ÇUKUROVA UNIVERSITY

INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

Use Efficiency of Organomineral Fertilizer Phosphorus in Wheat

Şeyhmus DÜNDAR

Soil Science and Plant Nutrition Department

February, 2025

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS APPROVAL

Use Efficiency of Organomineral Fertilizer Phosphorus in Wheat

---

Şeyhmus DÜNDAR

Soil Science and Plant Nutrition Department

This Doctorate Thesis was evaluated by the following Jury Members on …/.../…… and was approved by unanimity / majority of votes.

Jury : Prof. Dr. Emin Bülent ERENOĞLU (Advisor) …………

: Prof. Dr. Mustafa HARMANKAYA …………

: Prof. Dr. Hayriye İBRİKÇİ …………

: Prof. Dr. Hakan ÖZKAN …………

: Assoc. Prof. Abdullah ULAŞ …………

This Thesis was written in the Department of Soil Science and Plant Nutrition, Institute of Natural and Applied Sciences.

Thesis Number:

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

CONTENTS

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

PhD THESIS

Use Efficiency of Organomineral Fertilizer Phosphorus in Wheat

Şeyhmus DÜNDAR

Advisor: Prof. Dr. Emin Bülent ERENOĞLU
Department of Soil Science and Plant Nutrition

ABSTRACT

This PhD thesis investigates the effectiveness of phosphorus (P) containing organomineral fertilizers (P-OMF) in calcareous/alkaline soils through two greenhouse pot trials and an incubation study under controlled conditions. The P-OMF was formulated by combining an organic fertilizer (OF) derived from a biogas plant with triple superphosphate (TSP), a commercially available mineral fertilizer (MF). The first greenhouse experiment examined the P efficiency of P-OMF compared to P-MF across soils with increasing Olsen P concentrations (10.2, 16.4, and 24.1 mg $P \cdot kg^{-1}$), assessing agronomic performance and nutrient status of wheat (*Triticum aestivum* L. cv. Özkan). The second pot experiment and the incubation study were conducted simultaneously to test the effects of different forms (powdered and granular) of P-OMF and P-MF on soil P availability and wheat growth, agronomic traits, and mineral nutritional status of wheat. In both pot experiments, fertilizers were applied 5 cm below the seedbed, while in the incubation study, they were placed 3 cm below the soil surface. Then, two harvests were undertaken: one at the end of the tillering stage and another at the physiological maturity (ripening stage). Two plants in each pot were cut at tillering, and their dry weights were recorded. Also, at the physiological maturity, before the harvest, the morphological traits (plant height and spike length) and number of spikes per pot were taken. Thereafter, the remaining five plants were harvested and dried, and their yield components, such as straw yield, grain yield, and biological yield, were recorded. Grain and straw samples were ground separately and subjected to chemical analyses to determine their N, P, and K concentrations. Nutrient content and uptake values were calculated by multiplying their concentrations in plant samples by the respective dry weights. In the second pot experiment, additional parameters such as SPAD reading, Harvest Index, and Phosphorus Harvest Index were recorded. Concerning the incubation study, soil samples were collected twice, aligning with the harvests of the second experiment: 45 days post-planting (at the tillering stage) and 128 days post-planting (physiological maturity). Finally, soil Olsen P, an indicator of plant-available P, was determined. Results from the first greenhouse experiment revealed that the effectiveness of P-OMF diminished with increasing Olsen P concentrations, particularly for spike count, shoot dry weight at tillering, grain yield, and total plant P uptake including P contents in grains and straw. Conversely, the second greenhouse experiment and incubation study demonstrated that P-OMF applications in powdered or granular forms significantly outperformed MF in terms of grain, straw, and biological yield, as well as grain P content and produced similar or significantly higher total P uptake when applied in powdered and granular forms, respectively.

Keywords: Organomineral, phosphorus, Olsen P, fertilizer forms, wheat

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

DOKTORA TEZİ

Organomineral Gübre Fosforunun Buğdayda Kullanım Etkinliği

Şeyhmus DÜNDAR

Danışman: Prof. Dr. Emin Bülent ERENOĞLU
Toprak Bilimi ve Bitki Besleme Anabilim Dalı

ÖZ

Bu doktora tezinde, kireçli/alkali topraklarda organomineral gübrelerin (OMG) etkinliği, kontrollü koşullarda iki sera saksı denemesi ve laboratuvar koşullarında gerçekleştirilen bir inkübasyon çalışması ile araştırılmıştır. OMG, biyogaz tesisinden elde edilen organik gübre (OG) ve mineral bir gübre (MG) olan triple süper fosfat (TSP) bileştirilerek üretilmiştir. İlk sera denemesinde, artan Olsen P içeriklerine (10.2, 16.4, ve 24.1 mg $P \cdot kg^{-1}$) sahip topraklarda OMG ve MF (TSP) gübrelerindeki fosfor (P)'un etkinliği ve bu gübrelerin buğdayın agronomik performansı ile beslenme durumuna etkileri incelenmiştir. İkinci saksı denemesi ve inkübasyon çalışması ise OMG'nin farklı formlarının (toz ve granül) ve MG'nin toprakta P yarayışlılığı, buğday büyümesi, agronomik özellikler ve mineral beslenme durumu üzerindeki etkilerini araştırmak için eş zamanlı olarak yürütülmüştür. Saksı denemelerinde gübreler tohum yatağının 5 cm altına, inkübasyon çalışmasında ise yüzeyin 3 cm derinliğine uygulanmıştır. Bu çalışmalarda iki hasat gerçekleştirilmiştir: ilki kardeşlenme aşamasında, diğeri ise fizyolojik olgunluk döneminde. Kardeşlenme aşamasında, her saksıdan iki bitki hasat edilerek kuru ağırlıkları ölçülmüştür. Fizyolojik olgunluk döneminde, hasattan önce bitki boyu, başak uzunluğu ve başak sayısı gibi morfolojik özellikler kaydedilmiş ardından ise kalan bitkiler hasat edilerek anız, tane ve biyolojik verim değerleri belirlenmiştir. Sonrasında, tane ve anız (hasat artığı) örnekleri öğütülmüş ve içlerindeki N, P, K konsantrasyonları kimyasal analizlerle saptanmıştır. Besin elementlerinin (N, P ve K) alım değerleri, konsantrasyon değerlerinin ilgili aksamların kuru ağırlıkları ile (tane verimi ve anız verimi) çarpılmasıyla hesaplanmıştır. İkinci saksı denemesinde ayrıca SPAD okuması, Hasat İndeksi ve Fosfor Hasat İndeksi gibi ek parametreler de ölçülmüştür. İnkübasyon çalışmasında, toprak örnekleri ekimden 45 ve 128 gün sonra alınmış, içlerindeki bitkiye yarayışlı P seviyeleri analiz edilerek ölçülmüştür. Sonuçlar, ilk sera denemesinde OMG etkinliğinin toprakta artan Olsen P konsantrasyonlarıyla azaldığını, başak sayısı, kardeşlenme aşamasındaki sürgün kuru ağırlığı, tane verimi, tane ve anız P içerikleri ve bitkinin toplam P alımının düştüğünü göstermiştir. Buna karşın, ikinci sera denemesi ve inkübasyon çalışması, OMG'nin toz ve granül formlarının MG'ye kıyasla tane, anız ve toplam verim ile tane P içeriği açısından daha yüksek performans gösterdiğini ve toplam P alımını artırdığını ortaya koymuştur.

Anahtar Kelimeler: Organomineral, fosfor, Olsen P, gübre formları, buğday.

GENİŞLETİLMİŞ ÖZET

Artan dünya nüfusu, gelir artışındaki iyileşmeler ve kentleşmenin artması gıda talebinin artmasına neden olan temel sosyoekonomik faktörlerdir. FAO verilerine göre, insan nüfusunun 2050 yılında 9,1 milyara ulaşacağı bildirilmektedir. Bu artış, 2009 yılında 6,1 milyar olan dünya nüfusu göz önünde bulundurulduğunda %34'lük bir artışa tekabül etmektedir. Bu nedenle, gelecekteki dünya nüfusunun gıda güvenliğini sağlamak için, gıda üretiminin %70 oranında arttırılması gerekliliği ile karşı karşıyayız. Tarımsal üretim alanlarının arttırılması mümkün olmadığından, bu artışın sınırlı üretim alanlarındaki topraklar üzerinde yoğun girdili tarım ile sağlanması gerekecektir. Ayrıca, günümüzde yapılan yoğun tarımsal üretimin topraklar üzerinde baskı oluşturması sonucunda toprakların verimliliklerinde azalma meydana gelmiştir. Bundan dolayı, yapılacak olan tarımsal üretimin ve tarım arazileri yönetiminin sürdürülebilir bir yaklaşım ile yapılması bir zorunluluk olarak karşımıza çıkmaktadır.

Tarımsal üretim, bitkilerin sağlıklı büyümeleri ve optimum verime ulaşmaları için gerekli olan bitki besin elementlerince toprakların verimlilik seviyelerine doğrudan bağlıdır. Günümüzde yapılan modern bitkisel üretimde, bu bitki besin elementlerinin temel kaynağı dışarıdan ilave edilen ve yüksek maliyetli olan mineral gübreler olduğundan, gübre kaynaklarının da sürdürülebilir besin elementi yönetimi çerçevesinde kullanılması bir zorunluluk haline gelmiştir. Bitkisel üretimde azot (N)tan sonra en yaygın etkiye sahip olan elementin fosfor (P) olduğu, bu nedenle de sıklıkla P içeren gübrelerin kullanıldığı bilinmektedir. Fakat, yüksek oranda P kullanılması verim artışına katkıda bulunsa da yanlış kullanıldığı taktirde yüzey suları başta olmak üzere tatlı su kaynaklarına kadar ulaşarak çevresel riskler oluşturmaktadır. Bununla beraber, P'lu gübrelerin temel hammaddesi olan fosfat kayasının sınırlı bir hammadde olması, bu gübrelerin yönetiminde daha hassas davranmamız gerektiği olgusunu meydana getirmiştir. Bu nedenle, P'un gübrelemede doğru/etkin biçimde yönetilmesi daha ekonomik bir bitkisel üretim, sınırlı hammaddelerin ömrünün uzatılması ve ortaya çıkabilecek olası çevresel risklerin önlenmesi için oldukça önemlidir.

Bu bağlamda, bu çalışmada bitkisel ve hayvansal kökenli biyogaz tesisi atıklarından elde edilen organik gübre (OG) ve piyasada yaygın olarak bulunan bir mineral gübre (MG) olan TSP (Triple süperfosfat) kullanılarak son yıllarda kullanımı yaygınlaşan P'lu organomineral gübrelere (P-OMG) bir örnek üretilmiş ve bu gübrenin etkinliği serada ve laboratuvar koşullarında kireçli/alkalin bir toprakta P'lu mineral gübre (P-MG) olarak seçilen TSP gübresi ile karşılaştırılmıştır. İlk olarak, sera koşullarında yürütülen birinci saksı denemesinde, artan dozlarda uygulanan P-OMG'nin ve P-MG'nin farklı yarayışlı P (Olsen P) konsantrasyonlarına sahip topraklarda buğday bitkisinin mineral beslenme durumu, verim ve büyüme parametreleri üzerine etkileri incelenmiştir. Çalışmaların ikinci aşamasında ise, eş zamanlı olarak serada bir saksı denemesi ve laboratuvar ortamında cam kaplarda bir inkübasyon denemesi yürütülmüştür. Bu denemelerde, artan dozlarda ve farklı formlarda uygulanan P-OMG ve P-MG'nin buğdayın agronomik performansı, büyüme ve verim parametreleri ve toprakta yarayışlı P konsantrasyonu üzerine etkileri araştırılmıştır.

Birinci sera denemesinin sonuçlarına göre, artan dozlarda (0, 20, 40 mg P·kg toprak^{-1}) TSP ile 42 günlük bir süreçte ıslama-kuruma işlemine maruz bırakılan toprakların yarayışlı fosfor (Olsen P) içeriklerinin artarak sırasıyla 10,2, 16,4, ve 24,1 mg P·kg toprak^{-1} olduğu tespit edilmiştir. Havlin ve arkadaşlarına (2016) göre, Olsen P'u değerlerinin 8-11 ppm, 12-20 ppm ve >20 ppm aralıklarında sırasıyla orta, yüksek ve çok yüksek P verimlilik düzeylerine sahip toprakları temsil ettiği yüksek-çok yüksek P verimlilik değerine sahip toprakların P gübrelemesine yanıt vermesi beklenmediğinden, bu çalışmada elde edilen Olsen P'u değerlerinin sırasıyla orta, yüksek ve çok yüksek P verimliliği aralığında olduğu tespit edilmiştir. Bu çalışmada, ekimden 45 gün sonra (kardeşlenme aşamasının sonu) elde edilen saksı başına başak sayısı ve yeşil aksam kuru ağırlığının (g·[2 bitki]$^{-1}$) aynı eğilimi izledikleri tespit edilmiştir. Bu bağlamda, ORTA-P verimlilik seviyesinde, artan dozlarda uygulanan P-OMG ve P-MG, kontrol uygulamasına göre her iki parametreyi önemli ölçüde arttırmış. Ayrıca, P-OMG, P-MG'ye göre önemli ölçüde üstün bir performans göstermiştir. Fakat, toprak Olsen P konsantrasyonlarının artmasıyla beraber (YÜKSEK-P ve ÇOK YÜKSEK-P:), buğday bitkilerinin gübrelere olan tepkileri önemli oranda düşüş göstermiş ve gübrelerin etkinlikleri arasındaki fark ortadan kalkmıştır.

Bitki boyu ve başak uzunluğu parametreleri incelendiğinde, ORTA-P verimliliğine sahip toprakta artan dozlarda uygulanan OMG ve MG gübrelerinin kontrol uygulamasına oranla hem bitki boyunu hem de başak uzunluğunu önemli oranda arttırmıştır. Fakat, bütün Olsen P düzeylerinde P-OMG ve P-MG'nin etkinlikleri arasında herhangi bir fark görülmemiştir.

Olgunlaşma aşamasında örneklenen hasat artıkları ve toplam (hasat artığı + tane) ağırlık değerlerine bakıldığında, toprak P verimlilik seviyelerinden bağımsız olarak, artan dozlarda P-OMG uygulamalarının bitkilerin hem hasat artığı hem de toplam ağırlıklarını P-MG uygulamalarına kıyasla daha fazla arttırmış, bu artış istatistiki olarak önemli bulunmuştur. Ayrıca, artan dozlarda P gübresi uygulanan saksılardaki bitkilerin toplam ve hasat artığı ağırlıklarının, P uygulanmayan kontrol saksılarında yetiştirilen bitkilere oranla istatistiki olarak önemli derecede daha yüksek olduğu tespit edilmiştir. Olsen P düzeylerinin gübre etkinliği üzerindeki etkisine bakıldığında, ORTA-P düzeyinde, toplam ve hasat artığı kuru ağırlıklarının, MG 50 mg P·kg toprak^{-1} ile benzer sonuçlar veren MG 100 mg P·kg toprak^{-1} uygulaması hariç, P uygulamaları arttıkça istatistiki olarak önemli ölçüde arttığı açık bir şekilde görülmektedir. Söz konusu bu ilişki, topraktaki P verimliliği seviyesi yüksek ve çok yüksek olduğunda ise ortadan kaybolmuştur.

Tane verimi ile ilgili bulgular, artan dozlarda yapılan P uygulamasının her iki gübre tipinde de orta ve yüksek toprak P verimliliği seviyelerine sahip topraklarda kontrol uygulamalarına kıyasla daha yüksek tane kuru ağırlığı ürettiği tespit edilmiştir. Bununla beraber, OMG uygulaması yapılan saksılarda istatistiksel olarak daha yüksek tane verimi elde edilmiştir. Her ne kadar, YÜKSEK-P seviyesinde OMG uygulamaları MG uygulamalarından daha üstün bir etkinlik gösterse de ORTA-P seviyesindeki uygulamalara kıyasla daha küçük farklara yol açarak gübrelerin etkinliğinde bir azalma olduğunu göstermiştir. Ayrıca, ÇOK YÜKSEK-P verimlilik seviyesindeki topraklarda gübre etkinliğindeki düşüş daha belirgin hale gelerek her iki gübre arasındaki farklılıkları ortadan kaldırmıştır.

Kardeşlenme aşamasının sonunda, toprakların P verimlilik düzeylerinden bağımsız olarak artan dozlarda gerçekleştirilen OMG veya MG uygulamaları buğdayın yeşil aksamında benzer P konsantrasyonları ve yeşil aksam P içeriklerine neden olmuştur. ORTA-P verimlilik seviyesinde, artan miktarda P-OMG uygulanan saksılarda yetiştirilen bitkiler, P-MG ile muamele edilenlere kıyasla daha yüksek P alımına neden olsa da bu fark istatistiki olarak önemsiz bulunmuştur. Olgunlaşma aşamasındaki P beslenme durumları göz önünde bulundurulduğunda ise, orta düzeyde P verimlik değerine sahip topraklarda, gübre kaynaklarının, hasat artığı P konsantrasyonlarını ve tane P konsantrasyonlarını artırmadaki etkinlikleri arasında herhangi bir fark gözlenememiştir, ancak P-OMG uygulanan saksılarda yetişen bitkilerin daha yüksek hasat artığı P içeriği ve tane P içeriğine sahip olduğu tespit edilmiştir. Bununla beraber, P-OMG ile gübrelenen bitkilerin daha yüksek hasat artığı kuru ağırlıkları ve tane kuru ağırlıkları dikkate alındığında, bu sonuçlar, OMG uygulanan bitkilerdeki hasat artığı ve tane P konsantrasyonlarının seyreltme etkisine maruz kaldığı olgusunu ön plana çıkarmaktadır.

Topraktaki P verimlilik durumunun ORTA-P seviyesinden sırasıyla YÜKSEK-P ve ÇOK YÜKSEK-P seviyelerine yükselmesi, buğday bitkilerinin sap ve tanelerinde P alımı açısından uygulama dozları arasındaki farklarda önemli düşüşlere yol açmış ve kullanılan gübrelerin benzer etkinlik göstermesiyle sonuçlanmıştır. Ayrıca, P-OMG uygulamaları, YÜKSEK-P verimlilik seviyesinde P-MG'ye oranla anlamlı derecede daha yüksek toplam buğday P alımı sağlamıştır; fakat bu durumun yalnızca en yüksek uygulama dozu olan 100 mg P·kg toprak^{-1}'den kaynaklandığı açıkça belirlenmiştir.

Ekimden 45 gün sonra hasat edilen buğday bitkilerindeki sürgün N konsantrasyonu, kullanılan gübre çeşidinden önemli ölçüde etkilenmiş ve OMG, tüm toprak P verimliliği düzeylerinde MG'den daha iyi performans göstermiştir. Ek olarak, aynı dönemde hesaplanan yeşil aksam N içeriğinin yalnızca en düşük, yani, ORTA-P toprak P'u verimliliğine sahip topraklarda daha yüksek olduğu tespit edilmiş ve P-OMG ile gübrelenen bitkiler P-MG'den daha fazla N içeriğine neden olmuştur. Bu da organik maddenin (OM) bitki büyümesi ve bitkilerin ilk büyüme dönemlerinde besin elementi alımı üzerindeki olumlu etkisini göstermektedir. Ancak, toprakların P verimlilik seviyeleri arttıkça, kullanılan her iki gübrenin de yeşil aksam N içeriği açısından herhangi bir farkının olmadığı ve benzer etkinlikler gösterdiği tespit edilmiştir.

Olgunlaşma aşamasında tespit edilen N beslenme durumu değerlendirildiğinde, gübre formlarından bağımsız olarak artan dozlarda P gübresi uygulamalarının, hasat artığı N konsantrasyon ve içerikleri üzerinde hiçbir etkisi görülmemiştir. Tane N değerlerine bakıldığında ise, topraktaki P verimlilik seviyelerinden bağımsız olarak, tane N konsantrasyonlarının gübre tipi veya gübre uygulama dozlarından etkilenmediği görülmüştür, fakat ORTA-P verimlilik seviyesine sahip topraklarda artan dozlarda yapılan P-OMF uygulamalarının, P-MF uygulamalarına kıyasla tanede daha yüksek N içeriğine yol açtığı görülmüştür. Ancak, topraktaki P verimlilik seviyelerindeki artışlarla birlikte, her iki gübrenin tane N içeriği üzerindeki etkisi benzer hale gelmiştir.

Buğday bitkisinin K alımına ilişkin olarak, P-OMG uygulamalarının düşük toprak P verimlilik seviyelerinde (ORTA-P ve YÜKSEK-P) tane P ve N içeriğini artırmada etkili olmasına rağmen, K beslenmesi üzerinde herhangi bir etkisi gözlemlenmemiştir.

İkinci sera denemesinin bulguları göz önünde bulundurulduğunda, gübre formundan (granül ve toz) bağımsız olarak artan dozlarda OMG veya MG olarak gerçekleştirilen P uygulamalarının kontrol uygulamalarına göre kardeşlenme aşamasının sonunda (ekimden 45 gün sonra) hasat edilen buğday bitkilerinin sürgün kuru ağırlıklarını önemli ölçüde arttırdığı tespit edilmiştir. Bu bağlamda, granül formda gerçekleştirilen P-OMG ve P-MG uygulamalarının performansları arasında herhangi bir fark görülmemesine rağmen, P-MG ile muamele edilen saksılardaki bitkilerin, toz formda P-OMG ile muamele edilenlere göre daha yüksek sürgün kuru ağırlığına sahip olduğu görülmüştür. Bu sonuçlar, artan P uygulamalarının buğday bitkisinin ilk büyüme aşamalarında sürgün büyümesi üzerindeki faydalı etkilerini ortaya koymuştur.

Olgunlaşma aşamasında ölçülen morfolojik parametreler değerlendirildiğinde, P uygulamalarının gübre tipi ve formundan bağımsız olarak kontrol uygulamalarına (P uygulanmayan) kıyasla bitki boyu ve başak uzunluğunu önemli derecede arttırdığı belirlenmiştir. Ek olarak, P-OMG uygulamalarının P-MG uygulamalarına göre istatistiksel olarak daha iyi olduğu tespit edilmiş ve en düşük P-OMG miktarıyla (25 mg $P \cdot kg^{-1}$ toprak) muamele edilen bitkilerin, en yüksek P-MG dozuyla (100 mg $P \cdot kg^{-1}$ toprak) gübrelenenlere kıyasla benzer veya daha yüksek bitki boyları ve başak uzunluklarına neden olduğu görülmüştür.

Ekonomik verimin önemli bir göstergesi olan saksı başına başak sayısı incelendiğinde ise, artan dozlarda uygulanan her iki gübre formu olan granül veya toz uygulamalarında da P-OMG ile P-MG arasında başak sayısı açısından herhangi bir fark bulunamamıştır. Fakat, toz formunda artan miktarlarda yapılan P uygulamaları kontrol grubuna kıyasla başak sayısında istatistiki olarak önemli artışlar sağlarken, granül formdaki P uygulamalarında bu etki ortadan kalkmıştır. Bununla beraber, özellikle P-OMG uygulamaları altında bir artış trendi görülmüş olsa da bu istatistiki olarak önemsiz çıkmıştır.

