, A., Ebhin Masto, R., 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Bioresour. Technol. 98(18):3585–3592. doi:10.1016/j.biortech.2006.11.027

Maranguit, D., Guillaume, T., Kuzyakov, Y., 2017. Effects of flooding on phosphorus and iron mobilization in highly weathered soils under different land-use types: short-term effects and mechanisms. Catena 158, 161-170. https://doi.org/10.1016/j.catena.2017.06.023.

Msangi, S., Rosegrant, M., 2009. World agriculture in a dynamically changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints. FAO Expert Meeting on How to feed the World in 2050. Rome.

Mukuralinda, A., Tenywa, J.S., Verchot, L., Obua, J., Nabahungu, N.L., Chianu J.N., 2010. Phosphorus uptake and maize response to organic and inorganic fertilizer inputs in Rubona, Southern Province of Rwanda. Agroforest Syst 80:211–221, https://goi.org/10.1007/s10457-010-9324-9.

Nemergut, D.R., Townsend, A.R., Sattin, S.R., Freeman, K.R., Fierer, N., Neff, J.C., Bowman, W.D., Schadt, C.W., Weintraub, M.N., Schmidt, S.K., 2008. The effects of chronic nitrogen fertilization on alpine tundra soil microbial communities: Implications for carbon and nitrogen cycling. Environ. Microbiol., 10: 3093-3105.

Nobile, C.M., Bravin, M.N., Becquer, T., Paillat, J.-M., 2020. Phosphorus sorption and availability in an andosol after a decade of organic or mineral fertilizer applications: importance of pH and organic carbon modifications in soil as compared to phosphorus accumulation. Chemosphere, 239: 124709, https://doi.org/10.1016/j.chemosphere.2019.124709.

Ojo, J.A., Olowoake, A.A., Obembe, A., 2014. Efficacy of organomineral fertilizer and unamended compost on the growth and yield of watermelon (Citrullus lanatus Thumb) in Ilorin Southern Guinea Savanna zone of Nigeria. International Journal of Recycling of Organic Waste in Agriculture 3(4): 121-125. doi:10.1007/s40093-014-0073-z

Oliveira, M.; Machado, A.V. The role of phosphorus on eutrophication: A historical review and future perspectives. Environ. Technol. Rev. 2013, 2, 117–127.

Paré, M.C., Allaire, S.E., Khiari, L., Nduwamungu, C., 2009. Physical properties of organo-mineral Fertilizers - Short Communication. Canadian Biosystems Engineering/Le génie des biosystémes au Canada 51: 3.21_3.27.

Parent, L.-E., Khiari, L., & Pellerin, A. (2003). The P fertilization of potato: increasing agronomic efficiency and decreasing environmental risk. Acta Horticulturae, 627: 35e41.

Quilty, J., and Cattle, S., 2011. Use and Understanding of Organic Amendments in Australian Agriculture: A Review. Soil Research. 49:1-26.

Rady, M.M., 2012. A novel organo-mineral fertilizer can mitigate salinity stress effects for tomato production on reclaimed saline soil. South African Journal of Botany, 81: 8-1. https://doi.org/10.1016/j.sajb.2012.03.013.

Reddy, D.D., Rao, A.S., Rupa, T., 2000. Effects of continuous use of cattle manure and Fertilizer phosphorus on crop yields and soil organic phosphorus in a Vertisol. Bioresour. Technol. 75(2): 113-118. https://10.1016/S0960-8524(00)00050-X.

Reis, S., Bekunda, B., Howard, C.M., Karanja, N., Winiwarter, W., Yan, X., Bleeker, A., Sutton, M.A., 2016. Synthesis and review: Tackling the nitrogen management challenge: from global to local scales. Environ. Res. Lett. 11: 120205. https://doi.org/10.1088/1748-9326/11/12/120205.

Rochette, P., Angers, D.A., Flanagan, L.B., 1999. Maize Residue Decomposition Measurement Using Soil Surface Carbon Dioxide Fluxes and Natural Abundance of Carbon-13. Soil Sci. Soc. Am. J., 63: 1385-1396. https://doi.org/10.2136/sssaj1999.6351385x

Romaniuk, R., Giuffre, L., Costantini, A., Nannipieri, P., 2011. Assessment of soil microbial diversity measurements as indicators of soil functioning in organic and conventional horticulture systems. Ecol. Indic., 11: 1345-1353.