Bitki agronomik performansı bakımından, elde edilen bulgular artan P uygulamalarının, gübre tipi ve formundan bağımsız olarak, kontrol uygulamalarına göre biyolojik verim (toplam kuru ağırlık), anız ağırlığı (hasat artığı) ve tane kuru ağırlığını önemli derecede arttırdığını ortaya koymaktadır. Bununla beraber, P-OMG uygulamaları P-MG'ye oranla tutarlı bir şekilde daha üstün bir performans sergilemiş, en düşük P-OMG dozu ile yetiştirilen bitkiler, en yüksek P-MG miktarı uygulanan bitkilerle benzer etkinlikler göstermiştir. Elde edilen bu bulgular, P-OMG gübresinin kullanılmasıyla P'lu gübre uygulama oranlarının önemli ölçüde azaltılabileceğini ve çiftçilere hem verimi hem de ürün verimliliğini korurken gübre maliyetlerini düşürme fırsatı sunabileceğini ortaya koymaktadır.

Bitki agronomik performansı ile uyumlu olarak, SPAD okuması ve hasat indeksi parametreleri de benzer bir eğilim izlemiştir. Genel olarak, P-OMG uygulanan bitkiler, gübre formundan bağımsız olarak P-MG'den önemli ölçüde daha yüksek bir etkinlik göstermiştir. Daha spesifik olarak, en düşük P-OMG miktarı ile yetiştirilen bitkiler, en yüksek P-MG dozu uygulanan bitkilerle istatistiksel olarak karşılaştırılabilir sonuçlar elde etmiştir.

SPAD ölçümleri ile artan miktarlarda kullanılan P-OMG'nin, gübre formundan bağımsız olarak P-MG'ye kıyasla istatistiksel olarak daha yüksek sonuçlar elde edilmiştir. Ayrıca, P-OMG uygulamaları, artan dozlar arasında benzer SPAD değerlerine yol açmış olsa da kontrol uygulamalarından daha yüksek sonuçlar doğurmuştur. Buna karşılık, P-MG uygulamaları, 25 mg $P \cdot kg^{-1}$ toprak düzeyinde, gübre formundan bağımsız olarak SPAD sonuçlarında kontrol grubuna oranla hafif bir düşüşe neden olmuştur. Fakat, SPAD değerleri 50 mg $P \cdot kg^{-1}$ toprak dozu ile artmaya başlamış ve her iki gübre formu için 100 mg $P \cdot kg^{-1}$ toprak düzeyinde istatiksel olarak anlamlı bir farka ulaşmıştır.

Hasat indeksi verileri, gübre formundan bağımsız olarak hem gübre çeşitlerinin hem de artan uygulama dozlarının HI değerlerinde artışlara neden olduğunu göstermiştir. Ayrıca, P-OMG uygulamaları, P-MG'ye kıyasla tutarlı bir şekilde daha yüksek HI değerleri elde edilmesini sağlamıştır.

Kardeşlenme aşamasının sonunda örneklenen bitkilerin yeşil aksam P konsantrasyonları, gübre tipi ve formundan bağımsız olarak, artan P uygulama dozlarının yeşil aksam P konsantrasyonunu önemli ölçüde artırdığını göstermiştir. Kontrol gurubu bitkilerinin P konsantrasyonları, gübre uygulanan bitkilere oranla önemli ölçüde düşük bulunmuştur. Granül formda yapılan gübre uygulamalarında, her üç dozda P-OMG, P-MG'ye kıyasla daha yüksek yeşil aksam P konsantrasyonlarına neden olmuştur. Ancak, gübreler toz olarak kullanıldığında, her üç doz için de istatistiksel olarak önemli bir fark görülmemiş ve toz formunda yapılan uygulamalar, granül forma göre daha yüksek yeşil aksam P konsantrasyonlarına yol açmıştır.

Aynı dönemde hesaplanan yeşil aksam P içerikleri de yeşil aksam P konsantrasyonlarıyla benzer bir eğilim göstermiştir. Daha ayrıntılı olarak, gübre tipi ve formundan bağımsız olarak, yeşil aksamdaki P içeriği artan P uygulama dozları ile artış göstermiş, kontrol bitkilerinin ise gübre uygulanan bitkilere göre önemli derecede daha düşük P içeriğine sahip olduğu belirlenmiştir. Granül formda, P-OMG uygulamaları yeşil aksam P içeriğini artırmada P-MG'ye kıyasla daha etkili bulunmuştur. Ancak, toz formda gerçekleştirilen uygulamalarda, gübrelerin etkinlikleri genel olarak artmış ve OMG ile MG arasındaki istatistiksel fark ortadan kalkmıştır.

Olgunlaşma aşamasında buğdayın P ile beslenme durumu değerlendirildiğinde, P uygulamaları ile kontrol uygulamaları arasında buğday bitkilerinin hasat artığı P konsantrasyonu üzerinde istatistiksel olarak anlamlı bir fark bulunamamıştır. Gübre tipi ve formundan bağımsız olarak, kontrol bitkilerinin hasat artığı P konsantrasyonlarının, P gübresi uygulanan bitkilerin P konsantrasyonlarından daha yüksek veya benzer olduğu, bununla birlikte P-MG uygulanmış bitkilerin P-OMG uygulanmışlara göre daha yüksek olduğu tespit edilmiştir. Anız P konsantrasyonu sonuçlarına paralel olarak, artan dozlarda yapılan P-MG uygulamaları, gübre formundan bağımsız bir şekilde P-OMG uygulamalarına göre hasat artığındaki P içeriklerini istatistiksel olarak önemli derecede arttırmıştır. İki yönlü ANOVA analizine göre, kullanılan deneysel konular olan her iki gübre tipi ve P uygulama oranları, hasat artığı P içeriği üzerinde anlamlı etkiler göstermiştir. Fakat, her iki gübre formu için deneysel sonuçların genel yorumlanmasıyla ilgili anlamlı veriler elde edilememiştir.

Tane P durumu ile ilgili sonuçlar, granül formda ve artan dozlarda uygulanan P-MG gübresinin, P-OMG gübresine göre istatistiksel olarak daha yüksek tane P konsantrasyonuna neden olduğunu göstermiştir. Artan dozlarda yapılan P-OMG uygulamaları, kontrol grubuna oranla daha düşük tane P konsantrasyonu ile sonuçlanmıştır. Öbür taraftan, artan dozlarda uygulanan P-MG, kontrol uygulamaları ile istatistiksel olarak benzer P konsantrasyonları sağlamıştır. Toz formunda yapılan uygulamalarda ise P-OMG ve P-MG arasında tane P konsantrasyonu açısından istatistiki olarak önemli bir fark tespit edilememiştir. Tane P içeriklerine ilişkin sonuçlar, artan P uygulamalarının gübre tipi ve formundan bağımsız olarak tane P içeriğini önemli ölçüde artırdığını göstermiştir. Ayrıca, kontrol grubundaki bitkilerin tane P içerikleri hem granül hem de toz formda artan miktarda P uygulamalarıyla gübrelenen bitkilere kıyasla önemli derecede daha düşük bulunmuştur. Bununla beraber, P-OMG'nin P-MG'ye karşı istatistiksel derecede önemli üstünlük sağladığı tespit edilmiştir. Ayrıca, her iki gübre tipinde de toz olarak yapılan gübre uygulamalarının genel olarak granül formdaki uygulamalardan daha yüksek tane P içerikleriyle sonuçlandığı tespit edilmiştir.

Özet olarak, her bir gübre formu için ayrı olarak yapılan ANOVA analizleri, artan P uygulamalarının, gübre tipine ve formuna bakılmaksızın buğday bitkilerinin toplam P alımını istatistiksel olarak önemli seviyelerde artırdığını ortaya koymuştur. İlave olarak, kontrol bitkilerinin toplam P alımı hem granül hem de toz formunda ve artan dozlarda P gübreleriyle gübrelenen bitkilere oranla önemli derecede daha düşük bulunmuştur. İlaveten, granüler formda uygulanan P-OMG'nin P-MG'ye göre daha yüksek toplam P alım trendine sahip olsa da bu durum istatistiki olarak önemli bulunmamıştır. P-OMG uygulamalarının sadece toz formda uygulandığında P-MG'ye kıyasla daha iyi performans gösterdiği görülmüştür. Genel olarak, toplam P içeriklerinin, toz formda yapılan uygulamalarda granül formdaki uygulamalara göre daha yüksek olduğu bulunmuştur.

Fosfor hasat indeksi (PHI) bulguları, P uygulamalarının kontrol uygulamalarına kıyasla PHI'yi artırdığını ve OMG'nin gübre formundan bağımsız olarak MG'den önemli ölçüde üstün performans sergilediğini göstermiştir. Dahası, P-OMG uygulamaları tüm uygulama dozlarında P-MG'den daha yüksek PHI değerleri sağlamıştır.

Buğdayın N ve K beslenme durumuna ilişkin bulgular, gübre formuna bakılmaksızın, hasat artıkları (anız) N konsantrasyonu ve içeriklerinin, bilimsel literatürle uyumlu biçimde, tane N konsantrasyonu ve içeriklerine kıyasla istatistiki olarak anlamlı derecede daha düşük olduğunu göstermiştir. Buna karşın, K beslenmesinde bu durum tersine bir eğilim göstermiştir. Bitkilerin toplam N ve K alımları incelendiğinde, P-OMG ile gübrelenen bitkilerin, P-MG ile beslenenlere oranla daha yüksek N ve K alımları gerçekleştirdiği saptanmıştır. Bu fark, özellikle granül formda yapılan uygulamalarda istatistiksel olarak anlamlı bulunmuştur. Bunun yanı sıra, granül formda uygulanan en düşük P dozu hariç, bitkilerin hem N hem de K alımlarının, bitkilerin artan gübreleme ile gelişimlerindeki iyileşmelere paralel olarak arttığı tespit edilmiştir.

Çalışmaların ikinci aşamasında sera denemesi ile eş zamanlı olarak, laboratuvar ortamında kurulan inkübasyon denemesinde topraklar iki kez örneklenmiş ve içlerindeki bitkiye yarayışlı P içerikleri (Olsen P) belirlenmiştir. İlk örnekleme, denemenin kuruluşundan 45 gün sonra, ikinci sera denemesinde bitkilerin kardeşlenme döneminin sonunda örneklenmesiyle aynı günde yapılmıştır. Bu aşamada toprak örneklerinin Olsen P seviyeleri, gübre tipi ve formundan bağımsız olarak artan P uygulama oranlarıyla birlikte artmıştır. Granül uygulamalar için, P-OMG, P-MG'ye kıyasla önemli ölçüde daha yüksek Olsen P seviyeleri sağlamıştır. Buna karşılık, hem P-OMG hem de P-MG uygulamaları toz formunda benzer sonuçlara yol açmıştır. Bu sonuçlar, MG'nin toz olarak uygulandığında etkinliğinin OMG'ye kıyasla daha yüksek düzeylerde artmasıyla açıklanabilir.

İkinci örnekleme ise, denemenin başlamasından 128 gün sonra, ikinci sera denemesinde bitkilerin olgunlaşma döneminin sonunda hasat edildiği gün yapılmıştır. Genel olarak, toprakların Olsen P içerikleri, gübre tipi veya formundan bağımsız olarak artan dozlarda P uygulamalarıyla artmıştır. İlk örneklemenin sonuçlarının aksine, her iki gübre formunda da P-OMG uygulamaları P-MG'ye oranla toprakta daha yüksek Olsen P seviyelerine neden olmuştur. Bununla beraber, granüler formda uygulandığında, P-OMG ile inkübe edilen toprakların, P-MG ile inkübe edilenlere kıyasla istatistiksel olarak belirgin bir şekilde daha yüksek Olsen P seviyelerine sahip olduğu saptanmıştır. Fakat, toz olarak yapılan uygulamalarda, P-OMG yalnızca en yüksek P dozunda (100 mg $P \cdot kg^{-1}$ toprak) P-MG'ye oranla istatiksel olarak anlamlı bir üstünlük sergilemiş, daha düşük uygulama dozlarında ise (25 ve 50 mg $P \cdot kg^{-1}$ toprak) anlamlı bir fark tespit edilememiştir.

ACKNOWLEDGEMENTS

I wish to extend my deepest gratitude and appreciation to my mother, Perihan DÜNDAR, and my father, Mehmet DÜNDAR, to whom I dedicate this thesis in recognition of their unwavering support, love, kindness, sacrifice, and patience throughout my life.

I am also profoundly thankful to my siblings, Aliye DÜNDAR, Fırat DÜNDAR, Zehra DÜNDAR, and Zeynep DÜNDAR, as well as my grandmother, Aliye DÜNDAR, for their steadfast support and love.

My heartfelt thanks go to my uncles, Mehmet Ali DÜNDAR and Mehmet Selim DÜNDAR, for always standing by me and offering their encouragement.

I am deeply indebted to my esteemed supervisor, Prof. Dr. Emin Bülent ERENOĞLU for his tireless guidance, assistance, and encouragement over the years. His support has been instrumental not only during my PhD but also throughout my bachelor's and master's studies.

I am sincerely appreciative of Prof. Dr. Hayriye İBRİKÇİ, Prof. Dr. Hakan ÖZKAN, Prof. Dr. Mustafa HARMANKAYA, and Prof. Dr. Abdullah ULAŞ for their contribution as members of my thesis defense jury.

I also wish to express my appreciation to my colleagues and professors in the Department of Soil Science and Plant Nutrition for their help, collaboration and valuable contributions throughout my academic career.

I am profoundly thankful to my kind-hearted friends- Veysi AKŞAHİN, Rojin GÜLER, Feyzullah ÖZTÜRK, Tofeek Samuel WAHAB, Firuza KOBOYEVA, Adnan TÜSÜN, Kedir Abate FENTAW, Sidar AKTÜRK, Onur TÖSTEN, Nadia Ali Sir Elkhtim AHMET, İlknur ŞAHİN, Emin ALTIPARMAK, and Şahin CENKSEVEN- as well as my cousins, Selahattin BAYRAM, Ferhat DÜNDAR, and İbrahim GÜÇ for their contributions.

Finally, I would like to express my gratitude to my English teachers, Eser KAMIŞÇI and Başak TAN İRTEŞ, whose dedication at the English Language Preparatory School (School of Foreign Languages, Çukurova University) during the 2009-2010 academic year played a pivotal role in shaping my English proficiency and enabling me to write this dissertation in English.

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

AP	: Available Phosphorus
C	: Carbon
Ca-P	: Calcium phosphate
Cu	: Copper
DAP	: Diammonium phosphate
FBMPs	: Fertilizer Best Management Practices
Fe	: Iron
H_2PO_4	: Dihydrogen phosphate
HA	: Humic acid
HARV	: Humic-acid-rich vermicompost
HI	: Harvest index
HPO_4^{-2}	: Hydrogen phosphate
HS	: Humic Substances
MAP	: Monoammonium phosphate
MF	: Mineral fertilizer
MG	: Mineral Gübre
Mn	: Manganese
N	: Nitrogen
N_2	: Nitrogen gas
N_2O	: Nitrous oxide
NH_3	: Ammonia
NH_4-Ca-P	: ammonium-calcium-phosphate
NO_3	: Nitrate
NO_x	: Nitrogen oxides
OF	: Organic fertilizer
OM	: Organic matter
OMF	: Organomineral fertilizer
OMG	: Organomineral Gübre
OP	: Olsen phosphorus
P	: Phosphorus
PalHA	: Phosphorus-aluminum-humic acid
PCaHA	: Phosphorus-calcium-humic acid
PFeHA	: Phosphorus-iron-humic acid
pH	: Potential of hydrogen
PI	: Phosphorus index

P-MF : Phosphorus-containing mineral fertilizer

P-MG : Fosforlu mineral gübre

PMHA : Phosphorus-metal-humic acid complexes

P-OMF : Phosphorus-containing organomineral fertilizer

P-OMG : Fosforlu organomineral gübre

PR : Phosphate rock

PSC : Phosphorus sorption capacity

S : Sulphur

S_{max} : Soil maximum P sorption capacity

SOC : Soil organic carbon

SOM : Soil organic matter

SSP : Single superphosphate

Tg : Teragram

Total K : Total Potassium

Total N : Total Nitrogen

Total P : Total Phosphorus

TSP : Triple superphosphate

Zn : Zinc

1. INTRODUCTION

Presently, the main socioeconomic factors creating a necessity for increased food production are the rapidly increasing human population, declining human population in rural areas, changes in the human diet, and improvements in income growth. Based on a report released by FAO in 2009, the human population is anticipated to rise to 9.1 billion by the year 2050. Taking into account the population of 6.1 billion in 2009, this expected population growth rate is 34% (FAO, 2009). Therefore, in order to ensure global food security, scientists believe that food production must be increased by 70% (Kopittke et al., 2019). Since the possibility of increasing agricultural production areas is not a feasible option, most of the increases in food production will come from the limited arable land which is already placed under unprecedented pressure by intensive farming practices. As a result of this intensive agricultural production, the fertility of soils has decreased (Kopittke et al., 2017; OECD et al., 2017; Kopittke et al., 2019). Therefore, it is a necessity for agricultural production and agricultural land management to be carried out with a sustainable approach.

Chemical fertilizers enhance soil fertility, but they often fall short in improving soil's physical and biological properties, particularly in areas with low organic matter. This limitation underscores the need to bolster such soils with organic matter. Soil organic matter, derived from plant and animal residues, is a vital indicator of productivity in sustainable soil management. Microbial activity decomposes these residues, forming humus - a stable, homogeneous substance ranging in color from brown to black. In soil science, this organic matter is referred to as humus (Brady and Weil, 2017). Although it makes up a small percentage of soil composition, humus plays a crucial role in enhancing soil structure and fertility, thereby supporting sustainable agricultural practices.

Despite constituting a small percentage of soils, soil organic matter is a vital component that significantly influences soil fertility and structure in agriculture. Humus, which forms from the decomposition of plant and animal residues, coats the clay minerals in the soil, preventing them from bonding together and increasing the exchange capacity of these molecules. Its high cation exchange capacity improves the efficacy of chemical fertilizers, keeping them within the root zone and forming chelates with high-valent cations like iron (Fe^{+3}), copper (Cu^{+2}), and zinc (Zn^{+2}). This process neutralizes these cations and facilitates their uptake by plants while also enhancing the activity of soil microorganisms. Consequently, research on applying organic matter to soils, especially those with low organic content, and the impact of humus on plant growth and soil properties has gained momentum.

Turkey's soils, characterized by low organic matter content (Sönmez et al., 2018) and diminishing raw material resources (Cordell et al., 2009), underscore the urgent need for organic and organomineral fertilizer production. Research in Turkey and globally aims to utilize increasing organic waste from population growth and consumption to minimize environmental risks and enhance soil productivity.

Agricultural production depends on plant nutrients, which are necessary for healthy growth and optimum yield of plants. In today's modern agriculture, the primary source of these plant nutrients is costly mineral fertilizers applied; for that reason, using fertilizer resources within the framework of sustainable nutrient management holds great importance for future agricultural production. It is well-known that phosphorus (P) is one of the essential plant nutrients that has the most widespread effect after nitrogen in plant production. Hence, fertilizers containing P are frequently used. Although using high amounts of P contributes to increased yields, it might potentially contaminate groundwater and surface waters if used incorrectly and pose environmental risks. In addition, the finite nature of phosphate rock, the primary raw material for phosphate fertilizers, further underlines the significance of efficient management of phosphate-containing fertilizers. Considering the aforementioned factors, it is vital to adopt correct/effective management of this nutrient in fertilization for a more economical plant production as well as extending the life span of limited raw materials and preventing possible environmental risks that might emerge.

In this context, in the present PhD thesis, a P-containing organomineral fertilizer (P-OMF), which has become widespread in recent years, was produced using organic fertilizer (OF) obtained from biogas plant rests and TSP (Triple superphosphate), a commercially available mineral fertilizer and its effectiveness was tested in a calcareous/alkaline soil under greenhouse and laboratory conditions. Initially, in the first pot experiment conducted under greenhouse conditions, the effects of P-OMF and P-MF fertilizers applied at increasing amounts on the mineral nutritional status, yield, and growth parameters of wheat plants in soils with different plant-available P (Olsen P) concentrations were investigated. In the second part of the thesis, a greenhouse pot trial and an incubation study under laboratory conditions were conducted simultaneously. In these trials, the effects of P-OMF and P-MF fertilizers applied at increasing rates and in different forms (powdered and granular) on the agronomic performance, growth, and yield parameters of wheat, and Olsen P levels in the soil were investigated.

2. LITERATURE REVIEW

The primary socio-economic contributors to the escalating food demand are increasing urbanization, enhanced incomes, and population growth. According to an FAO report, the global human population is projected to reach 9.1 billion by 2050, a 34% increase from 6.1 billion in 2009 (FAO, 2009). To ensure global food security, global food production must increase by 70% by 2050 (FAO, 2009; Noel et al., 2015). Agriculture will have to achieve these increases through intensive farming practices in limited production areas while facing the risks posed by climate change, which already places unprecedented pressure on soils (FAO, 2009; Kopittke et al., 2019).

2.1. Nutrient Balance and Sustainable Management in Soils

Crop production relies principally on the cultivation of arable soils, which provide most of the human food and grassland (Roy et al., 2006; Kopittke et al., 2019; Gerke, 2022). Likewise, future food supplies are believed to depend on sustainable and efficient cultivation on agricultural land (Gerke, 2022). Therefore, the preservation of this vital natural resource is imperative to protect the environment and ensure that the current and future populations receive adequate amounts of food and are healthy(Papendick and Parr, 1992). In the future, most of the food and fiber production increases required to achieve global food security are anticipated to be supplied by yield growth per unit area of cultivated land rather than by area expansion (Kopittke et al., 2019). Yet, the soil is a limited source, and intensive farming practices to feed the rapidly growing population are already burdening soils (Spiertz, 2009; Kopittke et al., 2019). This intensive manner of cropping systems conducted over an extended period of time has tended to mine the soil for nutrients and caused an unsustainable degradation of soils (Bot and Benites, 2005; Kopittke et al., 2019). Thus, soil nutrients are depleted due to inadequate efforts to replenish the nutrients extracted from soils through repetitive harvesting of crops and the removal of crop residues used as fuel and fodder rather than being returned to the soil, which causes a decline in soil organic matter levels. The failure to restore organic matter and nutrient contents and maintain a good structure not only declines the soil fertility but also breaks the nutrient cycles and destroys the agroecosystems (Bot and Benites, 2005).

Plant nutrients play a crucial role in crop production and in providing nutritious food for the growing global population. As a result, they are a fundamental aspect of sustainable agriculture, and applying fertilizers and amendments is essential to ensure adequate nutrient supply and maximize yields (Baligar et al., 2001; Chen, 2006). However, due to intensive cultivation practices, many agricultural soils worldwide are deficient in one or more essential elements, and this degradation of land results in reduced fertility and productivity (Baligar et al., 2001).

In terms of nutrient balance, there have been several studies reporting a negative soil nutrient deficit. Vlek et al. (1997) stated that the annual global plant nutrient removal from soil was 230 million tons, while the amount of fertilizer applied annually stood at 130 million tons. Moreover, Tan et al. (2005) reported that nutrient removal from the soil due to crop harvest often significantly surpasses the input from natural replenishment and fertilizers, and the NPK deficit in areas of wheat, rice, maize, and barley production was estimated to stand at 20 million tons (20 Tg) in the year 2000. Since the amount of nutrients removed from soils exceeds the total nutrient supply, more fertilizers will inevitably be used to ensure future sustainable crop production. Daberkow et al. (2000) reported that the total fertilizer usage is projected to rise from 133 million tons per year in 1993 to approximately 200 million tons per year by 2030 to meet future needs. Fertilizer applications must be conducted within the framework of the "4R Nutrient Stewardship" as described by (Reetz, 2016), which requires the right source of nutrients to be given to the right place, at the right rate, and at the right time. This framework aims to create a cropping system to increase farmer profitability, improve environmental protection, and sustainably increase production.

2.2. Fertilizers

Fertilizers can be defined as substances containing one or more essential plant nutrients in available or potentially available forms and possessing properties that can increase soil fertility and productivity (Karagöz, 2021; Roy et al., 2006; Scherer, 2005). The primary purpose of fertilizer use is to increase the quantity of high-quality products per unit of cultivated area, thereby generating income for producers (Karagöz, 2021). As widely recognized, the utilization of fertilizers played a significant role in the realization of food security in recent times (Reetz, 2016). In this regard, Stewart et al. (2005) reported that 30-50% of the total increase in world food production since the 1950s has come about due to fertilizer addition. Similarly, fertilizers have been considered to be responsible for approximately half of the world's crop production, supplying food, feed, fiber, and fuel for a global population that is expected to increase to 9 billion. Also, the extent to which world food production depends on fertilizer use will inevitably increase in the future. Therefore, it can be concluded that ensuring adequate crop production relies on a robust and efficient global fertilizer industry. This industry is crucial in delivering the right nutrients at the right rates, precisely when and where they are needed (Reetz, 2016).

Depending on their nature, fertilizers can be of organic (fertilizers containing organic matter) and inorganic (also referred to as mineral or chemical) origin (Delgado et al., 2016). In general, mineral fertilizers are used more often than organic fertilizers due to their rich plant nutrient content and highly water-soluble properties (Roy et al., 2006; Karagöz, 2021). The main difficulties surrounding the application of organic fertilizers stem from their variable contents in terms of quality and quantity (Allam et al., 2022) and low N-to-P ratio, which can lead to the adoption of excessive application of P, thereby creating environmental problems (Smith et al., 2020).

Although substituting organic fertilizers for chemical fertilizers is considered economically viable and is recognized as an environmentally responsible long-term strategy for sustainable agriculture (Hui et al., 2017; Ning et al., 2017; Wang et al., 2018), their short-term effect on crop yield is slow compared to chemical fertilizers (Khaliq et al., 2006). Considering the fluctuating environmental conditions creating the risk of year-to-year variations in yields, the majority of growers rely on intensive chemical inputs rather than organic fertilizers to preserve yields (Smith et al., 2007).

A. Chemical (Mineral) Fertilizers

Chemical fertilizers are any substance that is partially or wholly of synthetic origin and is incorporated into soils or applied to plant tissues to provide one or more essential plant nutrients to support plant growth or to overcome plant nutrient deficiencies (Kumar et al., 2019; Karagöz, 2021). Although chemical fertilizers are available in solid and liquid forms, they are usually preferred as granules for ease of transportation and storage (Karagöz, 2021). Fertilizer utilization may be traced back to ancient times. People mostly relied on various sources, including white earth, manures, ash residues, mud, dead plants, and legumes, to support agricultural production (Kiiski et al., 2016b). Prior to the advent of mineral fertilizers in the 19th century, soil fertility was primarily sustained through the recycling of organic matter and crop rotations that incorporated nitrogen-fixing leguminous plants (FAO, 2006).

As industrialization and population growth pressured productive soils during the 19th century, agricultural lands gradually became less fertile. In this regard, the need to provide food for the growing world population necessitated the development of new technologies and an intensification of management to produce more food per unit of land (Stewart et al., 2005). These modern technologies included the commercial production of mineral fertilizers from the mid to late 19th century and, eventually, the development of the Häber-Bosch process in the 20th century. The mass production of synthetic ammonia from atmospheric nitrogen via the Häber-Bosch process is considered an essential breakthrough as the demand for nitrogen at the end of the 19th century soon outstripped the availability of natural fertilizers (Tilman et al., 2002; Stewart et al., 2005; Kiiski et al., 2016b). As a natural outcome of this breakthrough, the production of agricultural fertilizers on an industrial scale was initiated, and the fertilizer industry made substantial progress.

Starting from the 1960s, the significant rise in food demand, driven by a substantial increase in the global population and enhanced diets, has been largely addressed through advancements in agricultural productivity, with fertilizers playing a vital role (FAO, 2006). It has been reported that intensive, high-yield agriculture depends on the application of synthetic fertilizers (Tilman et al., 2002), which have sustained nearly half of the world's population (Erisman et al., 2008). According to Tilman et al. (2002), over the past 40 years, global cereal production has doubled, primarily due to increased yields from higher inputs of fertilizers, water, and pesticides, as well as the introduction of new crop varieties and other technologies from the 'Green Revolution'. It has been reported that world fertilizer use has increased almost fivefold since 1960 (FAO, 2006). Therefore, mineral fertilizers are crucial for human survival, as they help produce more and better food, contribute to economic prosperity, enhance human health, and support socio-political stability.

In the context of agronomy, mineral fertilizers present numerous advantages that make them a viable option for agricultural productivity:

a. High water solubility and nutrient content: Due to their higher macro and micro-nutrient content and greater water solubility, they are preferred over organic fertilizers (Karagöz, 2021; Allam et al., 2022).
b. Rapid release of nutrients: The high water solubility feature of chemical fertilizers makes them immediately available to plants (Kumar et al., 2019)
c. Reliability: Commercially used chemical fertilizers are reliable since their content is known (Karagöz, 2021).
d. Increased agricultural productivity: Utilizing the above-mentioned advantages increases agricultural productivity.

Mineral fertilizers are often viewed as a critical solution to combat nutrient depletion and ensure continuous food production (Elka and Laekemariam, 2020). From a fertilization perspective, the nutrients that plants require in large amounts and must be consistently provided through fertilization are particularly important. These include N, K, and P, with Ca, Mg, and S also being required to a lesser extent (Kiiski et al., 2016b). Therefore, most chemical fertilizers produced contain mainly N, P, and K (Morari et al., 2011). Nitrogen and P are the primary rate-limiting nutrients in most natural ecosystems and are key components of agrochemical fertilizers. Excessive human-induced nitrogen (N) and phosphorus (P) inputs have significant ecological and evolutionary effects on natural environments, affecting everything from individual species to entire ecosystems (Guignard et al., 2017). Therefore, close attention should be paid to managing these two nutrients when used in crop production.

Nitrogen fertilizers:

Most N fertilizers are manufactured artificially and contain ammonia produced through the Häber-Bosch process. The Häber-Bosch method produces anhydrous ammonia from the N_2 gas derived from atmospheric air via the chemical reaction [$3H_2 + N_2 \rightarrow 2NH_3$] under high temperature and pressure (Roy et al., 2006; Reetz, 2016). Eventually, the ammonia obtained is used as the primary raw material for most N fertilizers (Reetz, 2016).

Regardless of the type of N fertilizer used, most are transformed (in the soil) into nitrate and ammonium, which are the primary forms of plant-available N. Nitrogen is dynamic and subject to various biological and chemical processes affecting its availability throughout the growing season. While some of these processes make it less available (loss pathways), others make it more phytoavailable. The main pathways leading to N loss encompass volatilization and leaching. Volatilization entails the loss of N into the atmosphere from the soil or growing plants as N_2 gas, ammonia (NH_3), nitrous oxide (N_2O), or NO_x gases. In contrast, N leaching includes the loss of nitrate (NO_3^-) into soil water through leaching or runoff from the soil surface. N also significantly impacts the environment. In surface water bodies, nitrate-N is a key nutrient promoting aquatic plants and algae growth. As these organisms die and decompose, they tie up oxygen in the water, leading to hypoxic conditions that deprive aquatic animals of oxygen (Reetz, 2016). In this context, nitrogen pollution has surpassed numerous thresholds critical for human and ecosystem health. These include limits for drinking water (nitrates), air quality (smog, particulate matter, ground-level ozone), freshwater eutrophication, biodiversity loss, stratospheric ozone depletion, climate change, and coastal ecosystems (dead zones). Thus, human alterations to the global nitrogen cycle have significant repercussions. While there are benefits regarding increased food production, there are also considerable costs, including negative impacts on human health, biodiversity loss, and climate change (Erisman et al., 2013). Consequently, implementing fertilizer best management practices (FBMPs) for applying plant nutrients is essential to enhance nutrient use efficiency and reduce negative environmental impacts.

Phosphorus fertilizers:

As widely recognized, P is a macronutrient that plays a vital role in the growth and development of plants, and its deficiency hampers food production. Currently, most phosphorus-containing fertilizers rely on P derived from phosphate rock (PR), a non-renewable resource (Roy et al., 2006; Cordell et al., 2009). In this context, several scientists have stated conflicting estimates regarding the longevity of these finite resources. According to Van Kauwenbergh (2010), the existing phosphate rock reserves will be available for the next 300-400 years, while others stated that the current reserves will be depleted in less than 200 years (Roy et al., 2006; Cordell et al., 2009).

When phosphate rock (PR) is applied directly, its water solubility is often insufficient to meet the needs of growing crops. Therefore, phosphate-containing fertilizers undergo various reactions in the soil to be converted to plant-available forms (inorganic phosphate) and become agronomically and economically effective nutrient sources for crops. Most contemporary P fertilizers are treated with sulfuric or phosphoric acid to improve their uptake and solubility and prevent their fixation into insoluble compounds; therefore, they are highly soluble (Reetz, 2016).

The dynamic phosphorus cycle in the soil-crop system is influenced by continuous physical, chemical, and biological processes affecting the quantity and form of P in the soil (Reetz, 2016). It is well-known that plants do not take up 80-90% of mineral phosphorus fertilizers applied to the soil because they get adsorbed onto iron oxides/hydroxides, aluminum hydroxides, calcium, and magnesium carbonate surfaces or precipitate chemically. This leads to the formation of poorly soluble iron-phosphates (strengite) and aluminum-phosphates (variscite) in acidic soils and calcium-phosphates in alkaline soils (Balemi and Negisho, 2012). As a result, crops typically recover phosphorus from fertilizers by only 10-20% in the short term. Plants utilize a small amount of the P applied to the soil within the year of application, while a significant amount remains as 'residual P' (Bouwman et al., 2009). Although this reserve (residual phosphorus) can supply P to crops for many years, it has negative environmental implications. Excess P can move into water bodies due to heavy rainfall, soil erosion, runoff, and leaching, leading to algal blooms and eutrophication. This creates hypoxic zones that kill fish, shrimp, and other aquatic life (Bouwman et al., 2009; Reetz, 2016). Consequently, improving P use efficiency in crop production is essential to mitigate the environmental impacts of P fertilizers and waste, enhance the nutritional value of grains, and boost farm economies.

B. Fertilizers Containing Organic Substances

Organic fertilizers are defined as materials primarily obtained from agricultural by-products of plant and animal husbandry (Roy et al., 2006; Larramendy and Soloneski, 2019) including manures made from cattle dung, animal excreta and wastes (horns, bone meal, blood meal, hide meal, feather meals, met and carcass meal and guano), rural and urban wastes, composts, crop residues and even green manures(Roy et al., 2006; Kiiski et al., 2016a). The most commonly used organic fertilizers include manure, slurry, green manure, post-fermentation waste, and compost (Ciesielczuk et al., 2015).

Unlike synthetic and rapid-release fertilizers containing high contents of highly-soluble nutrients and, more specifically, N (Karagöz, 2021; Shaji et al., 2021), most organic fertilizers contain a balanced amount of raw nitrogen and thus work as slow-release fertilizers (Shaji et al., 2021). Inherently, organic fertilizers reduce the risk of overfertilization (Shaji et al., 2021) and provide various other advantages:

- Altering soil quality by improving soil microbiological, physical, chemical, and biochemical properties.
- Sustaining soil fertility through replenishment of organic matter loss in the short- and long-term.
- Minimizing environmental damage (reduced water and groundwater contamination) without compromising crop yield and achieving sustainable agricultural production levels.
- Enhancing soil nutrients and enabling healthy growth with minimum nutrient densities.

Although various methods follow the same fundamental attributes when classifying organic-based fertilizers, the literature uses different terminology. According to the European Consortium of Organic-Based Fertilizer Industry (ECOFI), organic-based fertilizers are classified under three major groups (ECOFI, 2020; Karagöz, 2021).

a. Organic fertilizer: a fertilizer principally designed to supply nutrients in organic forms from organic substances originating from animals and/or plants.
b. Organo-mineral fertilizer: a fertilizer formulated into liquid or solid forms (except for dry mixes) by combining one or more mineral fertilizers with one or more organic fertilizers and organic soil improvers.
c. Organic soil improver: a soil conditioner containing high rates of carbon-rich materials of plant and/or animal origin whose main task is to preserve or increase the soil organic matter content.

2.3. Soil Organic Matter and Fertilization

Soil organic matter consists of any plant or animal material that is returned to the soil and undergoes decomposition. This biological process involves the physical breakdown and biochemical transformation of complex organic molecules from dead materials into simpler organic and inorganic molecules (Bot and Benites, 2005). In other words, soil organic matter's generation consists of a complex network of relationships from soil microorganisms to soil minerals (Coonan et al., 2020). The ecosystem and soil properties influence the total amount of organic matter. In a given ecosystem, the speed and rate of organic matter decomposition and accumulation are dictated by soil microbial (biological) activity, the quality of organic matter, and soil physical and chemical properties such as texture, pH, temperature, moisture, aeration, and clay mineralogy (Brussaard, 1994; Bot and Benites, 2005).

Although most soils contain low amounts of soil organic matter (SOM), it is considered an essential indicator of soil quality exerting profound effects on various soil biological, physical, and chemical properties (Gong et al., 2009; Brady and Weil, 2017). Organic matter performs various significant tasks within soils. From an agricultural standpoint, it is important for two main reasons: (i) it acts as a 'revolving nutrient fund' and (ii) it helps improve soil structure, maintain soil tilth, and reduce erosion (Bot and Benites, 2005). In the context of plant nutrition, organic matter performs two main functions as revolving nutrient storage:

i. As organic matter originates mainly from plant residues, it contains all essential plant nutrients. Hence, it acts as a nutrient storage. Specifically, SOM serves as the primary reservoir for nutrients such as N and S, and in many soils, it also plays a crucial role in storing P (Bot and Benites, 2005; Gerke, 2022). Almost all the nitrogen and significant amounts of phosphorus and sulfur in soils are part of SOM. Soil organic matter is the main long-term storage and the primary short-term source of these and other nutrients (Weil and Magdoff, 2004).
ii. Crop residues are a vital source of plant nutrients released through mineralization (Weil and Magdoff, 2004). The stable organic fraction, or humus, adsorbs and retains these nutrients in a form that plants can easily access. Upon decomposition, it releases nutrients in a plant-available form (Bot and Benites, 2005; Gerke, 2022). This is particularly true for micronutrients like iron (Fe), copper (Cu), and, to some extent, zinc (Zn). Therefore, SOM is crucial in determining the availability of the aforementioned micronutrients to plants (Gerke, 2022).

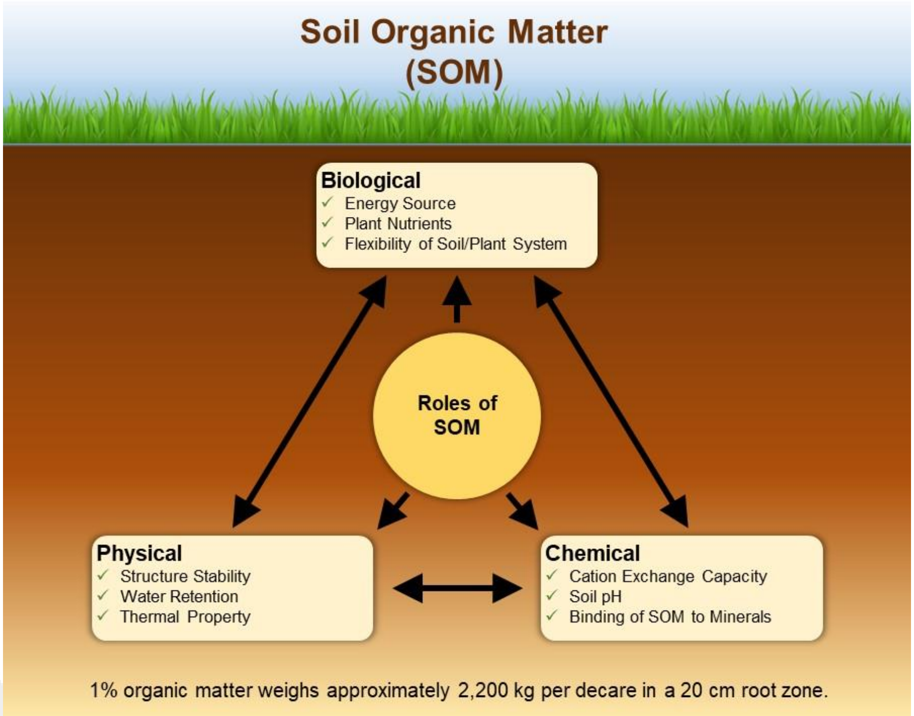

Figure 2.1. Soil organic matter and its relationships with physical, biological, and chemical processes in soil (Adopted from Emad Morsy, 2022)

In light of the information above, it can be concluded that maintaining an adequate level of soil organic matter (SOM) directly enhances cropping systems' long-term sustainability and productivity (Manna et al., 2003; Lal, 2006). However, intensive conventional farming practices lead to losing organic matter (Kopittke et al., 2019). In a global meta-analysis, Kopittke et al. (2017) studied the effects of long-term land use on the changes in soil stocks of organic C, total N, total P, and total S. The authors reported that due to the conversion of native vegetation to cropping (long-term cropping), the average C, N, P, and S stocks decreased by 43%, 42%, 27%, and 33%, respectively. The data underline the correlation between soil OM and the soil's inherent fertility. Consequently, these types of systems cause a gradual decrease in soil fertility in the long term due to the loss of OM, leading to high dependence on fertilizer application.

Although fertilization is a necessary practice for farming activities and significantly increases crop yields (Dai et al., 2013; Guo et al., 2019), utilization of different fertilizers (organic and mineral fertilizers) results in alterations in soil pH, soil nutrient contents, soil water content, and microbial species (Beauregard et al., 2010; Creamer et al., 2015; Ding et al., 2016; Guo et al., 2019). This, in turn, affects the decomposition, transformation, and turnover of soil organic matter (SOM) and organic carbon by soil microorganisms. Microbes play a crucial role in soil biochemical processes. Their abundance, activity, and composition are often closely linked to soil organic carbon mineralization, which is directly influenced by fertilization (Simonsen et al., 2015; Guo et al., 2019). Previous studies reported that long-term application of mineral and organic fertilizers significantly influences microbial communities' activity, size, diversity, and relative abundance (Fan et al., 2012;

Ding et al., 2016; Dai et al., 2017; Guo et al., 2019). Specifically, fertilization was found to alter the microbial community of nitrogen-fixing rhizobium bacteria (Simonsen et al., 2015), cellulolytic fungi (Fan et al., 2012), and methanotrophic bacteria (Hu and Lu, 2015). Moreover, Beauregard et al. (2010) reported that long-term phosphorus fertilization influences the composition of soil fungi and bacteria communities through impaction on the soil environment but does not affect the arbuscular mycorrhizal (AM) fungi community.

2.4. Organic Matter-P Relations in Soils and Plants

In terms of agricultural crop production, P stands out as the second most important macronutrient after nitrogen in limiting yields (Holford, 1997; Balemi and Negisho, 2012) and hence regarded as a significant variable in achieving high crop yields (Pelá et al., 2017). However, P is affected by several fertility problems. Although P is present in abundant amounts in many agricultural soils, its total content is relatively low, and the P compounds commonly found are highly insoluble, making it mostly unavailable for plants (Vance et al., 2003; Havlin et al., 2016; Brady and Weil, 2017). Due to its high reactivity, P mobility and availability are low and can be impacted by numerous factors (Havlin et al., 2016; Figure 2.2). As depicted in Figure 2.2, precipitation-dissolution and adsorption-desorption reactions control the availability of inorganic-P ($H_2PO_4^-$, HPO_4^{-2}) to plants. Moreover, P can be adsorbed to clay minerals (especially 1:1 clays) and other mineral surfaces, rendering it unavailable for plant uptake.

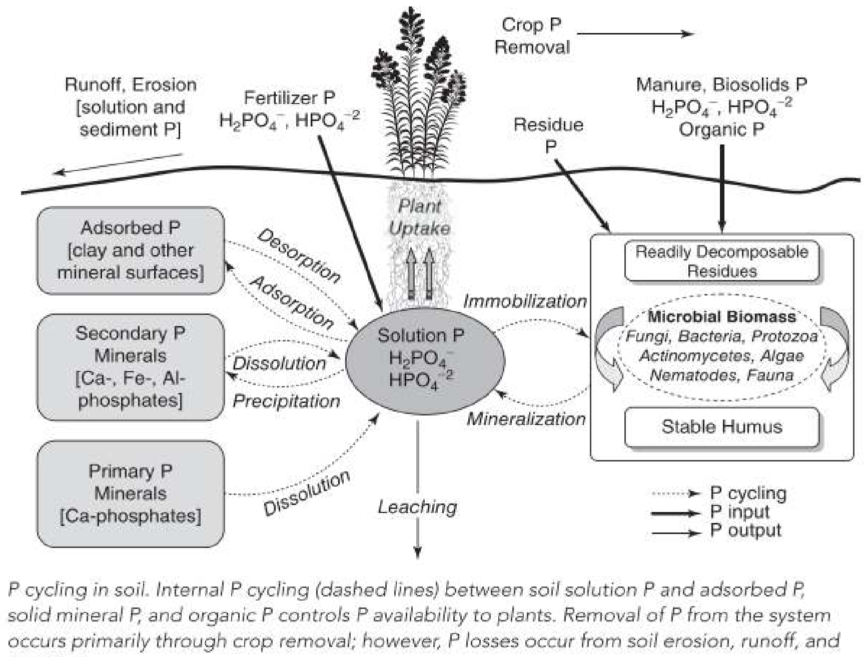

Figure 2.2. P cycle and dynamics

The movement of P and P-fixation reactions in soils varies according to soil types and is highly related to soil pH (Brady and Weil, 2017, Figure 2.3). In acid soils (pH<7), P solubility is reduced due to its adsorption on Fe^{3+}, Al^{3+}, and Mn^{3+} oxide surfaces (fixation) and precipitation as insoluble Fe/Al-P compounds ($Al/FePO_4 \cdot 2H_2O$). Conversely, in calcareous soils (pH>7), soluble $H_2PO_4^-$ rapidly undergoes precipitation reactions with Ca and Mg, thereby forming insoluble Ca and Mg phosphate precipitates (Hinsinger, 2001; Balemi and Negisho, 2012; Havlin et al., 2016; Brady and Weil, 2017).

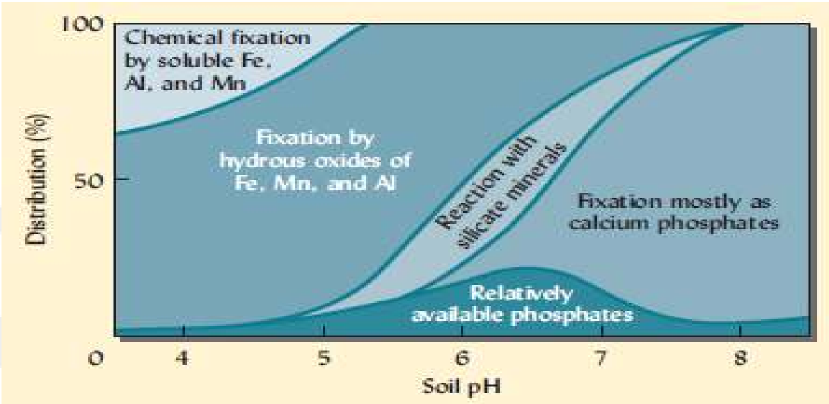

Figure 2.3. Phosphorus availability and pH

In this context, the major portion (80-90%) of mineral P fertilizers applied to soils cannot be absorbed by plants, which is why the recovery of applied mineral P by crops within the same growing season does not exceed 20% (Balemi and Negisho, 2012). To overcome this inefficiency and achieve the desired crop productivity, farmers use higher rates of fertilizers (Izhar Shafi et al., 2020). This, in turn, creates residual soil P pool, which can contribute to the eutrophication of water bodies (Cordell et al., 2009; Elser and Bennett, 2011; Chowdhury et al., 2014; Rowe et al., 2016; Conijn et al., 2018; Zhou et al., 2021). Enhancing P utilization efficiency in plants is crucial for boosting crop yield and quality, lowering nutrient input costs, and addressing environmental issues (Baligar et al., 2001).