Rowe, H., Withers, P.J.A., Baas, P., Chan, N.I., Doody, D., Holiman, J., Jacobs, B., Li, H., MacDonald, G.K., McDowell, R., Sharpley, A.N., Shen, J., Taheri, W., Wallenstein, M., Weintraub, M.N., 2016. Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy, and water security. Nutrient Cycl. Agroecosyst., 104: 393-412, https://doi.org/10.1007/s10705-015-9726-1.

Sakurada, L.R., Batista, L.M.A., Inoue, T.T., Muniz, A.S., Pagliar, P.H., 2016. Organomineral phosphate fertilizers: Agronomic efficiency and residual effect on initial corn development. Agron. J. 108(5): 2050-2059. http://10.2134/agronj2015.0543.

Schimel, J.P., Weintraub, M.N., 2003. The implications of exoenzyme activity on microbial carbon and nitrogen limitation in soil: a theoretical model. Soil Biol. Biochem., 35: 549-563.

Shafi, M. I., Adnan, M., Fahad, S., Wahid, F., Khan, A., Yue, Z., et al., 2020. Application of single superphosphate with humic acid improves the growth, yield and phosphorus uptake of wheat (Triticum aestivum L.) in Calcareous Soil. Agronomy 10:1224. https://10.3390/agronomy10091224.

Shen, J.; Yuan, L.; Zhang, J.; Li, H.; Bai, Z.; Chen, X.; Zhang, W.; Zhang, F. Phosphorus dynamics: From soil to plant. Plant Physiol. 2011, 156, 997-1005. https://doi.org/10.1104/pp.111.175232.

Simonsen, A.K., Han, S., Rekret, P., Rentschler, C.S., Heath, K.D., Stinchcombe, J.R., 2015. Short-term Fertilizer application alters phenotypic traits of symbiotic nitrogen fixing bacteria. Peer J, 3: e1291.

Smith, J., Smith, P., Wattenbach, M., Zaehle, S., Hiederer, R., Jones, R.J.A., Montanarella. L., Rounsevell, M.D.A., Reginster, I., Ewert, F., 2005. Projected changes in mineral soil carbon of European croplands and grasslands, 1990–2080. Glob. Chang. Biol., 11: 2141-2152.

Steiner, C., Teixeira, W.G., Lehmann, J., Nehls, T., de Macêdo, J.L.V., Blum, W.E.H., Zech, W., 2007. Long-term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil 291(1–2): 275-290. https://10.1007/s11104-007-9193-9.

Süzer, S. and Çulhacı, E., 2017. The effects of different organomineral and inorganic compound fertilizers on grain yield and some yield components of winter bread wheat (in Turkish). Toprak Bilimi ve Bitki Besleme Dergisi, 5: 87-92.

Farklı organomineral ve inorganik kompoze gübrelerin kışlık ekmeklik buğday tane verimi ve bazı verim unsurları üzerine etkileri

Tahir, M.M., Khurshid, M., Khan, M.Z., Abbasi, M.K., Kazmi, M.H., 2011. Lignite-Derived Humic Acid Effect On Growth Of Wheat Plants İn Different Soils. Pedosphere, 21: 124-131.

Tian, W., Wang, L., Li, Y., Zhuang, K.M., Li, G., Zhang, J.B., Xiao, X.J., Xi, Y.G., 2015. Responses of microbial activity, abundance, and community in wheat soil after three years of heavy fertilization with manure-based compost and inorganic nitrogen. Agric. Ecosyst. Environ., 213: 219-227.

UN, 2011. Seven Billion and Growing the Role of Population Policy in Achieving Sustainability. Technical Paper No. 2011/3.

Van Kauwenbergh, S., 2010. World Phosphate Rock Reserves and Resources. IFDC Technical Bulletin

Vlek, P.L.G., Kuhne, R.F., Denich, M., 1997. Nutrient resources for crop production in the tropics. Phil. Trans. R. Soc. Lond. B 352: 975-985.