However, applying fertilizers at rates exceeding plant needs can have several drawbacks. To begin with, modern agriculture relies heavily on phosphate rock as the primary source of commercial P fertilizers, a finite and non-renewable source (Cordell et al., 2009), raising concerns regarding the longevity of the available phosphate rock reserves. On this matter, some scientists (Cordell et al., 2009; Stewart et al., 2005b) stated that current reserves would be exhausted in the next 50-100 years, while Van Kauwenbergh (2010) pointed out that the current phosphate rock reserves will be available for another 300-400 years. Furthermore, the widely recognized view that the quality of remaining PR reserves is declining and the production costs are increasing further emphasizes the situation's fragility (Cordell et al., 2009).

The cycling of organic matter is recommended as an efficient strategy to improve P availability in soils with low P levels (Brady and Weil, 2017). Therefore, there have been efforts to enhance the OM levels of agricultural soils. It has been reported that the long-term addition of organic amendments causes significant increases in soil organic matter (SOM) content (Lu, 2015; Li et al., 2021; Zhang et al., 2022). Moreover, the utilization and addition of different organic sources in long-term, and short-term experiments have proved to be significantly effective in improving P availability and use efficiency (Guo et al., 2018; Andriamananjara et al., 2019).

Even though OM has little capacity to firmly fix phosphate ions, utilizing the ameliorating properties of organic sources, particularly the decomposable materials, might reduce phosphorus fixation through various mechanisms (Brady and Weil, 2017). The primary mechanisms involved in decreasing P fixation and improving P uptake could be attributed to a) reduction in soil P fixation caused by organic anions released during microbial decomposition/mineralization of SOM, b) gradual release (slow release) of P which entails that the immediate fixation is avoided, c) improved soil moisture conditions that increase the rate of diffusion of P ions into the soil solution, d) more extensive root architecture (geometry) induced in the presence of organic materials, thereby increasing P interception by the plant roots, e) chelation of reactive metals such as Al and Fe (Canellas and Olivares, 2014; Brady and Weil, 2017; Andriamananjara et al., 2019).

a. **Microbial activity:** As organic substances go through microbial decomposition, P is released slowly and can be taken up by plants before they are fixed by the soil (Brady and Weil, 2017). During the breakdown and decomposition process of organic materials, humic substances (HS) are formed. Humic substances (humic acids, fulvic acids, and humins) are a significant component of SOM (60-80%) and represent the stable part of soil organic carbon (SOC) (Brady and Weil, 2017; Urrutia et al., 2020; Gerke, 2022). The enhanced availability of P, and thus plant P uptake, is attributed to the increased microbial activity promoted by organic matter, which acts as a C substrate for microbial biomass (Liu et al., 2009; Andriamananjara et al., 2019). Likewise, various scientists have underlined that humic substances as carbon-rich materials serve as substrates for microbes, thereby exerting positive influences on soil microbial population and diversity. Maji et al. (2017) demonstrated that applying humic-acid-rich vermicompost (HARV) substantially increases the number of fungal and bacterial populations in the rhizosphere and soil respiration. Similarly, Sellamuthu and Govindaswamy (2003) reported that incorporating humic acids into a calcareous soil markedly increased the soil microbial population (bacteria, fungi, and actinomycetes) in the sugarcane rhizosphere, along with phosphatase enzyme activity in the soil treated with humic acid. Also, Li et al. (2019) carried out a long-term experiment over three consecutive years to investigate the effect of the humic acid application on available phosphorus(AP), total phosphorus, soil phosphatase activity, and microbial community. The experiment underlined that the application of humic acid led to increments in the contents of available P and total P year by year and reached statistically significant levels in the third year. Furthermore, compared with the control treatment, the phosphatase activity was significantly affected by the introduction of humic acid throughout the experiment. Additional benefits of humic acids include enhancing soil physicochemical properties, such as aggregate stability, porosity, and pH, which ensure adequate nutrient supply and aeration for microbial reproduction, thereby fostering a favorable environment for the growth of P-solubilizing microorganisms (Yang et al., 2021).

b. pH: The solubility and behavior of mineral P in soils are highly dependent on the soil pH and redox potential, which in most cases result in the fixation of P under both acidic and alkaline conditions, restricting its availability (Guo et al., 2018; Zhang et al., 2021b). In this regard, due to their strong buffering capacity, humic acids can be utilized to bring the soil pH range in the upper 0-20 cm to the range most beneficial to the supply of P (Garcıia-Gil et al., 2004). Adding humic acid has lowered the pH value of alkaline soils thanks to its carboxyl groups, which release H+, thereby neutralizing the OH^- in the solution concentration (Motojima et al., 2012). In acidic soils, applying humic acids can increase the soil pH and phosphorus solubility while reducing the solubility of Fe and Al (Ifansyah, 2014).

c. Microsite acidification: Long-term application of organic amendments (straw and/or manure) tends to enhance P availability by increasing the Olsen-P and total P concentrations of soil, reducing soil maximum P sorption capacity (S_{max}), and creating a slight and/or microsite acidification in calcareous soils (Guo et al., 2018; Yan et al., 2018; Zhang et al., 2022). Soil microsite acidification, in turn, promotes the conversion of Ca-P into Al/Fe-P in different soils (Yang et al., 2015; Liu et al., 2017; Chen et al., 2018). In a recent study, Zhang et al. (2022) reported a significant conversion of Ca-P into Fe/Al bound P due to manure application to a calcareous soil. They attributed this change to a high proportion of humic-like substances in the dissolved organic matter (DOM) in the 0-20 cm manure-treated soil.

d. Metal oxides: Phosphorus interaction with soil is significantly influenced by metals like Al and Fe, which govern both plants' P uptake and its environmental behavior (Hiradate and Uchida, 2004). Humic substances are abundant in oxygen-containing functional groups and surface charges, enabling them to form strong interactions with metal oxides in the soil (Yang et al., 2021). Consequently, such interactions increase the competition between humic substances and phosphate ions for adsorption sites and lead to a reduction in the adsorption rate of phosphates on various soil minerals (goethite and aluminum hydroxide) (Guan et al., 2006; Antelo et al., 2007). Likewise, Yan et al. (2016) investigated the effects of P fixation by iron oxides (FeO) by coating goethite and ferrihydrite with humic acids. The results revealed that the presence of humic acid decreases the specific surface area of FeO (especially amorphous FeO) hence the adsorption capacity of FeO. Phosphate and organic matter compete for adsorption on metal (hydr)oxides. As SOC content increases, phosphate solubility also increases. Overall, adsorption interactions significantly influence phosphate (PO_4) solubility and the soil's stabilization of organic matter and phosphate (Regelink et al., 2015). Brady and Weil (2017) demonstrated that the large humic molecules could reduce the sorption of P in soils by covering the fixation sites and preventing them from interacting with P (Figure 2.4.).

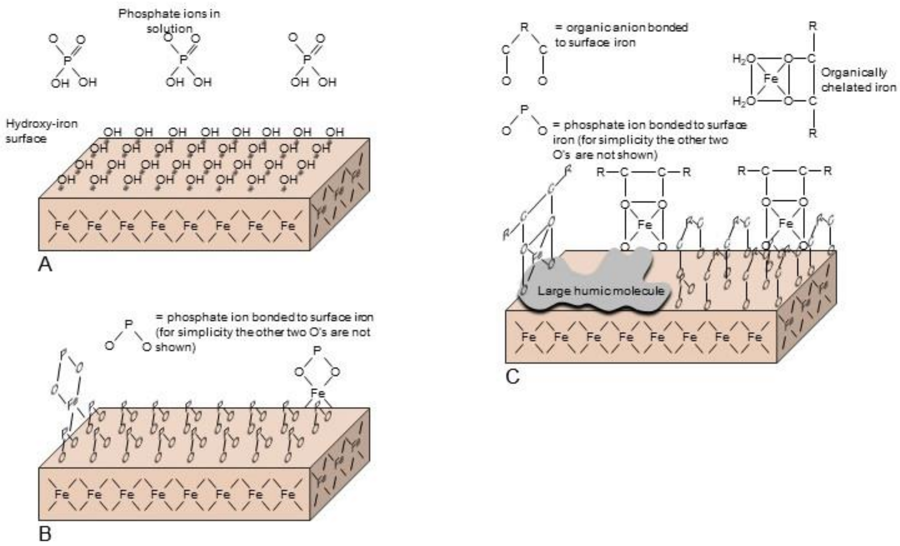

Figure 2.4. The interaction between humic acid (HA), a large organic molecule, and phosphorus fixation induced by hydroxy iron is the primary cause of phosphorus fixation. The phosphorus fixation level on the surface covered with organic molecules decreases (Brady and Weil, 2017)

e. Complexation reactions: The beneficial effects of the main functional groups (carboxyls, phenolic hydroxyls, alcoholic hydroxyls, ketones, and quinones) of humic substances (humic acids) (Russo and Berlyn, 1991) are not confined to the competition for adsorption sites and include the complexation reactions as well (Yang et al., 2021). These humic substances have been reported to increase P availability by complexing ions into stable compounds, thereby enabling the P ion to remain exchangeable for plants' uptake (Seyedbagheri, 2010). Such complex reactions have been shown to increase P recovery by preventing the precipitation of P with metal elements such as Ca, Fe, and Al. This mechanism avoids the formation of Ca-P precipitates in calcareous soils (Delgado et al., 2002) and Fe-P and Al-P precipitates under acidic conditions (Hinsinger, 2001; Brady and Weil, 2017), which would otherwise limit the ability of plants to absorb and utilize P. Similarly, Urrutia et al. (2013) concluded that P-metal-humic acid complexes (PMHA) of PFeHA, PAlHA, and PCaHA prepared by combining phosphate, humic acid, and Fe, Al, and Ca, respectively, can provide plant-available P both in the long-term (slow-release) and short term (quick-release). Based on these findings, we can suggest that fertilizers formulated with PMHA complexes could serve as highly efficient phosphorus sources for crops grown in various soil types.

f. Chelation: Phosphorus availability and uptake by plants can be enhanced through the formation of chelates. Chelates are stable organometallic complexes formed when cationic micronutrients react with organic molecules. These organic molecules can be produced by plant roots or microorganisms and released into the surrounding soil. They may also be found in soil organic matter or be synthetic compounds in micronutrient fertilizers, added directly to the soil to improve micronutrient availability. In their chelated form, the cations are protected from reacting with inorganic soil constituents that would cause them to form insoluble precipitates or otherwise make them unavailable for plant uptake. During the chelation process, certain metals such as Fe and Al are entrapped by organic compounds and rendered unavailable to undergo reactions with P ions in solution. Fe, Zn, Cu, and Mn are cations forming metal–chelate complexes (Brady and Weil, 2017).

g. Root growth and activity: In addition to its beneficial effects on P availability in the soil, humic substances encourage root growth and activity, which subsequently lead to increasing either root length or surface area, as depicted in Figure 2.5 (Canellas and Olivares, 2014). Consequently, such changes improve phosphorus uptake by plants at varying degrees as reported by different studies (Barley and Rovira, 1970; Newman and Andrews, 1973; Gahoonia et al., 2001; Brown et al., 2012; Wang et al., 2016).

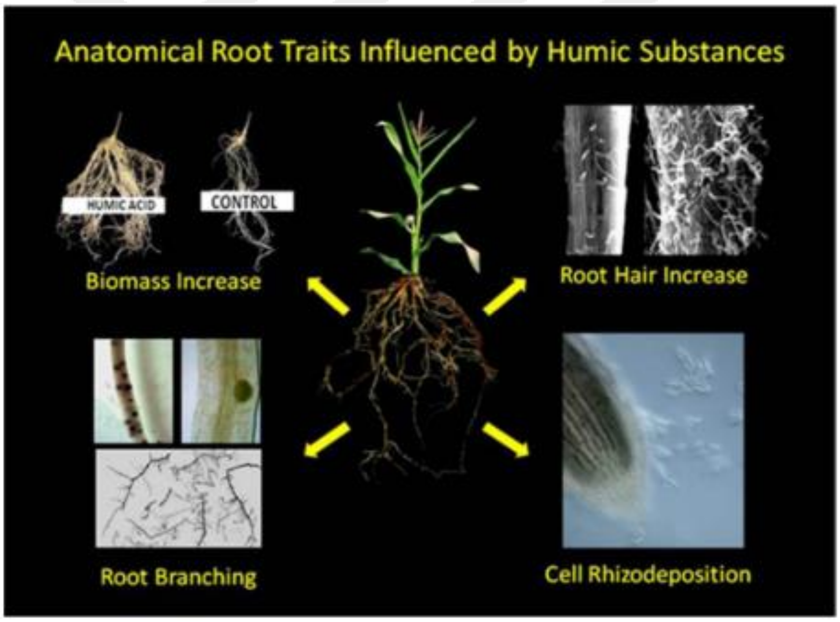

Figure 2.5. The effect of humic substances on root growth and activity (Canellas and Olivares, 2014)

2.5. Organomineral Fertilizers and their Role in Crop Production

Mineral fertilizers are widely regarded as a crucial solution for tackling nutrient depletion and maintaining food production (Elka and Laekemariam, 2020). Yet, due to their high solubility, the use of mineral fertilizers may lead to nutrient losses through volatilization (Lourenço et al., 2016) and/or leaching of N (Xu et al., 2013), fixation and precipitation of P (Andriamananjara et al., 2019), and K leaching (Rosolem et al., 2017). Considering the high cost of mineral fertilizers and their harmful impact on soil microorganisms (Geisseler and Scow, 2014; Elka and Laekemariam, 2020), the attention of various stakeholders has been drawn to the use of organic resources (Suge et al., 2011). Organic fertilizers, particularly those derived from animal production (such as waste or manure), offer an alternative to soluble fertilizers. These fertilizers are characterized by low nutrient concentration and slow nutrient release rate (Antille et al., 2014). Manures add organic matter to the soil and, when used correctly, can create conditions for crop production that exceed those provided by mineral fertilizers alone (Reddy et al., 2000; Fernandes et al., 2003; Steiner et al., 2007; Ayinla et al., 2018). For instance, Steiner et al. (2007) found out that applying chicken manure significantly increased the yields of rice (Oryza sativa L.) and sorghum (Sorghum bicolor L.) compared to mineral fertilizers while also improving soil pH and levels of extractable phosphorus (P), calcium (Ca), and magnesium (Mg). However, crop yields are similar in many cases between plots treated with manure and those treated with chemical fertilizers (Eghball and Power, 1999), indicating that both are excellent nutrient sources. Despite its widespread use, manure has several drawbacks. Its low nitrogen (N) to phosphorus (P) ratio often leads to the over-application of P when meeting the N needs of crops, causing environmental issues over time. Additionally, the high application rates required, along with the challenges of transport and application, limit the use of these fertilizers (Mumbach et al., 2020).

One effective practical approach is to combine organic nutrient sources with mineral fertilizers to overcome the limitations of mineral and organic fertilizers. This process, carried out on an industrial scale, produces organomineral fertilizers, which enhance fertilization efficiency (Antille et al., 2013; Sá et al., 2017; Borges et al., 2019; Frazão et al., 2019). Many materials, such as food waste and other industrial wastes obtained from sewage sludge treatment plants and biogas plants, have been used to produce organomineral fertilizers (Chassapis and Roulia, 2008; Rady, 2012; Antille et al., 2014; Kominko et al., 2017; Erenoglu and Haciruestemoglu, 2022). Typically derived from local organic sources, the end product can be granules, pellets, or powder (Crusciol et al., 2020). During the manufacturing process of organomineral fertilizers, their nutrient concentration is increased to be applied in lower amounts, creating a more balanced, stable, and uniform product. As they become commercially available, they will be packaged and labeled with grades clearly stating their precise nutrient composition. This will enable users to apply nutrients at the desired rates needed for any crop. Another advantage is the predictability of nutrient availability rates (Sakurada L et al., 2016; Smith et al., 2020). Adopting organomineral fertilizers presents the simultaneous benefits of supplying a group of macro- and micronutrients and organic matter to the soil. Moreover, the combination of animal manure and mineral fertilizers provides a significant opportunity to reduce the risk of environmental pollution through the recycling of organic wastes, enhance crop yields, improve conditions of degraded arable soils, and maintain the productivity of undisturbed agricultural soils (Abadia Ventura et al., 2020; Smith et al., 2020).

In this regard, numerous studies have been conducted on various crops, reporting that application of organomineral fertilizers often led to either higher or comparable crop yields, soil productivity and nutrient uptake compared to the sole application of mineral or organic fertilizers (Sá et al., 2017; Frazão et al., 2019; Grohskopf et al., 2019; Borges et al., 2020; Crusciol et al., 2020; Bouhia et al., 2023; Erenoğlu et al., 2023; Sitzmann et al., 2024). It should be underlined that the diverse chemical composition and organic structure of organomineral fertilizers cause significant variabilities, preventing broad generalizations about their effectiveness (Benites et al., 2022).

2.5.1. Phosphorus-Containing Organomineral Fertilizers

Owing to the reactive nature of P in the soil, its mobility and availability are limited and can be affected by many factors, including soil texture (i.e., high clay content), mineralogy, pH, P source and application strategy (Baligar and Bennett, 1986; Havlin et al., 2016). For this reason, P is often regarded as the macronutrient with the lowest use efficiency in crop production, with P-fertilizer efficiency generally low, typically ranging between 10–20% in the short term (Chien et al., 2009; Borges et al., 2019). Phosphorus not adsorbed or fixed by soils can be lost through leaching, runoff, and erosion, leading to eutrophication in water bodies (Conijn et al., 2018). The widely accepted view that the quality of remaining phosphate rock reserves is declining and increasing production costs further exacerbates the situation (Cordell et al., 2009). Therefore, enhancing P use efficiency in plants is crucial for improving crop yield and quality, reducing nutrient input costs, addressing environmental concerns such as nutrient loss to water bodies, and extending the lifespan of remaining P reserves.

In this regard, the re-use of secondary P resources, such as pig and cattle manure, poultry litter, and residues of sugarcane processing, has been suggested as an essential practice to deal with the shortage of natural P sources (Withers et al., 2018) and improve P uptake (Singh et al., 1988; Eghball et al., 1996; Dotaniya and Datta, 2014). Hence, it has been stated that organomineral fertilizers effectively and efficiently recycle P from organic residues (Benites et al., 2022). Organomineral fertilizers allow the joint application of mineral and organic fertilizers. Their efficiency is based on the synergy between these two types since the organic fertilizers, even at low rates, through the release of organic compounds such as humic and fulvic acids, could reduce P fixation and precipitation (Delgado et al., 2002; Antelo et al., 2007; Tahir et al., 2011), increase P movement allowing it to be transported to longer distances (Erenoğlu and Dundar, 2020), and consequently, increase its availability in the soil. This concept relies on the idea that organic compounds can occupy P adsorption sites before orthophosphates do, thereby preventing soil P fixation and increasing its availability (Weng et al., 2012; Fink et al., 2016).

Combining mineral P sources with various organic materials obtained from animals (such as manure, poultry litter, and goat/sheep production waste) and/or plants (like sugarcane straw, filter cake, and olive waste sludge compost) in OMF has been shown to decrease P adsorption by soil minerals. This is because organic compounds interact positively with P, which in turn enhances the effectiveness of inorganic P fertilizers in different crops (Koch et al., 2018; Frazão et al., 2019; Araújo et al., 2020; Bouhia et al., 2023). Numerous studies on various crops have reported that the application of organomineral fertilizers often results in greater agronomic efficiency and crop yield compared to the sole use of mineral fertilizers, whereas P uptake by plants did not differ between fertilizers (Sá et al., 2017; Grohskopf et al., 2019; Crusciol et al., 2020). While organomineral fertilizers have been effective in enhancing P availability across different soil types, their superiority over mineral fertilizers is most evident in soils with high phosphorus sorption capacity (PSC) (Frazão et al., 2019; Borges et al., 2020), verifying the phenomenon that the ameliorating effect of organomineral fertilizers on P availability and phosphorus use efficiency (PUE) is highly dependent on the PSC of soils.

For instance, in a field-scale experiment, Izhar Shafi et al. (2020) reported that the joint application of a locally produced humic acid (HA) with single superphosphate (SSP) to a calcareous soil significantly increased wheat grain, straw, biological yield, spike length, number of grains per spike, 1000-grain weight, and plant height and maintained higher plant P concentrations and P uptake compared to sole application of SSP. Similarly, Erenoğlu et al. (2023) conducted a greenhouse trial under calcareous conditions. They underlined that an OMF fertilizer prepared by mixing an organic fertilizer (OF) obtained from a biogas facility and a commonly used TSP caused significantly higher total plant P uptake (mg. P. pot^{-1}) and P accumulation in wheat grains than the TSP alone at P rates close to the application rates adopted under field conditions (25 mg P.kg^{-1} soil). The findings obtained from the study of Erenoglu and Haciruestemoglu (2022) using the same biogas facility-based OF corroborates the promoting effect on both growth and P uptake of wheat plants grown in the same calcareous soil.

2.6. Phosphorus Nutrition and Fertilizer Forms

Phosphorus (P) is a crucial nutrient for plants, significantly influencing both biomass production and the quality of crops (Wang and Chu, 2015). However, phosphorus nutrition of crops is highly challenging, limiting plant growth in both acidic and calcareous or alkaline soils due to the rapid fixation of P into sparingly soluble forms that are not readily accessible to plants (Bertrand et al., 2006; Montalvo et al., 2015). The present study used alkaline/calcareous soils with high clay and CaCO3 content, primarily located in areas under Mediterranean climate or with low rainfall (Wahba et al., 2019). In such soils, plant-available P contents are often low (Lombi et al., 2004), leading to the application of water-soluble fertilizers (WSP) or waste P to increase P in soil solution (Havlin et al., 2016; Erenoğlu et al., 2023).

Currently, most commercial P fertilizers, such as mono ammonium phosphate (MAP) and triple superphosphate (TSP), provide P in a water-soluble form (Everaert et al., 2017). When water-soluble P fertilizers such as TSP, SSP, DAP, and MAP are applied to alkaline soils, they tend to form more crystalline calcium-phosphate (Ca–P) and/or ammonium-calcium-phosphate (NH_4–Ca–P) compounds (Lindsay et al., 1989). For this reason, there has been growing interest in research and development aimed at modifying the physical properties of conventional water-soluble P fertilizers to reduce P fixation by the soil, thereby enhancing P efficiency for plant uptake (Chien et al., 2009). One strategy explored to improve the efficiency of P fertilizers involves using fertilizers in different physical forms, such as granular, powdered, or fluid (Hagin, 1957; Montalvo et al., 2015; Everaert et al., 2017). Given that powdered fertilizers are generally impractical to apply and produce a significant amount of dust during storage and handling, commercial fertilizers are typically used in granular form instead of powders (Havlin et al., 2016; Everaert et al., 2017; Ganetri et al., 2021). Granular fertilizers offer several benefits: they are easy to handle and apply using both machinery and manual methods (Bolland and Gilkes, 2017). Additionally, granules reduce transportation and storage costs, slow down the nutrient release rate, minimize segregation, and enhance the uniformity of the final product (Zhang Zhengqing et al., 2018; Lustosa Filho et al., 2019). Holloway et al. (2001) postulated that granular fertilizers are more prone to precipitation reactions under alkaline conditions as the precipitates form in the area surrounding the granule. In this context, several scientists reported the significance of soil types and point of fertilizer placement to the effect of fertilizer forms (granular, fluid, and powdered applications) (Hagin, 1957; Holloway et al., 2001; Degryse et al., 2017).

Hagin (1957) conducted a greenhouse experiment to evaluate the agronomic effectiveness of superphosphates (16.5% P_2O_5) applied in powdered or granular form to alkaline soils with varying $CaCO_3$ contents. Fertilizers were mixed with the upper half of the soil in each pot. The author reported that the application of superphosphate, either as powder or granules, produced similar clover yields in two alkaline soils with lower $CaCO_3$ (%1.2-%12.8), while higher clover yields were obtained in the alkaline soil with a higher $CaCO_3$ (%39.2) when superphosphate was applied in powdered form. The results gave the impression that two totally different fertilizers were used. Moreover, the findings revealed that the powdered applications caused significantly higher P concentration in plant tissues and higher plant P content per pot in soils.

According to Degryse et al. (2017), MAP applications as granules or powder produced similar shoot dry matter yield, whereas the powdered treatments led to higher shoot P concentration, and P uptake of wheat plants grown on an acidic soil with a weak P sorption capacity (PSC). On the other hand, granular application of MAP caused significantly higher wheat dry matter yield, shoot P concentration, and P uptake compared to powdered treatments on an alkaline soil possessing a higher PSC. These results are attributed to the higher P fixation of powdered applications as the fertilizers are ground and mixed uniformly throughout the soil leading to a higher dilution. In contrast, the granular applications are conducted in bands, thereby providing roots with higher P concentrations during the early growth stages.

Lustosa Filho et al. (2019) manufactured a biochar-based slow-release P fertilizer (BBF) by mixing poultry litter biochar and MgO with TSP (PLB-TSP-MgO). Then, the influence of biochar-based fertilizer and the water-soluble TSP fertilizer, applied in both powdered and granular forms, was investigated on the agronomic effectiveness of maize grown in an Oxisol under greenhouse conditions. The prepared slow-release biochar-based fertilizers showed dry matter yields comparable to that of TSP when applied in powdered form. Still, in granular form, TSP caused significantly higher shoot dry matter yield than the biochar-based fertilizer. In addition, the biochar-based fertilizer applied in powdered form were more effective in increasing shoot dry matter yield than their granular forms. At the same time, there were no statistically significant differences between the forms of TSP. Overall, fertilizer applications in powdered forms showed greater P uptake than their granular applications regardless of fertilizer source (TSP or biochar-based fertilizer). In addition, TSP applications showed greater P uptake compared to biochar-based fertilizers regardless of application forms.

Bertrand et al. (2006) stated that granular fertilizers such as DAP, MAP, and TSP are extensively used. Still, their efficiency under alkaline conditions remains questionable, which prompted his studies to include examining the efficiency of both liquid and powdered fertilizers. The authors found out that the P availability of liquid P fertilizers was higher, which was attributed to the fact that large proportions of P in powder fertilizers (DAP, MAP, and TSP) was fixed into non-labile pools under calcareous conditions, possibly through precipitation of Ca-P compounds which is not plant-available. Another possible reason could be the formation of concentrated zones around the powder, which is likely to be more pronounced in field conditions, where the solubility product of calcium phosphate can be readily exceeded in dry conditions due to slow diffusion and dissolution of P. Applying liquid fertilizers could lead to a more homogenous distribution of soluble orthophosphate ions in the soil, minimizing concentrated zones around the powder particles. Similarly, Lombi et al. (2004) examined the chemistry of the zone around fertilizer granules and liquid droplets. They confirmed that while the dissolution of MAP granules is rapid, fixation of this P into non-labile pools occurs equally fast. Powdered products could also experience this phenomenon, but to a reduced degree.

Furthermore, several other scientists have attempted to test the efficiency of fluid P fertilizers to overcome constraints surrounding P fixation/sorption and precipitation. Application of liquid forms of P fertilizers leads to greater P availability (Holloway et al., 2001) and mobility (Lombi et al., 2004, 2005; Erenoğlu and Dundar, 2020), and superior agronomic performance of crops compared to granular applications in calcareous soils (Holloway et al., 2001; Erenoğlu and Dundar, 2020). Although fluid forms enhanced P diffusion in the acidic soils of andisols and oxisols compared to granular treatments, they do not have any effects on P availability (lability and solubility)

(Montalvo et al., 2014) or agronomic performance of crops (Montalvo et al., 2015). Conversely, it was stated that using fluid P fertilizers improved the concentration of labile and dissolved P in calcareous soils (Montalvo et al., 2014).

2.7. Phosphorus Availability and Soil OLSEN-P Levels

It is widely accepted that soils need a sufficient amount of plant-available P and other nutrients to achieve optimal crop yields and maximize the efficiency of other annual inputs, particularly N fertilizers. (Johnston et al., 2013). To keep plant-available P at adequate levels, high amounts of fertilizers are used each year (Izhar Shafi et al., 2020). Given the low P recovery of fertilizers, most of the fertilizers applied annually remain in the soil, creating a residual P pool, which can create environmental problems (Balemi and Negisho, 2012; Chowdhury et al., 2014). Moreover, increasing fertilizer costs forces farmers to search for alternative solutions to maintain Olsen P at a lower concentration on some soils without losing yield (Poulton et al., 2013). Therefore, understanding the relationship between phosphorus use efficiency and soil phosphorus fertility is highly significant to quantify the optimum soil phosphorus level for the best management strategy of phosphorus resources. Proper management practices, such as precision application and soil testing, are crucial in achieving sustainable agriculture (Shan et al., 2018).

Olsen P is the P value extracted from the Olsen solution (0,5 N $NaHCO_3$), which is used globally to characterize the content of available P in calcareous soils. In many countries, Olsen's method determines plant-available soil P (Olsen, 1954). After the concentration of plant-available P is determined, the results are expressed in mg/L. However, Olsen P is usually indicated in mg/kg as used in the present PhD thesis since data expressed as mg/L or mg/kg are very similar for most mineral soils (Johnston et al., 2013). Following the determination of optimum Olsen P, the soil is assigned to a P Index as indicated in the Fertilizer Manual (RB209) published by (Defra, 2010) and fertilizer P recommendations are conducted accordingly.

The Olsen P level is the main factor influencing crop yield and P-use efficiency (PUE) (Aziz et al., 2020). Determining critical soil P levels is crucial for enhancing phosphorus use efficiency (PUE) and maximizing agronomic yields. The critical soil P level for crop production is the threshold below which crop yield significantly responds to P fertilizer application. In contrast, above this level, the response becomes minimal (Ibrahim et al., 2021). When soil phosphorus (P) falls below the critical level, crops cannot absorb sufficient P for growth, resulting in significant yield reductions (Edmeades et al., 2006). According to Poulton et al. (2013), crop yield can be linked to Olsen P levels and is associated with a certain proportion of the plateau yield deemed the critical level for the specific crop and soil in that year. The Fertilizer Manual (RB209) by Defra (2010) recommends a Target Index of phosphorus (P) at P Index 2 for both arable crops and grass, corresponding to 16–25 mg/L Olsen P.

The critical level of Olsen P usually depends on the crop type (Colomb et al., 2007), target yield, availability of other elements, and location due to differences in soil characteristics and climate (Johnston et al., 2014; Ibrahim et al., 2021). In addition, the models used to determine the agronomic critical values of soil Olsen P cause variations in the estimation of critical OP ranges. These methods include Cate-Nelson, Mitscherlich, and linear plateau (Colomb et al., 2007; Tang et al., 2009; Bai et al., 2013; Johnston et al., 2013; Poulton et al., 2013; Wu et al., 2018).

Findings from Poulton et al. (2013) in long-term field experiments using the Mitscherlich response model demonstrated that sustaining Olsen-P at 20 mg/kg (equivalent to the midpoint of P index 2) in the plow layer of a silty clay loam soil (Chrome Luvisol, FAO classification) (Avery and Catt, 1995) is sufficient to prevent yield loss in winter wheat and spring barley. In contrast, a complementary long-term study by Johnston et al. (2013) utilizing the same model (Mitscherlich response function) advised maintaining the critical OP at 20-25 mg⁄kg (upper half of P index 2) for various crops (winter wheat, spring barley, potato, and sugar beet) grown on heavier textured soils (a sandy clay loam and a poorly structured heavy textured silty clay loam). These results align with the early work (Johnston et al., 1986) conducted on a sandy clay loam (pH 6-5-7-0) reporting that winter wheat's agronomic critical OP level is 20 mg P. kg^{-1}.

In a long-term study (1990–2012), Qihua et al. (2020) used three models (linear-linear and linear-plateau, and the Mitscherlich model) to assess the optimal Olsen P range for maize and maize-wheat cropping in three distinct Chinese soils: a clay loam soil with neutral pH (pH ranged from 6.0 to 7.7), light loam soil with calcareous pH (pH 7.9 to 8.5), and clay soil with very acidic pH (pH 4.0 to 5.7) which are classified by FAO as Luvic Phaeozem, Calcaric Cambisol, and Eutric Cambisol respectively. The results revealed that the optimal Olsen P range for accomplishing high crop yield, PUE, and soil fertility should be 13-40, 10-40, and 29-40 $mg \cdot kg^{-1}$ in soils with neutral, calcareous, and very acidic pH, respectively.

Moreover, Colomb et al. (2007) evaluated the response of grain P concentration and grain yield data of various crops (wheat, maize sunflower, sorghum, and soybean) obtained from a 36-year P experiment to soil Olsen P concentration on a deep alluvial silty-clay/clay soil with varying $CaCO_3$. Based on the results obtained, it was ruled out that the grain P concentration showed an asymptotic increase as a function of soil OP concentration, and the critical OP level determined using the Cate-Nelson and Mitscherlich approaches was at 3.3-7.2 mg $P \cdot kg^{-1}$ and 4.4-11.2 mg. P kg^{-1} respectively. Although the threshold differed for the two methods employed, crops ranked similarly with both methods. There was no significant difference in Olsen-P critical values between the calcareous and non-calcareous parts of the experiment.

Wu et al. (2018) determined the critical OP using two different methods (Linerplateau and Mitscherlich) at 16 winter wheat-maize crop rotation sites in cinnamon soil classified as Luvisols in the FAO system. The crop yield and soil Olsen P were measured yearly for 5-18 years. The mean critical OP value for winter wheat was 14.4 mg kg^{-1} and 14.2 mg kg^{-1} for maize when using the Linear-plateau and Mitscherlich models.

Tang et al. (2009) identified the critical Olsen P values using linear-linear, linear-plateau, and Mitscherlich models for continuous maize-winter wheat cropping systems over a 15-year field experiment in three different calcareous soils with varying pH levels. According to the FAO classification, these soils are Haplic Luvisol (pH 8.2), Calcaric Cambisol (pH 8.3), and Calcaric Regosol (pH 8.6). The average critical values for maize across all experimental sites were 12.0, 13.2, and 20.7 mg P kg^{-1}. They were 12.5, 14.6, and 21.7 mg P kg^{-1} for winter wheat, using the linear-linear, linear-plateau, and Mitscherlich models, respectively.

In a similar study, Shan et al. (2018) conducted a pot trial using loess soils obtained from a 25-year long-term experiment under a winter wheat-summer maize cropping system to test the responses of P use efficiency to soil Olsen P levels. The authors determined that the P use efficiency in the entire winter wheat-summer maize cropping system, dependent on soil Olsen-P levels, closely resembled that of summer maize. The P use efficiency reached 100% at the soil Olsen-P of 18 mg/kg at an annual P application rate of 60 kg·ha^{-1} (wheat 30 kg·ha^{-1} and maize 30 kg·ha^{-1}), and the maximum value of P use efficiency reached 131% at Olsen-P of 40 mg·kg^{-1}. The optimum soil Olsen-P contents are from 17 mg·kg^{-1} to 40 mg·kg^{-1} for winter wheat and from 13 mg·kg^{-1} to 34 mg·kg^{-1} for summer maize in the loess soil of Guanzhong area. For the entire winter wheat-summer maize cropping system, it is recommended to maintain optimal soil Olsen-P content between 17-40 mg·kg^{-1}, along with an annual phosphorus (P_2O_5) application rate of 6-12 kg·da^{-1}.

Ibrahim et al. (2021) reported the critical Olsen P level for maize grown on a clay loam soil (32% clay) identified as Luvic Phaeozems according to FAO system classification to be 28 mg kg^{-1}. The authors underlined that the P use efficiency (%) positively correlated with the Olsen P level and negatively correlated with the P application rate. In summary, phosphorus (P) use efficiency values either slightly increased or remained stable as soil Olsen P levels rose under most fertilization treatments in the study area. However, when soil Olsen P levels are excessively high, P use efficiency declines, resulting in wasted P resources and causing significant environmental issues, such as the eutrophication of water bodies.

3. MATERIALS AND METHODS

3.1. Materials

3.1.1. Experimental Soil

The present study used an Arık series soil, classified as Haplic Vertisol based on World Reference Base (WRB, 2015), and as fine, smectitic, active, mesic Typic Haploxerert according to Taxonomy (2014) published by United States Department of Agriculture. This soil type represents the soils of the Çukurova Region of Adana, Türkiye. Characterized by high pH (7.82), clay content (50%), and calcium carbonate levels (24.4% $CaCO_3$), as well as low organic matter content (1,2%), the experimental soil was obtained from the field, air-dried, and sieved (*4 mm mesh).* Selected physico-chemical properties of the experimental soil are demonstrated in Table 3.1.

Table 3.1. Some of the chemical and physical properties of the experimental soil.

Parameter	**Level**	**Rating**	**Method**
Organic Matter, %	1,2	Low	(Walkley and Black, 1934)
$CaCO_3$, %	24.4	Very High	(Hızalan and Ünal, 1966)
pH (1:2.5 Soil:Water)	7.82	Slightly Alkaline	(Jackson, 1958)
Electrical Conductivity (EC)	0.15 dS m^{-1}	Non-saline	(Jackson, 1958)
Extractable P, kg $P_2O_5 \cdot da^{-1}$	7.7	Moderate	(Olsen, 1954)
Extractable K, kg $K_2O \cdot da^{-1}$	119	High	(Carson, 1980)
Sand-Silt-Clay Contents, %	18-32-50	Clay	(Bouyoucos, 1962)

3.1.2. Plant Material

A bread wheat (*Triticum aestivum L. cv.* Özkan) cultivar was used as a model plant in pot experiments.

3.1.3. Fertilizers

Three types of fertilizers were used in the experiments: i) a P-containing organomineral fertilizer (P-OMF) with17.2% P_2O_5 and 19,5% organic matter, manufactured by mixing 37,5 kg of organic residues derived from a biogas plant (Table 3.2), 37,5 kg of triple superphosphate (TSP; 43% P_2O_5) and 25 kg of quartz sand; ii) triple superphosphate (TSP; 43% P_2O_5), a commercially available P-containing mineral fertilizer (MF); and iii) urea (46% N), an N source. Initially produced as granules, the fertilizers were thoroughly ground into a fine powder depending on the objective of the experiments, as detailed in the methods section.

Table 3.2. Some chemical properties of the solid organic material originating from a biogas plant waste used in the manufacturing of the organomineral fertilizer

Properties	Content (%)
Organic Matter (%)	52
Humic +Fulvic	20
Total N	2
Total P (P_2O_5)	3
Water-soluble K (K_2O)	1
Maximum humidity	35
pH	7,5-8,5
Maximum EC (dS/m)	8

3.2. Methods

3.2.1. Experimental Set Up

3.2.1.1. Effectiveness of P-Containing Organomineral Fertilizers in Growth and P Uptake of Wheat in a Calcareous Soil Differing in P Availability (*Experiment I*)

A pot trial was conducted under greenhouse conditions to investigate the effects of increasing levels of Olsen P on the efficiency of P-OMF and P-MF. The experimental design was completely randomized (RCD) in three factorial (Pre-incubation x Fertilizer Types x P Rates) arrangements. The variables correspond to three pre-incubation levels (0, 20, 40 mg P·kg^{-1} soil), two fertilizer types (OMF and MF), and four fertilizer rates (0, 25, 50, 100 mg P·kg^{-1} soil), with three replicates.

Pre-incubation: Initially, the pots used in the experiments were filled with 3 kg of soil and were treated with TSP at increasing rates of 0, 20, and 40 mg P·kg^{-1} to obtain soils differing in Olsen-P levels. Thereafter, the pots were subjected to a pre-incubation period of 42 days under greenhouse conditions. The pots were irrigated at 70% of field capacity during that period. At the end of the incubation period, the soils in each pot were evenly mixed, passed through a 2 mm sieve, and eventually subjected to Olsen P analysis (Olsen, 1954).

Post-incubation: Following the soil extractable P (Olsen P) determination, the pots were treated with different rates of P-OMF and P-MF before planting. The variables employed in the experiment are given in Table 3.3. The basal P fertilization using MF and OMF for both experiments (*I* and *II*) was done at increasing P rates of 0, 25, 50, and 100 mg P·kg^{-1} soil at 5 cm below the seedbed prior to planting. Urea, an extensively used N source, was applied as both the starter (base) and the top-dressing fertilizer at 150 mg N·kg^{-1} in two split applications: half of it (75 mg N·kg^{-1}) prior to planting and the remaining half (75 mg N.kg^{-1}) at the end of the tillering stage. The seeds were planted at 2 cm depth, with each pot receiving twelve seeds. Next, the thinning was carried out at the seedling stage, leaving 7 plants in each pot. Throughout the experiment, the pots were regularly weighed and watered at 50% of the field capacity during the first week and 80% until the end of the experiment. The experiment was conducted between the 15th of February and the 30th of May 2022 (103 days), utilizing only granular form of fertilizers.

Plant Sampling, Morphological Parameters Recording, and Harvest: The experiment continued until the harvest (physiological maturity). At the end of the tillering stage (Zedoks 29), 45 days after planting, two plants from each pot were cut off (mid-harvest). The plants were washed with deionized water, placed in kraft paper bags, and oven-dried at 65 °C for 48 hours in a forced air-circulation oven until the plants reached their constant weight. Subsequently, the dry weights of samples were recorded, and the plants were ground using a grinder and thoroughly mixed.

Table 3.3. Fertilizer types, pre-incubation levels, and P rates used in *Experiment I*

Fertilizer Types	**Pre-incubation Level mg P·kg^{-1} soil**	**P Rate mg P·kg^{-1} soil**	**Required P Amount mg P·(3 kg)$^{-1}$ soil**
P-OMF (17.2 P_2O_5+ 19.5 OM)	0	0	0
		25	998
		50	1,997
		100	3,994
	20	0	0
		25	998
		50	1,997
		100	3,994
	40	0	0
		25	998
		50	1,997
		100	3,994
P-MF (TSP) (43 P_2O_5)	0	0	0
		25	399
		50	799
		100	1598
	20	0	0
		25	399
		50	799
		100	1598
	40	0	0
		25	399
		50	799
		100	1598

At the physiological maturity stage, morphological components such as plant height, spike length, and number of spikes per pot were taken and recorded. Following this, the wheat harvest was performed, and the grain and straw samples were collected separately and dried in an oven at 65 °C until constant weight. Thereafter, kernels were manually threshed from the husks. Finally, the grain yield and straw yield (shoots + husks), and biological yield (straw yield + grain yield) were determined separately, expressed in g.pot^{-1}, and homogenously ground using a grinder.

Nutrient Analysis: Subsamples of shoots taken at the tillering stage, straw, and grains were subjected to chemical analyses, and their primary macronutrient (N, P, K) concentrations were determined. Nitrogen concentrations were quantified using the Kjeldahl method (Bradstreet, 1954). While P concentrations were determined using UV-visible spectrophotometry following the procedure employed by Olsen (1954), K concentrations were determined using AAS (Atomic Absorption Spectroscopy). Eventually, the N, P, and K contents in straw and grains were calculated by multiplying their respective concentrations with the corresponding dry weights and were expressed in mg·pot^{-1}. In contrast, total uptakes of N, P, and K were calculated by summing their contents in grain and straw and expressed as mg·pot^{-1}.

3.2.1.2. Comparisons of Granular and Powdered P-Containing Organomineral Fertilizers for Growth and P Uptake of Wheat in a Calcareous Soil (*Experiment II*)

This experiment consists of a pot trial conducted under greenhouse conditions. The purpose of the present trial is to assess the effects of different fertilizer types (P-OMF and P-MF) and forms (granular and powdered) on the agronomic performance and P uptake of wheat plants. Although pot size (3 kg of soil per each), fertilizer types, and P rates remained the same as in *Experiment I*, different forms (granular and powdered) of the fertilizers were introduced as an additional variable in *Experiment II*. The information regarding the experimental variables, including fertilizer types, fertilizer forms and P rates, is provided in Table 3.4. *Experiment II* was carried out over 128 days from December 8, 2023, to April 25, 2024, until the plants reached maturity.

Table 3.4. Fertilizer types, forms, and P levels used in *Experiment II*

Fertilizer Types	Fertilizer Forms	P Level (mg P·kg^{-1} soil)	Require P Amount (mg P·[3 kg^{-1}] soil)
P-OMF (17.2 P_2O_5+ 19.5 OM)	Granular	0	0
		25	998
		50	1,997
		100	3,994
	Powdered	0	0
		25	998
		50	1,997
		100	3,994
P-MF (TSP) (43 P_2O_5)	Granular	0	0
		25	399
		50	799
		100	1598
	Powdered	0	0
		25	399
		50	799
		100	1598

The procedures for pot fertilization, seed planting, seedling thinning, irrigation, plant sampling, recording of morphological parameters, harvesting, and determining the mineral nutritional status of wheat plants through chemical analyses followed the same methods as in *Experiment I.* However, in *Experiment II,* an extra SPAD reading was conducted on flag leaves during the middle of the boot stage. Additionally, parameters such as Harvest Index (HI) and Phosphorus Harvest Index (PHI) were calculated using the following formulas:

A) Harvest Index (%) = (Grain yield/Biological yield) × 100
B) Phosphorus Harvest Index (%) = (P uptake by grain / P uptake by total plant biomass) × 100

3.2.1.3. Effect of P-Containing Organomineral Fertilizer Forms (granular and powdered) on Olsen-P Levels of a Calcareous Soil (*Experiment III*)

In this part of the study, as described below, an incubation trial parallel to *Experiment II* was carried out to test the effect of different forms (Granular and Powdered) and rates (0, 25, 50 100 mg P·kg^{-1} soil) of OMF and MF on $NaHCO_3$-Extractable P levels (Olsen-P) of experimental soil.

The present incubation study was conducted in containers filled with 300 g of soil, and the experimental design was ultimately the same as *Experiment II*. Details on the experimental variables, including fertilizer types, fertilizer forms, and P rates, are shown in Table 3.5. In addition, the timing and the rate of N application as a base and top-dressing fertilizer in *Experiment II* were also adopted/mimicked in the present trial. In this regard, 150 mg N·kg^{-1} soil was added to the containers: 75 mg N·kg^{-1} soil just before the establishment of the experiment and 75 mg N·kg^{-1} soil (45) days after the experiment, corresponding to the top-dressing nitrogen fertilization in *Experiment II*.