Warrinnier, R., Bossuyt, S., Resseguier, C., Cambier, P., Houot, S., Gustafsson, J.P., Diels, J., Smolders, E., 2020. Anaerobic respiration in the unsaturated zone of agricultural soil mobilises phosphorus and manganese. Environ. Sci. Technol. 54, 4922-4931. https://doi.org/10.1021/acs.est.9b06978.

Wikipedia (2020): Fertilizer. https://en.wikipedia.org/wiki/Fertilizer.

Xing, B., Ouyang, M., Graham, N., Yu, W., 2020. Enhancement of phosphate adsorption during mineral transformation of natural siderite induced by humic acid: Mechanism and application. Chem. Eng. J., 393: 124730.

Yadav, S., Lal, M., Naresh, R., Chandra, M., 2019. Effect of organic and inorganic nutrient sources on productivity, grain quality of rice and soil health in north-west IGP: a Review. Int. J. Curr. Microbiol. Appl. Sci. 8 https://doi.org/10.20546/ijcmas.2019.812.293.

Yan, Z., Chen, S., Dari, B., Sihi, D., Chen, Q., 2018. Phosphorus transformation response to soil properties changes induced by manure application in a calcareous, and I soil. Geoderma 322, 163–171. https://doi.org/10.1016/j.geoderma.2018.02.035.

Yan, Z., Chen, S., Li, J., Alva, A., Chen, Q., 2016. Manure and nitrogen application enhances soil phosphorus mobility in calcareous soil in greenhouses. J. Environ. Manag. 181, 26–35. https://doi.org/10.1016/j.jenvman.2016.05.081.

Yang, K., Zhu, J., Gu, J., Yu, L., Wang, Z., 2015. Changes in soil phosphorus fractions after 9 years of continuous nitrogen addition in a Larix gmelinii plantation. Ann. For. Sci. 72, 435–442. https://doi.org/10.1007/s13595-014-0444-7.

Yang, Y., Zhang, H., Qian, X., Duan, J., Wang, G., 2017. Excessive application of pig manure increases the risk of P loss in calcic cinnamon soil in China. Sci. Total Environ. 609, 102–108. https://doi.org/10.1016/j.scitotenv.2017.07.149

Zhang, S., Chen, S., Fenton, O., Li, Y., Chen, Q., 2021a. Enhanced topsoil P leaching in a short-term flooded calcareous soil with combined straw and ammonium nitrogen incorporation. Geoderma 402, 115322. https://doi.org/10.1016/j.geoderma.2021.115322.

Zhang, S., Wang, L., Chen, S., Fan, B., Huang, S., Chen, Q., 2022. Enhanced phosphorus mobility in a calcareous soil with organic amendments additions: Insights from a long term study with equal phosphorus input. Journal of Environmental Management, 306: 114451. https://doi.org/10.1016/j.jenvman.2022.114451.

Zhang, S., Yang, X., Hsu, L.C., Liu, Y.T., Wang, S.L., White, J.R., Shaheen, S.M., Chen, Rinklebe, Q. J., 2021b. Soil acidification enhances the mobilization of phosphorus under anoxic conditions in an agricultural soil: Investigating the potential for loss of phosphorus to water and the associated environmental risk. Sci. Total Environ., 793 (2021), p. 148531, https://doi.org/10.1016/j.scitotenv.2021.148531.

Zhao, S., Li, K., Zhou, W., Qiu, S., Huang, S., He, P., 2016. Changes in soil microbial community, enzyme activities and organic matter fractions under long-term straw return in north-central China. Agriculture, Ecosystems & Environment, 216: 82-88. https://doi.org/10.1016/j.agee.2015.09.028.

Zhou, J., Zhang, Y., Wu, K., Hu, M., Wu, H., Chen, D., 2021. National estimates of environmental thresholds for upland soil phosphorus in China based on a meta-analysis. Sci. Total Environ., 780 (2021), p. 146677, https://doi.org/10.1016/j.scitotenv.2021.146677.

CURRICULUM VITAE

Mahmoud Emad MORSY MOHAMED MORSY, finished high school in 2012, I studied bachelor's degree at Alexandria university in the Soil science and water science department and graduated in 2016. Then I went to the military. I applied for a Turkish scholarship YTP, and I had one to study for a master's degree at Çukurova University, Department of Soil Science and Plant Nutrition, from 2018 to now.