The containers were regularly weighed and watered at 50% of the field capacity during the first week and 80% until the end of the experiment. At the end of the 45-day and 128-day incubation periods, the soil samples in the containers were dried in an oven at 40 °C, homogeneously mixed, air dried, passed through a 2mm sieve, and subjected to $NaHCO_3$-Extraction (Olsen-P analysis) following the procedure designed by Olsen (1954).

Table 3.5. Fertilizer types, forms, and P levels used in *Experiment III*

Fertilizer Types	**Fertilizer Forms**	**P Level (mg P·kg^{-1} soil)**	**Require P Amount (mg P·[0.3 kg]$^{-1}$ soil)**
P-OMF ($17.2\ P_2O_5$+ 19.5 OM)	Granular	0	0
		25	100
		50	200
		100	400
	Powdered	0	0
		25	100
		50	200
		100	400
P-MF (TSP) ($43\ P_2O_5$)	Granular	0	0
		25	40
		50	80
		100	160
	Powdered	0	0
		25	40
		50	80
		100	160

3.3. Statistical Analysis

The data obtained in this thesis study were subjected to a three-factorial analysis of variance using the R statistical program to reveal the effects of each variable in each experiment, including all possible combinations of variables. After that, the results were statistically compared for each experiment using the Duncan test following two-way and one-way variance analysis with different variables, as explained below.

In *Experiment I*, after three-way ANOVA, a two-way analysis of variance was conducted for each *soil P fertility level* (MODERATE-P, HIGH-P, and VERY HIGH-P) using fertilizer types and P rates as variables. The results obtained from these analyses were then compared using the Duncan test. Thereafter, at each soil P fertility level for each fertilizer type, the means of fertilizer rates were compared using a one-way analysis of variance followed by the Duncan test.

For *Experiments II* and *III*, two-way ANOVA analysis was run for each *fertilizer form* (granular and powdered) using fertilizer types and P rates variables, as in *Experiment I*. As in Experiment I, the results obtained from these analyses were compared using the Duncan test. Thereafter, in each fertilizer form for each fertilizer type, the means of fertilizer rates were compared using a one-way analysis of variance followed by the Duncan test.

4. RESULTS AND DISCUSSION

4.1. Effectiveness of P-Containing Organomineral Fertilizers in Growth and P Uptake of Wheat in a Calcareous Soil Differing in P Availability (*Experiment I*)

In this part of the thesis, the experimental soil was incubated with increasing amounts (0, 20, and 40 mg P·kg^{-1} soil) of a mineral P fertilizer (triple super phosphate-TSP) over a 42-day incubation period to obtain soils differing in P fertility level. As seen in Table 4.1., Olsen-P levels of the experimental soil enhanced with increasing P applications. They were 10.2, 16.4, and 24.1 ppm (mg P·kg^{-1} soil), respectively, showing that the soils used in the experiment had significantly different P fertility statuses.

Table 4.1. Plant-available P (Olsen P) concentrations (Values are the means of three independent replicates ± SE. Small letters show the significant differences between pre-incubation rates according to data obtained with one-way ANOVA followed by Duncan's test using R statistical software) and P fertility statuses of experimental soils pre-incubated with 0, 20, and 40 mg P·kg^{-1} soils over a 42-day incubation period.

Pre-incubation Rate (mg P·kg^{-1})	Olsen P (mg P·kg^{-1}) ±SE	Soil P Fertility Status
0	10.2±0.0 *a*	Moderate
20	16.4±0.4 *b*	High
40	24.1±0.0 *c*	Very High

4.1.1. Plant Growth Parameters and Yield

4.1.1.1. Tillering Stage

The three-way ANOVA results testing the effects of various soil P fertility levels, fertilizer types, and P rates, as well as their interactions, on the shoot dry weights of wheat plants, harvested 45 days after planting (at the end of the tillering stage), are presented in Appendix 1. Phosphorus fertility levels, P rates, and their interaction (SOIL P*RATE) significantly affected shoot dry weight. However, the individual effect of fertilizer types and all other interactions involving fertilizer types, except for SOIL P*FERTYPE, were not statistically significant.

The results showing the effects of different fertilizer types and P rates on wheat shoot growth over 45 days at each P fertility level are given individually in Figure 4.1. Although soils with different P fertility levels were evaluated separately, it was obvious that the effectiveness of fertilizer types and application rates diminished as fertility levels increased. Fertilizer types significantly influenced the shoot dry weight of wheat grown in soils with moderate P fertility (10.2 mg P·kg^{-1} soil), with P-OMF outperforming P-MF (Figure 4.1A). Yet, these differences between fertilizer types disappeared in the plants grown in soils with high P fertility (pre-incubated with 20 mg P·kg^{-1} soil; Figure 4.1B) and very high P fertility (40 mg P·kg^{-1}; Figure 4.1C). The mean shoot dry weights of plants grown at moderate P fertility, where statistical differences between P-OMF and P-MF were identified according to the two-way ANOVA, were further analyzed through one-way ANOVA. In this analysis, the differences between increasing treatment rates are shown by lowercase letters in the graph. The P-OMF produced superior results compared to P-MF at each P rate (Figure 4.1A).

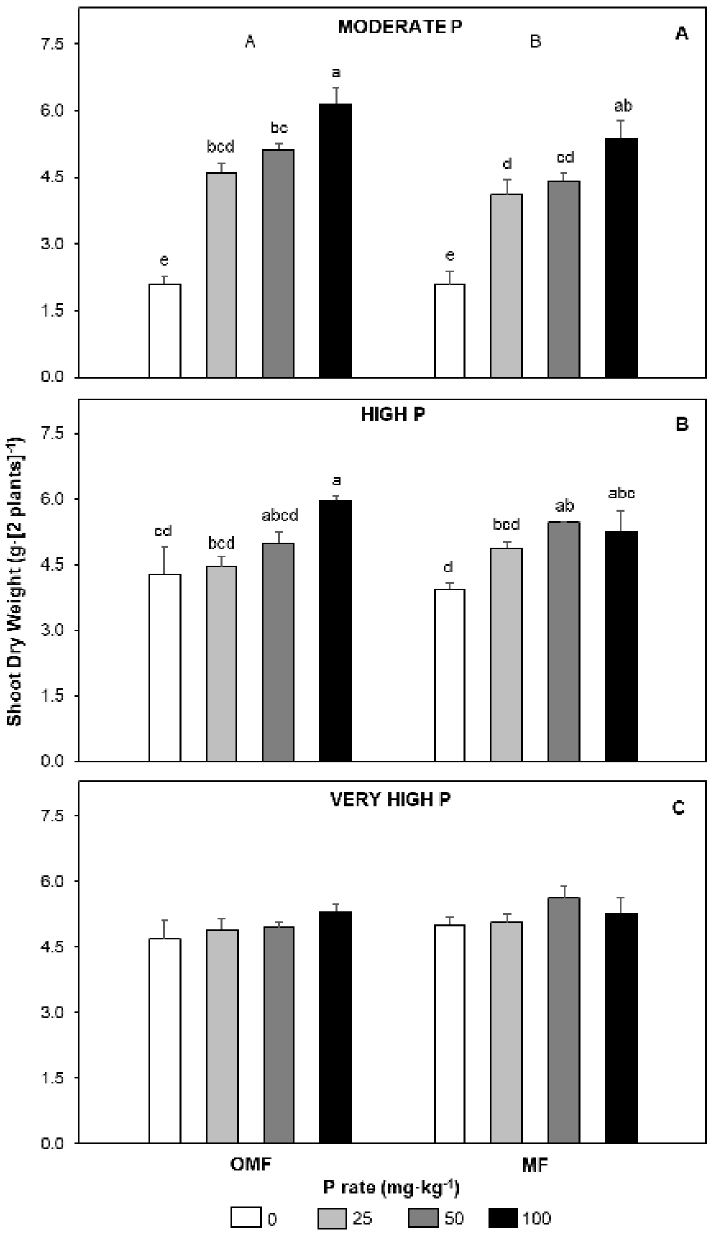

Figure 4.1. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot dry weight (g·[2 plants]$^{-1}$) of wheat grown in soils with different P fertility levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 2, 3, and 4). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 5).

4.1.1.2. Ripening Stage

Table 4.2. details the findings of multiple three-way ANOVA analyses conducted to assess the effects of increasing soil P fertility levels (SOIL P), fertilizer types (FERTYPE), fertilizer application rates (RATE), and their interactions on the growth parameters of wheat plants harvested at the end of the ripening stage, 103 days after planting. The table shows that the three-way interaction of these independent variables (SOIL P* FERTYPE*RATE) did not significantly influence wheat growth parameters. The primary purpose of this trial was to investigate the effect of soil P fertility levels on the effectiveness of P-OMF and -MF fertilizers concerning plant growth parameters and nutritional status of primary macronutrients (N, P, and K). While soil P fertility level had no significant effect on wheat spike length, it significantly affected plant height and yield parameters, including the number of spikes per pot, biological yield, straw yield, and grain yield. Moreover, fertilizer type also affected all growth parameters at statistically significant level, except for plant height and spike length. Phosphorus application rate caused statistically significant changes in all growth parameters, as well. When binary interactions are considered, SOIL P*FERTYPE did not show statistically significant effects on any growth parameter, while SOIL P* RATE caused significant results in all parameters except spike length. In the FERTYPE*RATE interaction, biological yield, straw yield, and grain yield produced statistically significant results at varying levels.

Table 4.2. Results of multiple three-way ANOVA analyses for growth parameters of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil P fertility levels (10.2, 16.4, and 24.1 mg P·kg^{-1} soil), fertilizer types (P-OMF and P-MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil)

Growth Parameters	Individual Variables and Their Interactions							
	SOIL P	FERTYPE	RATE	SOIL P* FERTYPE	SOIL P*RATE	FERTYPE*RATE	SOIL P* FERTYPE*RATE	APPENDIX No
Ripening Stage								
Plant Height	**	ns	**	ns	**	ns	ns	6
Spike Length	ns	ns	***	ns	ns	ns	ns	7
Number of Spikes	***	*	***	ns	***	ns	ns	8
Biological Yield	***	***	***	ns	***	***	ns	9
Straw Yield	***	***	***	ns	***	**	ns	10
Grain Yield	***	**	***	ns	***	*	ns	11

The sources include SOIL P: Soil P fertility, FERTYPE: Fertilizer types, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Plant Height: Figure 4.2 presents the impact of various fertilizer types and P rates, analyzed statistically using both two-way and one-way ANOVA, on the heights of wheat plants cultivated for 103 days in soils pre-incubated at different P levels. As demonstrated, no statistically significant differences were observed between fertilizer types across all three soil P fertility levels (Figures 4.2A, B, C).

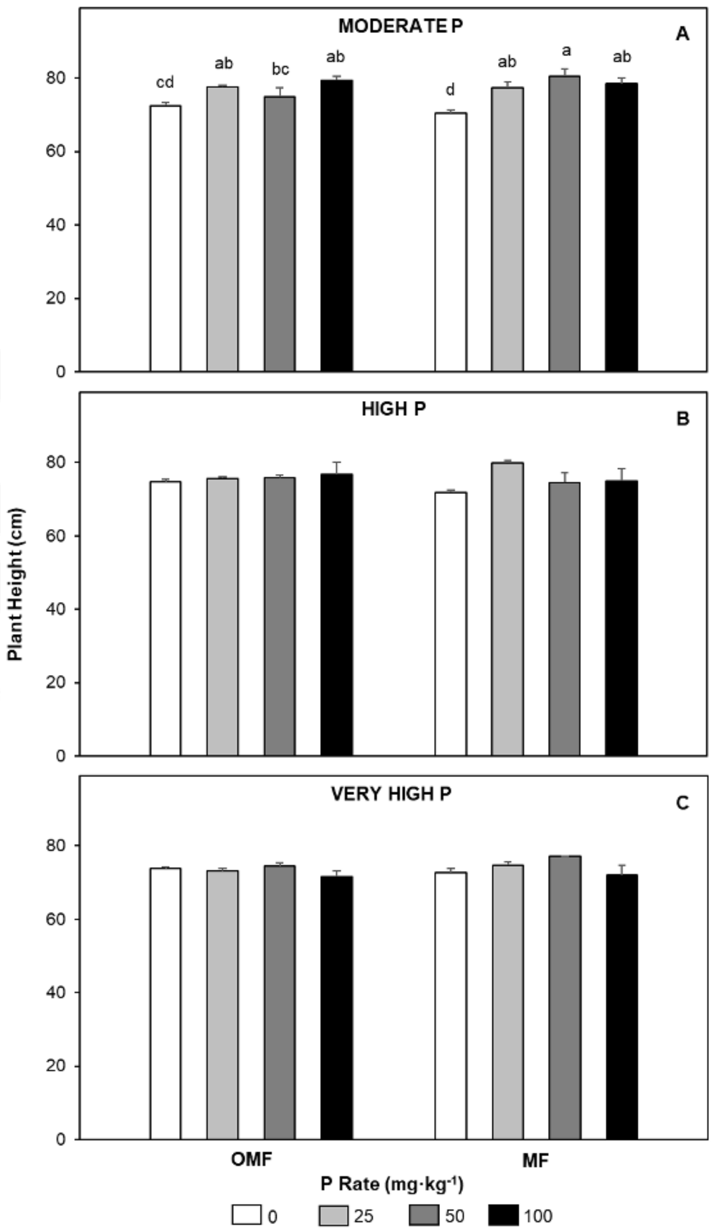

Figure 4.2. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on plant height (cm) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital shows the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 12, 13, and 14). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 15).

Spike Length: The effects of different fertilizer types and P rates on wheat spike length, statistically analyzed by both two-way and one-way ANOVA, are displayed in Figure 4.3 for plants grown for 103 days in soils with varying P fertility levels. Irrespective of the types of fertilizers used, the application of higher levels of P fertilizers resulted in notable increments in spike length (cm) at MODERATE-P (Figure 4.3A) and VERY HIGH-P (Figure 4.3C) compared to control treatments. In contrast, such a trend was not observed at HIGH-P (Figure 4.3B). Regarding the types of fertilizers employed, there were no significant differences across all soil fertility levels (Figure 4.3).

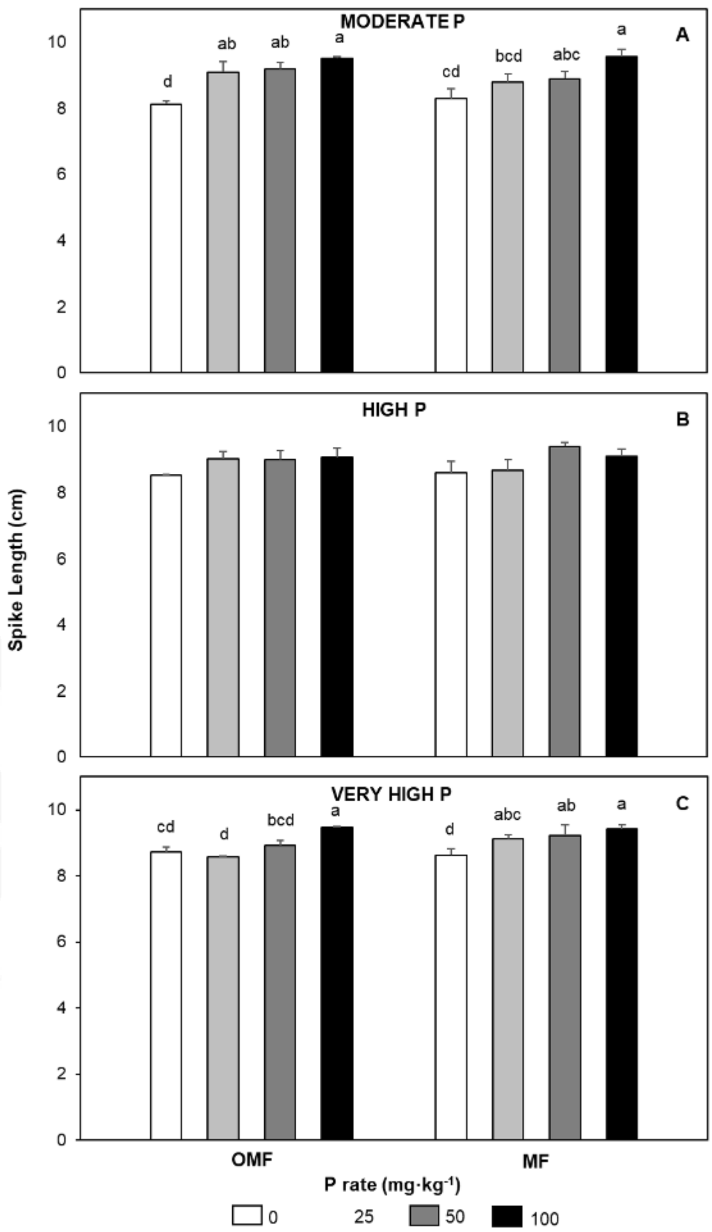

Figure 4.3. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on spike length(cm) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 16, 17, and 18). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 19).

Spike Count: The effects of varying soil P fertility levels on the effectiveness of P-OMF and -MF and their application at increasing amounts concerning spike count are given in Figure 4.4. As can be seen, the effectiveness of different fertilizer types and their application rates on the number of spikes per pot decreased with increasing P fertility levels obtained after pre-incubation. In this context, increasing fertilizer application amounts raised the number of spikes per pot at the

MODERATE-P level (Figure 4.4A), but this impact disappeared at the HIGH-P (Figure 4.4B) and VERY HIGH-P levels (Figure 4.4C). Regarding fertilizer types, a statistically significant difference in efficiency between P-OMF and -MF on spike count was observed only at the MODERATE-P level (Figure 4.4A), with P-OMF demonstrating significantly better performance than P-MF, except for the lowest application rate.

Biological yield (Straw + Grain): Figure 4.5 depicts the results of ANOVA analyses (both two-way and one-way) conducted to reveal the effects of varying rates of P, applied as either P-OMF or -MF, in soils with different P fertility levels on the biological yield of wheat plants harvested at the end of the ripening stage. As indicated, irrespective of fertilizer types, P application significantly increased the biological yield of wheat plants across all levels of P fertility compared to control treatments (no P applied). Regarding fertilizer types, P-OMF applications led to statistically more effective results than P-MF across all P fertility levels, especially at the MODERATE-P level (Figure 4.5A, B, C). Moreover, in MODERATE-P soil, P-OMF significantly increased biological yield compared to P-MF at all rates except the lowest application dose of 25 mg $P \cdot kg^{-1}$ soil (Figure 4.5A).

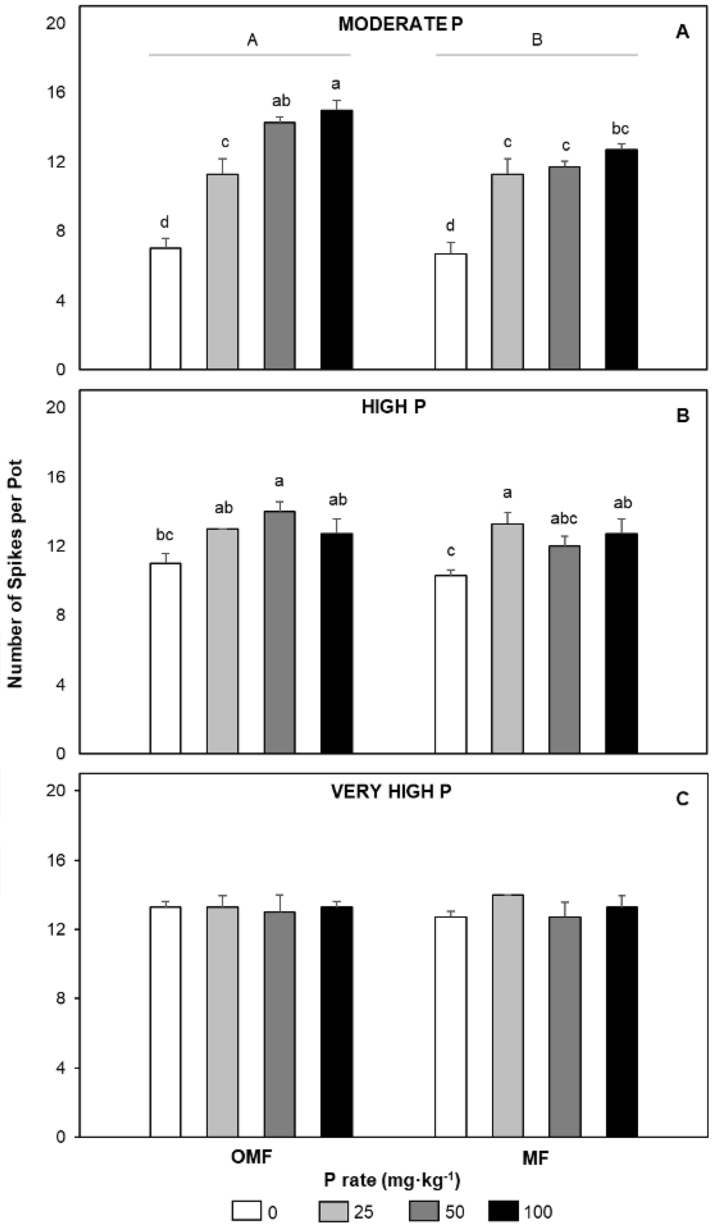

Figure 4.4. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on spike count (number of spikes per pot) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 20, 21, and 22). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 23).

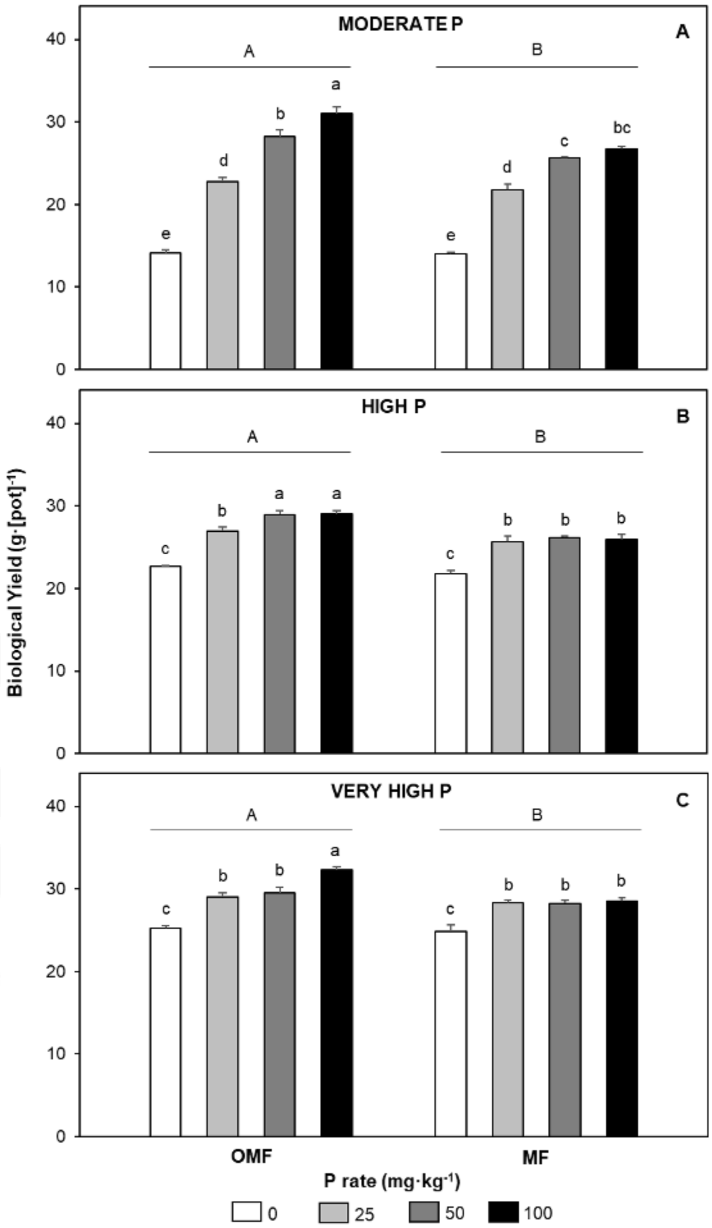

Figure 4.5. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on biological yield (g·[pot]$^{-1}$) of wheat (straw + grain) grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 24, 25, and 26). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 27).

Straw yield: Figure 4.6 illustrates the results of multiple ANOVA analyses (both two-way and one-way) on the straw yield of wheat plants harvested after 103 days of growth (the end of the ripening stage), assessing the effects of increasing P-containing OMF or MF fertilizers in soils differing in P fertility. As demonstrated, the straw yield of wheat plants increased significantly with P application, irrespective of its application rate, P fertility status, or the sources of fertilizers relative to control treatments. Additionally, it was observed that the P-OMF outperformed the P-MF at a statistically significant level throughout all soil P fertility levels (Figures 4.6A, B, C). Regarding the relationship between the soil P fertility statutes and P rate, higher differences in straw yield were obtained with increasing fertilizer application amounts at MODERATE P (Figure 4.6A). However, as soil P fertility increased because of pre-incubation with P, the higher efficiency of P-OMF over P-MF, while still present, declined substantially, paralleling the trend in biological yield. In this regard, applying higher rates of P-MF did not result in significant differences at HIGH and VERY HIGH-P fertility levels, whereas using P-OMF sustained minor yet observable differences (Figures 4.6B, C).

Grain yield: The efficiency of various sources of P-containing fertilizers and their application rates on the grain yield of wheat cultivated in soils with increasing levels of soil P fertility is demonstrated in Figure 4.7 using ANOVA analyses (both two-way and one-way) . Results indicate that the soil P fertility levels affected grain yield per pot to varying degrees. The P application increased grain yields across almost all P fertility levels compared to control plants (Figure 4.7A, B, C). However, this effect became smaller when the soil P fertility level was at its highest and even disappeared with P-MF applications (Figure 4.7C). Notably, rising fertilizer rates at MODERATE-P level resulted in marked differences in grain yield (Figure 4.7A). Yet, as soil P fertility levels rose to HIGH-P (Figure 4.7B) and VERY HIGH-P (Figure 4.7C), the distinction among fertilizer application rates gradually diminished. Despite this trend, increasing P-OMF treatments could still produce small yet noticeable differences, whereas P-MF applications did not exhibit such effects. Furthermore, the influence of fertilizer types diminished with higher soil P fertility; P-OMF demonstrated a statistically significant superiority over P-MF at MODERATE-P and HIGH-P levels, but this distinction disappeared at the VERY HIGH-P fertility level.

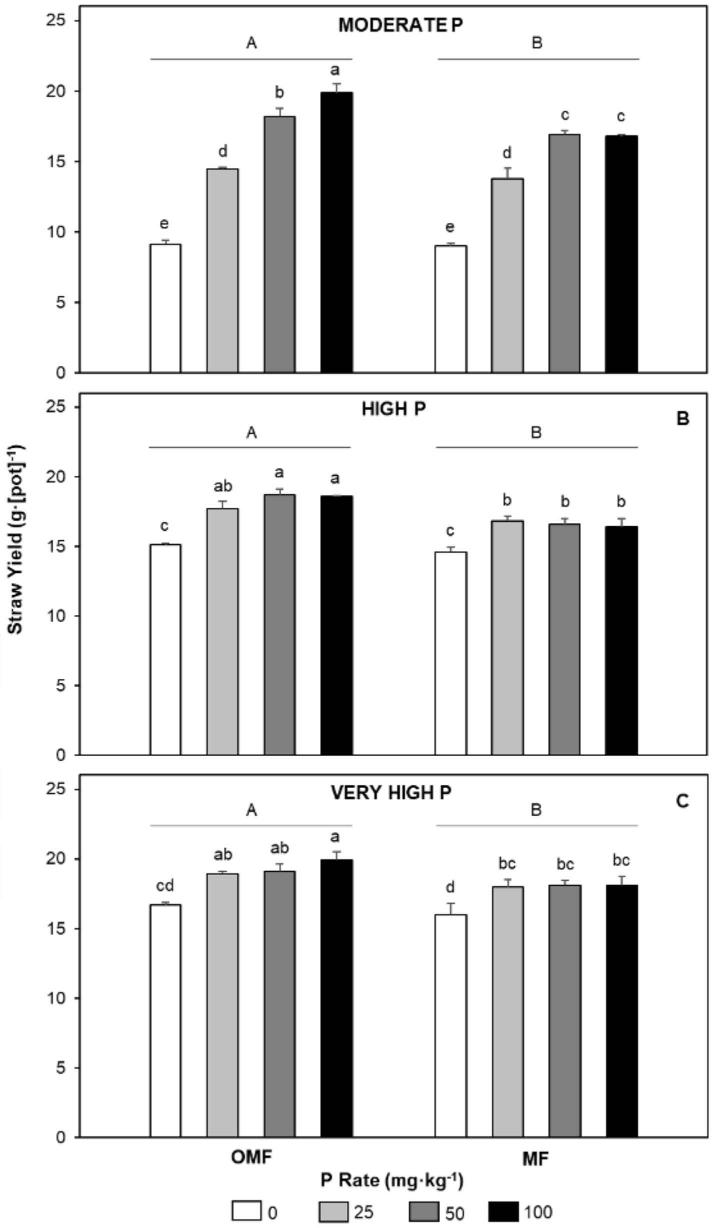

Figure 4.6. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw yield (g·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 28, 29, and 30). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 31).

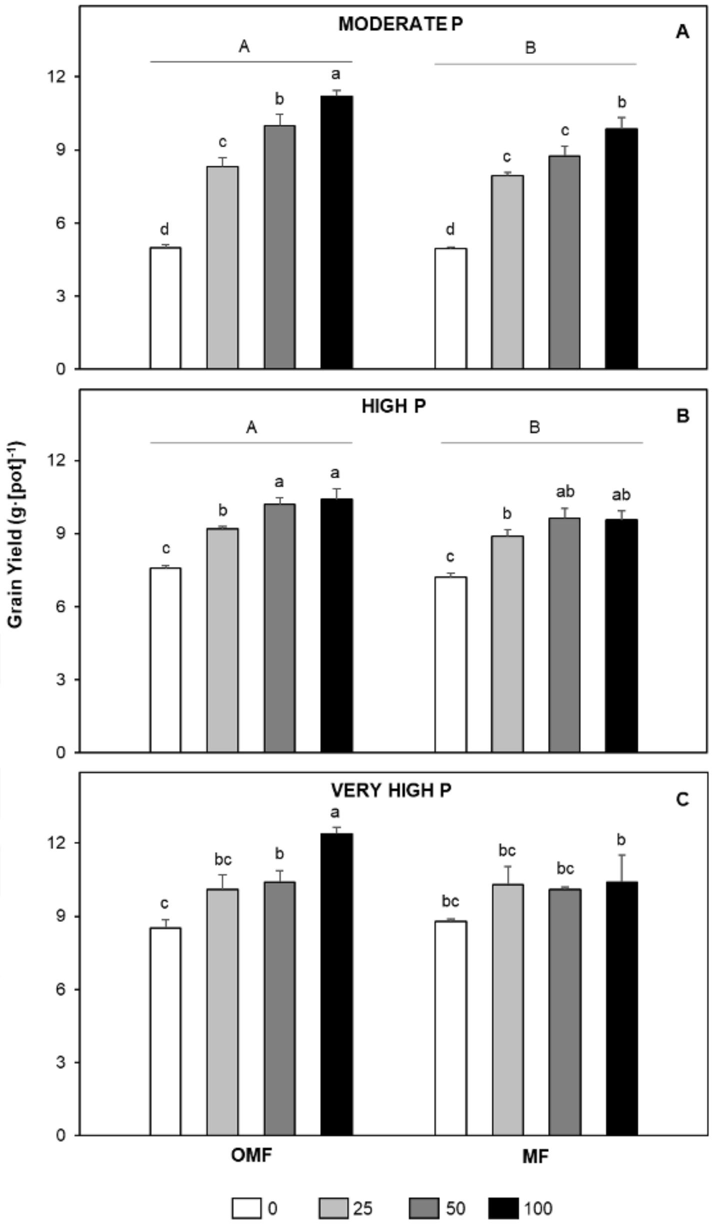

Figure 4.7. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain yield (g·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 32, 33, and 34). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendices 35).

4.1.2. Phosphorus Nutrition and Uptake

4.1.2.1. Tillering Stage

Shoot P Concentration

Appendix 36 presents the findings of a three-way ANOVA on shoot P concentration (%) in wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil P fertility levels, fertilizer types, and P rates. The results reveal that soil P fertility levels and P application rates had statistically significant effects, while different fertilizer types did not. In addition, all interactions among INC, RATE, and FERTYPE were statistically insignificant.

The impact of various fertilizer types, P rates, and their interactions on the shoot P concentration of wheat cultivated for 45 days in soils pre-incubated at different P levels, as tested statistically using both two-way and one-way ANOVA, is presented separately in Figure 4.8. Considering the soil P fertility levels, significant differences in shoot P concentrations (%) were evident only at the MODERATE-P level due to varying fertilizer application amounts. Irrespective of fertilizer sources, shoot P concentrations (%) increased with rising P application rates relative to control plants (Figure 4.8A), and these increases were statistically significant (Appendix 40). However, fertilizer sources did not cause any significant effect on shoot P concentration throughout all soil P fertility levels (Figure 4.8A, B, C).

Shoot P Content (Uptake)

The outcome of a three-way ANOVA investigating the effects of soil P fertility levels, fertilizer types, P rates, and their interactions on shoot P uptake (mg·[2 plants]$^{-1}$) of wheat harvested 45 days after planting is reported in Appendix 41. As shown, soil P fertility levels and P rates significantly affected shoot P content, whereas the influence of fertilizer types was statistically insignificant. Considering the interactions among variables, all interactions, except for the interactions SOIL P*FERTYPE*RATE and SOIL P*FERTYPE, caused significant changes.

Considering the soil P fertility status, although significant differences in shoot P uptake were observed with increasing fertilizer rates at MODERATE-P and HIGH-P levels (Figure 4.9A, B) compared to the control treatment, no significant differences were found between fertilizer types at either level. At the VERY HIGH-P level, no meaningful relationships were determined among fertilizer types and rates concerning shoot P uptake (Figure 4.9C).

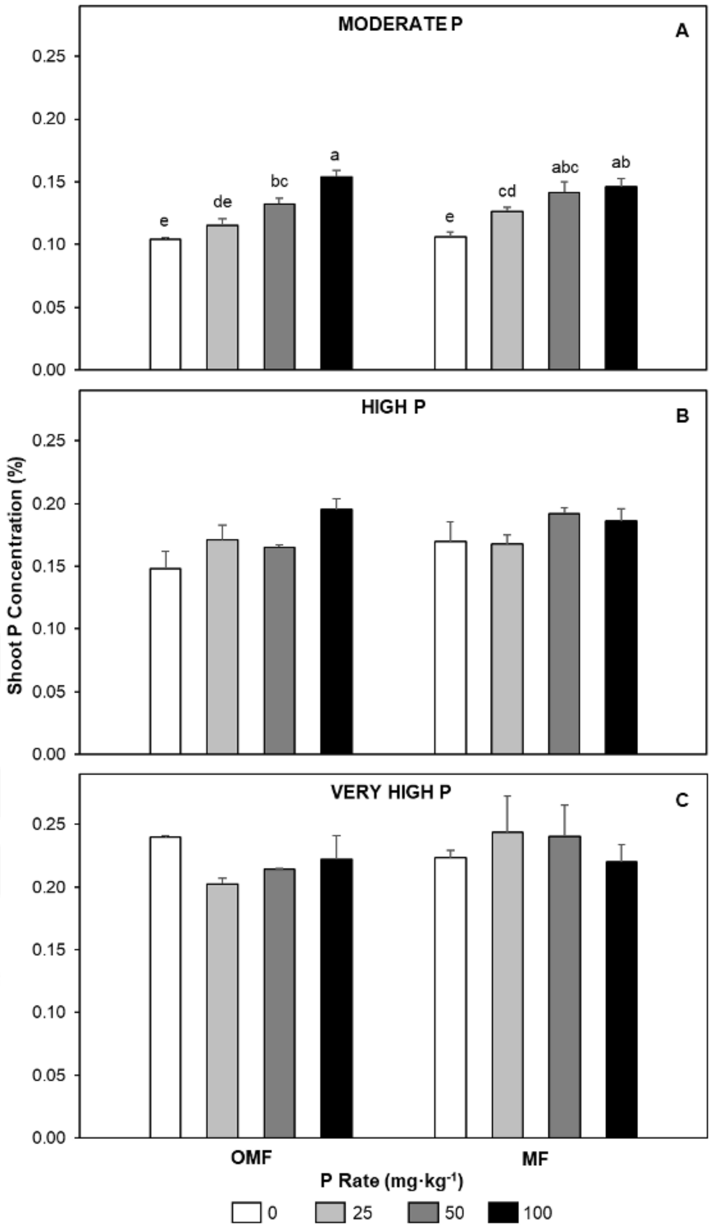

Figure 4.8. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot phosphorus (P) concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 37, 38, and 39). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 40).

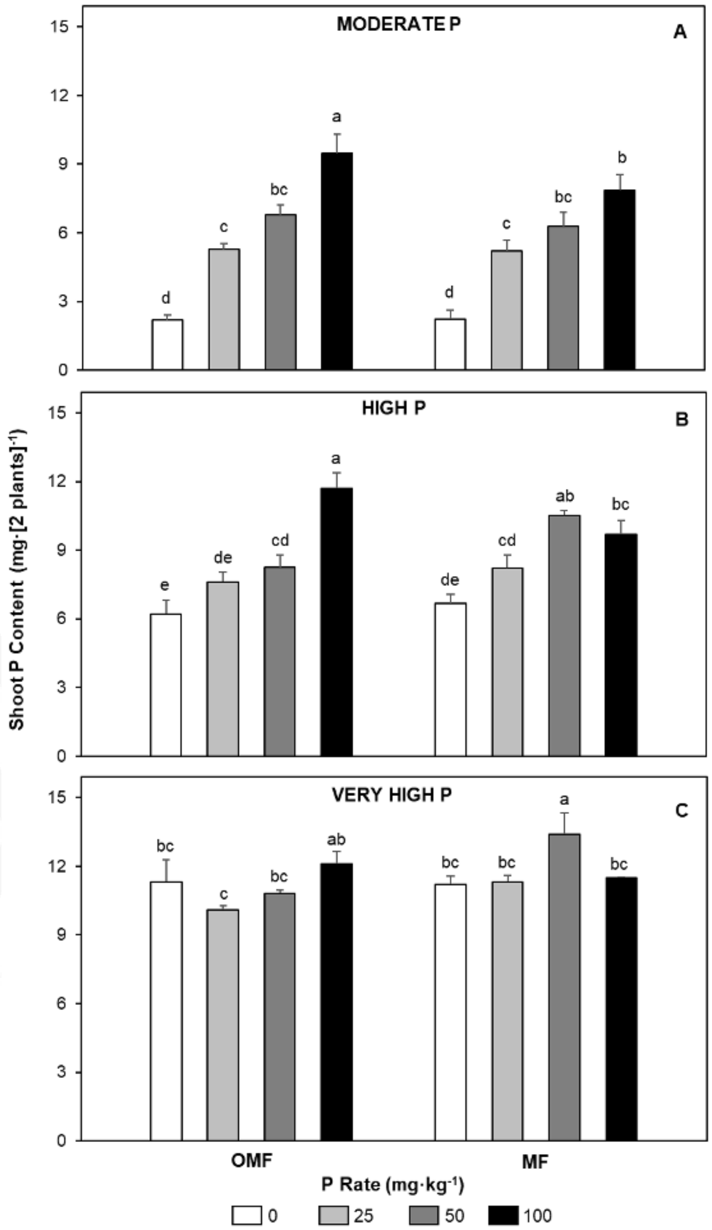

Figure 4.9. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot P content (mg·[2 Plants]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 42, 43, and 44). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 45).

4.1.2.2. Ripening Stage

Table 4.3 presents the findings of a series of three-way ANOVA analyses investigating the impact of Olsen P levels, fertilizer types, application rates, and their interactions on the P nutritional parameters of wheat plants harvested at the end of the ripening stage, 103 days after planting. Based on the findings, the interaction among the independent variables (SOIL P*FERTYPE*RATE) had no significant influence on the P nutritional status of wheat. Considering the contribution of soil P fertility levels, the core objective of this experiment, all P nutritional parameters were significantly influenced by SOIL P. Moreover, fertilizer type also affected grain P contents and total P uptakes at a statistically significant level. The P application rate also caused statistically significant changes in all growth parameters. When binary interactions are considered, SOIL P*FERTYPE did not show statistically significant effects on any P nutritional parameter, while SOIL P*RATE caused significant results in all parameters. In the FERTYPE*RATE interaction, grain P content and total P uptake produced statistically significant results at the $P < 0.01$ level.

Table 4.3. Results of multiple three-way ANOVA analyses for phosphorus nutritional status of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil P fertility levels (10.2, 16.4, and 24.1 mg $P \cdot kg^{-1}$ soil), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil).

P Nutritional Parameters	Individual Variables and Their Interactions							
	SOIL P	**FERTYPE**	**RATE**	**SOIL P* FERTYPE**	**SOIL P*RATE**	**FERTYPE*RATE**	**SOIL P* FERTYPE*RATE**	**APPENDIX No**
Ripening Stage								
Straw P Concentration	***	ns	***	ns	***	ns	ns	46
Grain P Concentration	***	ns	**	ns	**	ns	ns	47
Straw P Content	***	ns	***	ns	***	ns	ns	48
Grain P Content	***	*	***	ns	***	**	ns	49
Total P Uptake	***	**	***	ns	***	**	ns	50

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

P Concentration

Straw P Concentration: Figure 4.10 expands on the contribution of increasing rates of P-containing fertilizers, applied as either OMF or MF, in soils with different P fertility levels to the straw P concentration (%) of wheat plants as analyzed through ANOVA analyses (both two-way and one-way). As can be seen, increasing applications of P-OMF or P-MF had no statistically significant effects on straw P concentration at MODERATE-P (Figure 4.10A) and HIGH-P (Figure 4.10B) fertility levels compared to control treatments. Yet, at VERY HIGH-P level, increasing fertilizer applications led to notable differences in straw P concentration, with P-MF exhibiting a superior performance over P-OMF, highlighting the significant impact of both RATE and FERTYPE (Figure 4.10C).

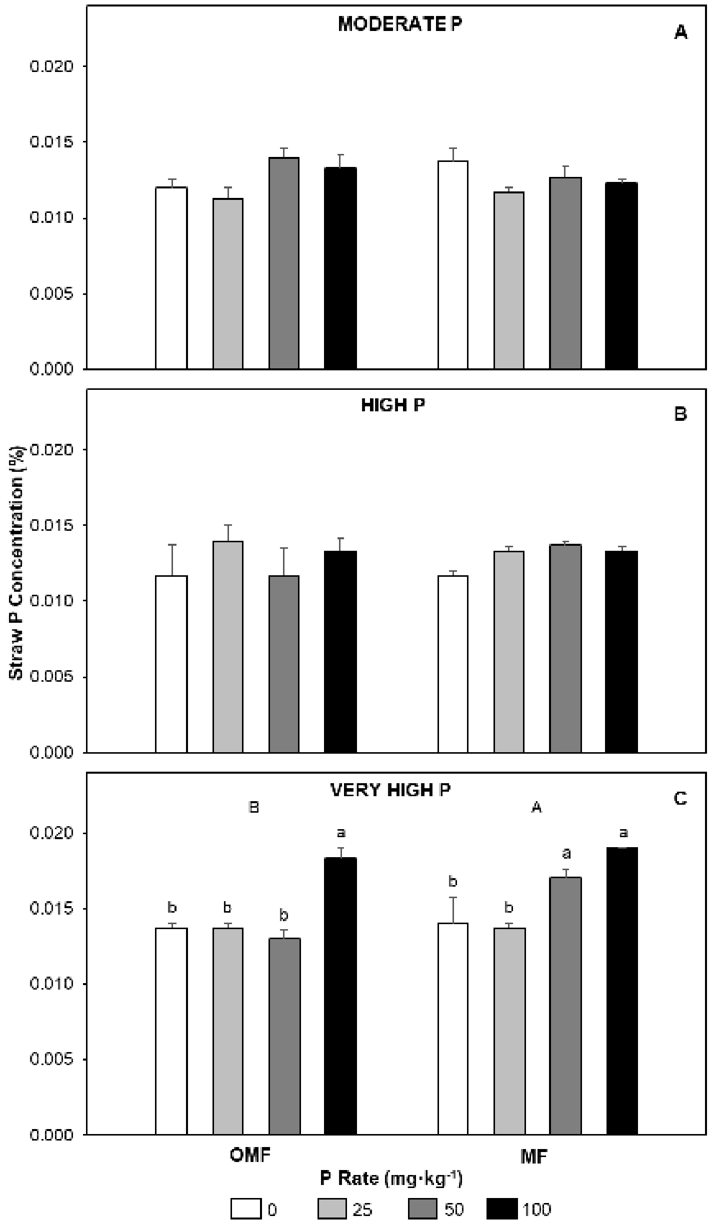

Figure 4.10. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw P concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 51, 52, and 53). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 54).

Grain P Concentration: The outcomes of ANOVA analyses (both two-way and one-way) conducted to examine the efficiency of various P-containing fertilizer sources and application rates on wheat grain P concentration across soils with different P fertility levels are illustrated in Figure 4.11. Fertilizer sources did not affect grain P concentration across all soil P fertility statuses (Figures 4.11A, B, C). Regarding the influence of P application rates, increasing P-OMF treatments showed limited influence at the MODERATE-P level, while increasing P-MF applications significantly increased grain P concentration compared to control plants (Figure 4.11A). Furthermore, statistically significant differences in wheat grain P concentrations were recorded at the HIGH-P level with increasing fertilizer rates; nevertheless, these differences were not significantly related to fertilizer rate or type (Figure 4.11B).

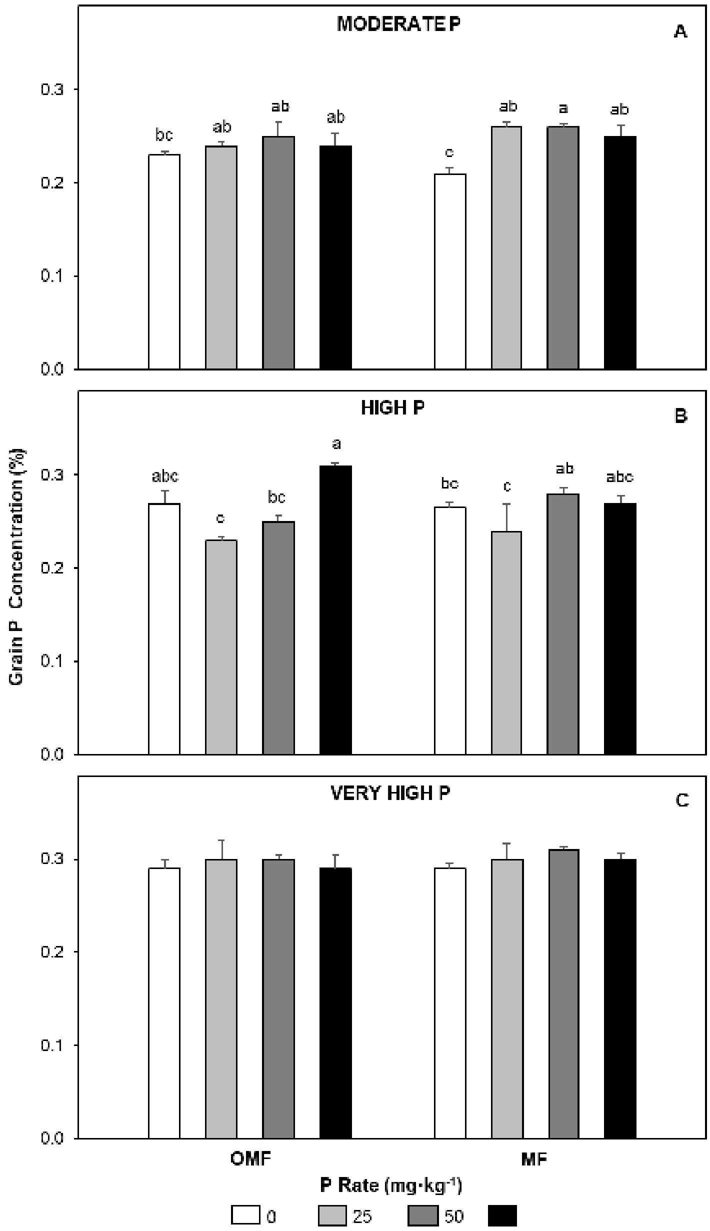

Figure 4.11. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain P concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 55, 56, and 57). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 58).

P Content and Uptake

Straw P Content: Figure 4.12 depicts the results of multiple ANOVA analyses (both two-way and one-way) assessing the effects of increasing P applications as OMF or MF on straw P content of wheat plants grown in soils with varying P fertility statuses. As seen, wheat straw P content increased with P application, irrespective of rate, soil P fertility status, or fertilizer source, relative to control treatments (Figure 4.12A, B, C). Additionally, it was observed that the P-OMF outperformed the P-MF at a statistically significant level in soil with MODERATE-P fertility, where the highest straw P content was observed at the two highest OMF application rates (Figures 4.12A). These values were significantly higher than those observed in plants supplied with the same rates of P-MF. Moreover, as the P fertility status of experimental soils increased to HIGH-P (Figure 4.12B) and VERY HIGH-P (Figure 4.12C) levels, the distinction between fertilizer types became negligible, highlighting a negative correlation between fertilizer type and soil fertility level (FERTYPE*SOIL P).

Grain P Content: The findings of multiple ANOVA analyses (both two-way and one-way) on P content in wheat grain, elaborated in Figure 4.13, reveal the impact of fertilizer types and their increasing application rates in soils with different P fertility levels. Considering the soil P fertility statuses, regardless of the fertilizer types, significant increases in the grain P content were observed due to the P applications (Figures 4.13A, B, C). Grain P content increased with increasing P fertility levels (Appendix 66). Namely, the lowest grain P contents were found in plants grown in MODERATE-P soil (Figure 4.13A), while the highest values were observed in VERY HIGH-P soil (Figure 4.13C). Moreover, statistically significant results demonstrated that P-OMF exhibited superiority over P-MF only at the MODERATE-P level (Figure 4.13A; uppercase letters). Yet, this effect was statistically substantial at the highest P rate (100 mg $P \cdot kg^{-1}$ soil), with no significant differences recorded at the other rates (Figure 4.13A; lowercase letters).

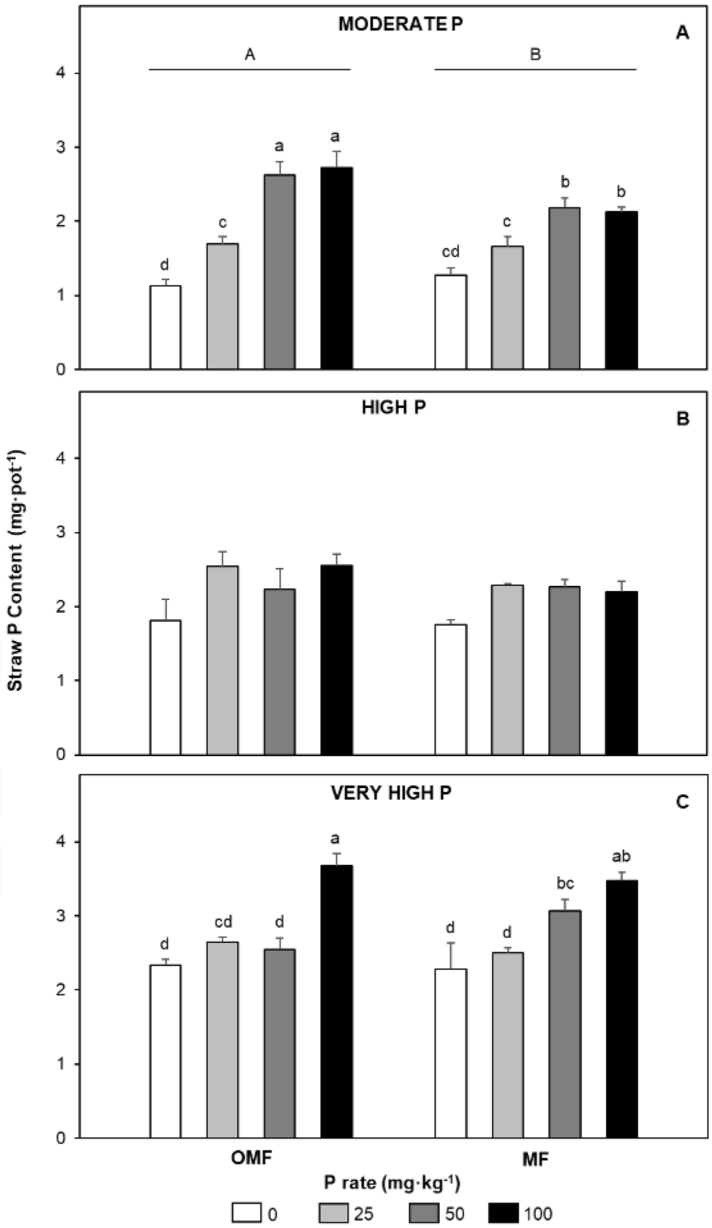

Figure 4.12. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw P content (mg P·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 59, 60, and 61). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 62).

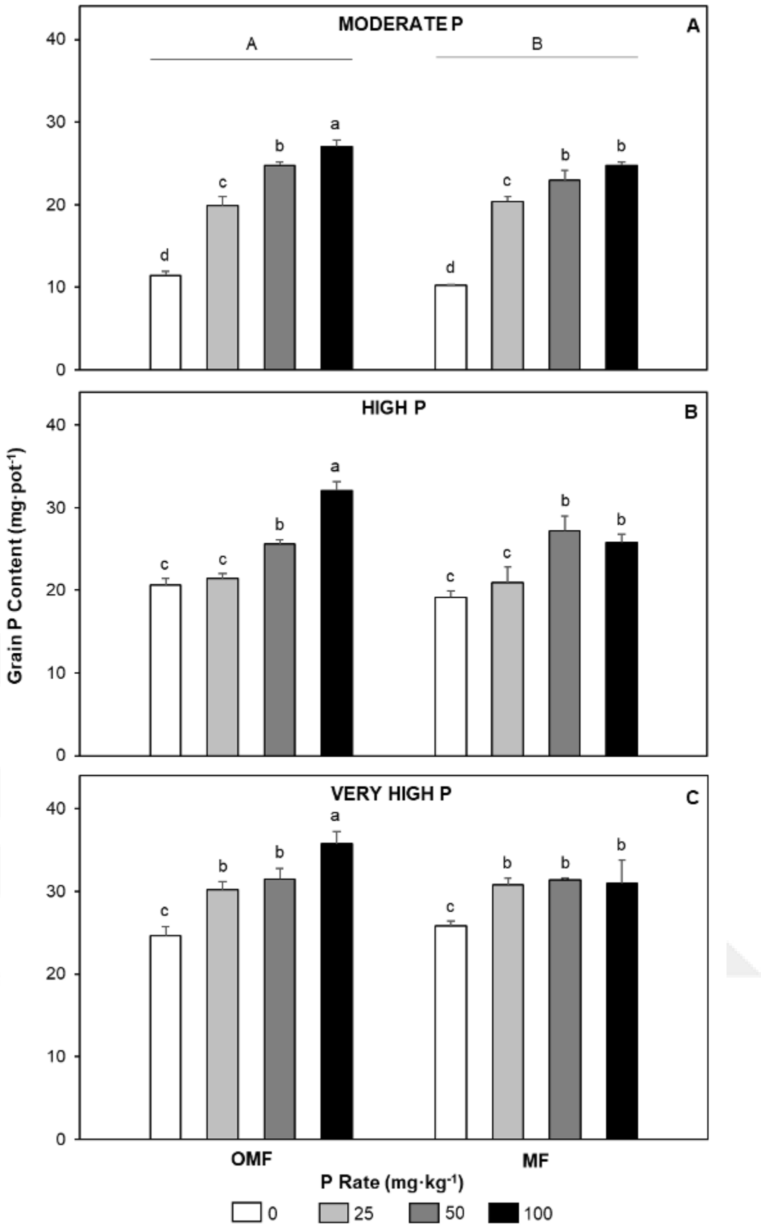

Figure 4.13. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain P content (mg P·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 63, 64, and 65). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 66).

Total P Uptake: Figure 4.14 depicts the efficiency of various P-containing fertilizers and their application rates on total P uptake by wheat grown in soils with increasing soil P fertility. In general, the effects of fertilizer type and application rate on the total P uptake ($mg.pot^{-1}$) diminished with higher P fertility levels achieved through pre-incubation (Figure 4.14A, B, C). In addition, P applications as either OMF or MF led to significant increments in total P uptake by wheat compared to control treatments across all P fertility levels (Figure 4.14A, B, C), with P-OMF outperforming P-MF at MODERATE-P (Figure 4.14A) and HIGH-P levels (Figure 4.14B). However, like grain P content, this effect was statistically significant only at the highest P rate (Figure 4.14A, B; lowercase letters).

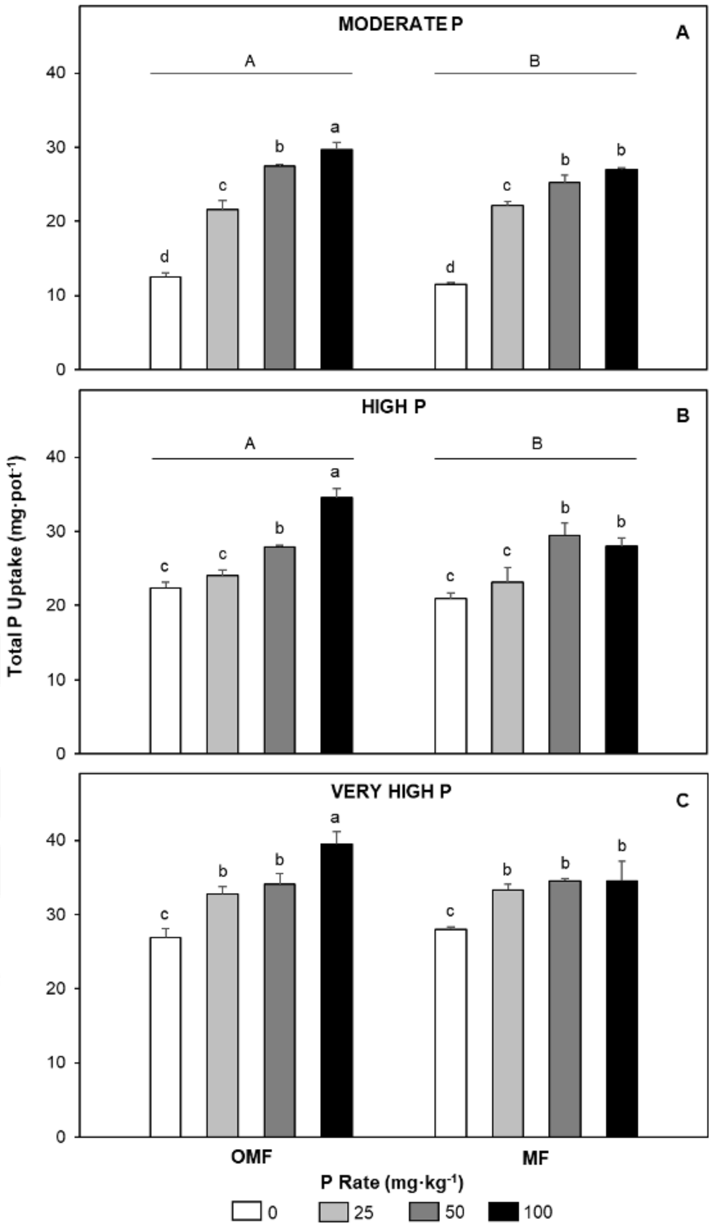

Figure 4.14. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total P uptake (mg P·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 67, 68, and 69). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 70).

4.1.3. Nitrogen Nutrition and Uptake

4.1.3.1. Tillering Stage

Shoot N Concentration

The findings of a three-way ANOVA for shoot N concentration (%) in wheat plants harvested at the end of the tillering stage, 45 days post-planting, are shown in Appendix 71. According to the results, the soil P fertility level ($P<0.05$) and fertilizer type ($P<0.001$) statistically affected the shoot N concentration. Conversely, the isolated impact of the P rate and all interactions among the factors under consideration were insignificant.

At all soil P fertility statuses, applications of P-OMF were superior to those of P-MF concerning shoot N concentration (Figure 4.15A, B, C). However, the differences in N concentrations related to fertilizer types and P rates were not statistically significant.

Shoot N Content (Uptake)

Appendix 76 presents the details of a three-way ANOVA conducted to determine the effect of various factors (SOIL P, P-containing fertilizer sources, and P rates) on shoot N content of wheat plants harvested at the end of the tillering stage (45 days after planting). Each factor tested in the experiment was statistically significant individually at levels ranging from $P<0.01$ (FERTTYPE) to $P<0.001$ (SOIL P and RATE) for shoot N content. Regarding the interactions among the factors, all interactions, except those involving SOIL P*FERTYPE- produced statistically significant (at different levels) increments.

Figure 4.16 shows the results of ANOVA analyses (both two-way and one-way) testing the effectiveness of P fertilizer types and P rates on shoot N uptake separately at each soil P fertility level at the end of the tillering stage. As observed, the statistically significant efficacies of fertilizer types and P rates decreased with increasing soil P fertility levels, highlighting a negative correlation between soil P fertility and these factors. Notable differences in shoot N content emerged with increasing P application compared to control treatments in MODERATE-P soil (Figure 4.16A), with P-OMF performing significantly better than P-MF. Yet, at the HIGH-P fertility level (Figure 4.16B), the effect of P application began to decrease, and the significant differences observed in the MODERATE-P soil (pre-incubated with 0 mg $P \cdot kg^{-1}$) between plants supplied with P-OMF and P-MF disappeared entirely. Furthermore, minor yet visible differences compared to control treatments (Figure 4.16B; lowercase letters) were recorded, which vanished at the VERY HIGH-P fertility level (Figure 4.16C).

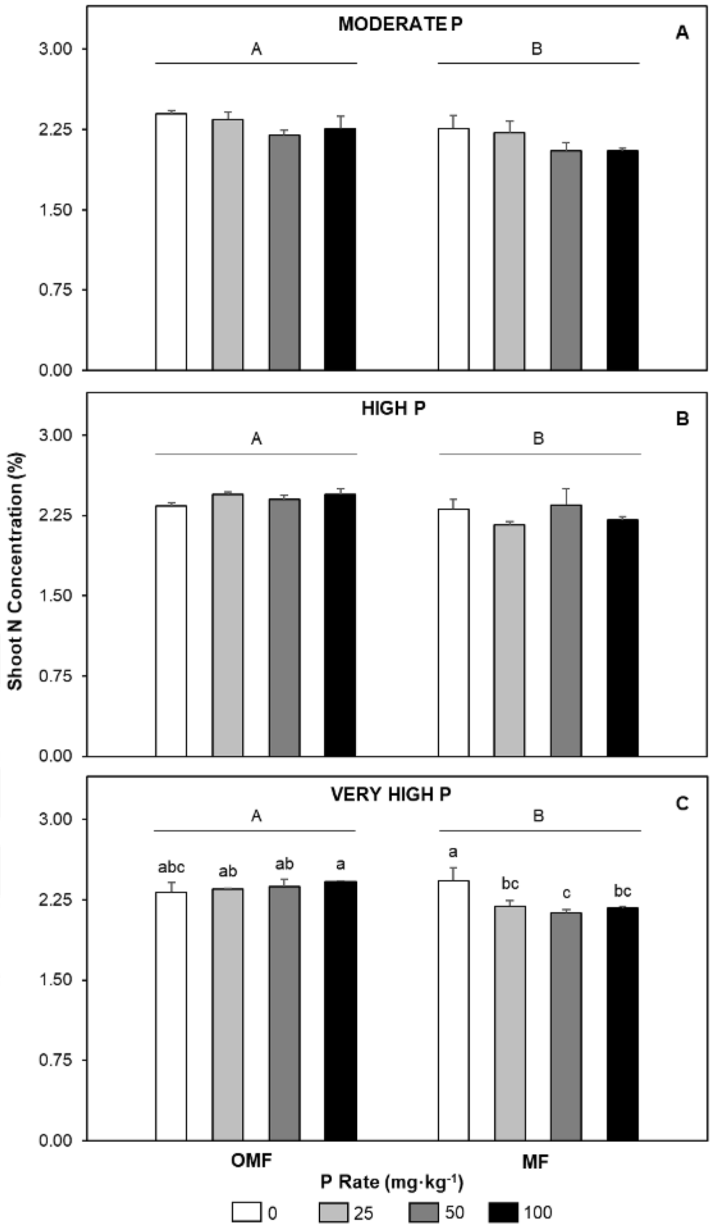

Figure 4.15. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot N concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 72, 73, and 74). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 75).

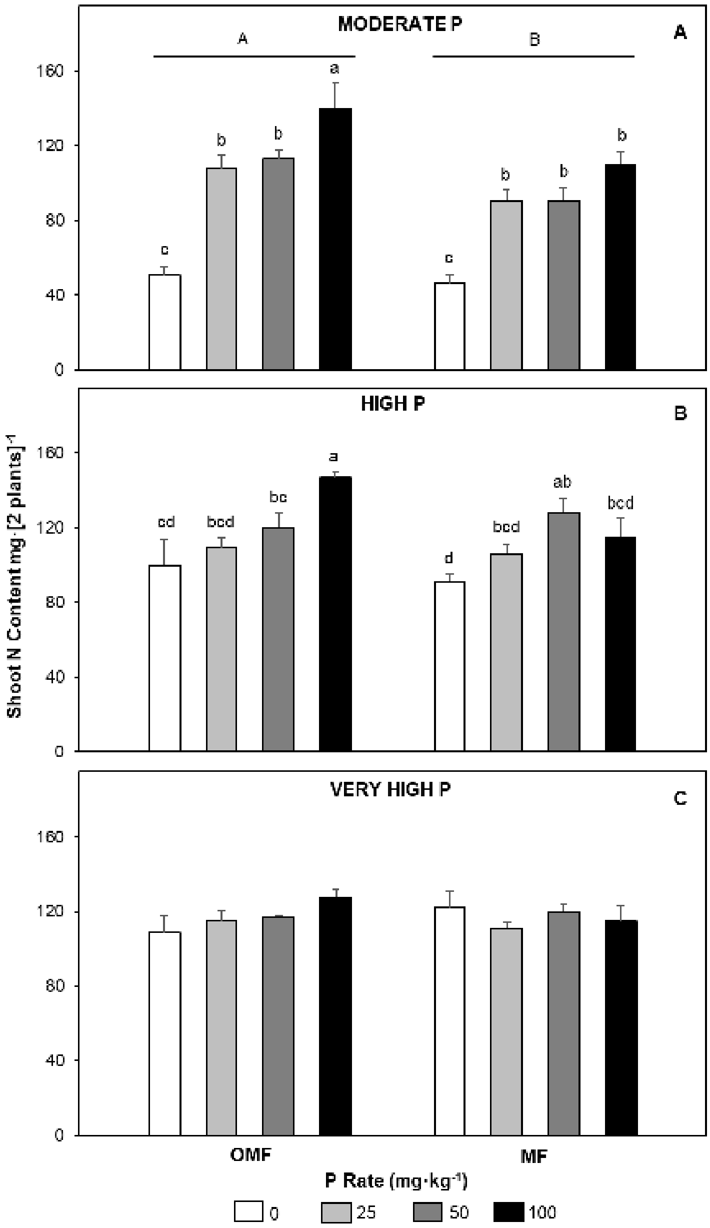

Figure 4.16. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot N content (mg·[2 plants]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 77, 78, and 79). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 80).

4.1.3.2. Ripening Stage

Table 4.4 provides the detailed results of three-way ANOVA analyses analyzing the influence of P fertility levels, fertilizer types, P application rates, and their interactions on N nutritional parameters of wheat at the end of the ripening stage (103 days post-planting). As can be read from the table, the three-way interaction (SOIL P*FERTYPE*RATE) showed no effect on wheat N status. Moreover, although SOIL P significantly impacted grain N content and total N uptake, its effect on grain N concentration, straw N concentration, and straw N content was insignificant. Also, fertilizer type also affected grain N content statistically significantly. The P application rate also caused statistically significant changes in all growth parameters except for straw N content. When binary interactions are considered, SOIL P*FERTYPE did not show statistically significant effects on any N nutritional parameter. At the same time, SOIL P*RATE caused substantial results in grain N content and total N uptake. In the FERTYPE*RATE interaction, none of the nutritional parameters produced statistically significant results.

Table 4.4. Results of multiple three-way ANOVA analyses for nitrogen nutritional status of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil P fertility levels (10.2, 16.4, and 24.1 mg P·kg^{-1} soil), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

N Nutritional Parameters	Individual Variables and Their Interactions							
	SOIL P	FERTYPE	RATE	SOIL P* FERTYPE	SOIL P*RATE	FERTYPE*RATE	SOIL P* FERTYPE*RATE	APPENDIX No
Ripening Stage								
Straw N Concentration	ns	ns	**	ns	ns	ns	ns	81
Grain N Concentration	ns	ns	*	ns	ns	ns	ns	82
Straw N Content	ns	ns	ns	ns	ns	ns	ns	83
Grain N Content	***	*	***	ns	***	ns	ns	84
Total N Uptake	***	ns	***	ns	***	ns	ns	85

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Nitrogen Concentration

Straw Nitrogen Concentration: Figure 4.17 displays the findings of multiple ANOVA analyses (both two-way and one-way) examining the role of increasing P applications, as OMF and MF fertilizers, in influencing wheat straw N concentrations (%) in soils with various soil P fertility levels. At all pre-incubation levels, resulting in different soil P fertility statuses, fertilizer types had no difference in their effects on the straw N concentration (Figure 4.17A, B, C). At the MODERATE-P fertility level, a decreasing trend in straw N concentration was observed with increasing P rates, regardless of fertilizer type; however, these results were statistically insignificant (Figure 4.17A). No statistically significant results were found between P rates and straw N concentrations at the other two soil P fertility levels: HIGH-P and VERY HIGH-P (Figure 4.17B, C).

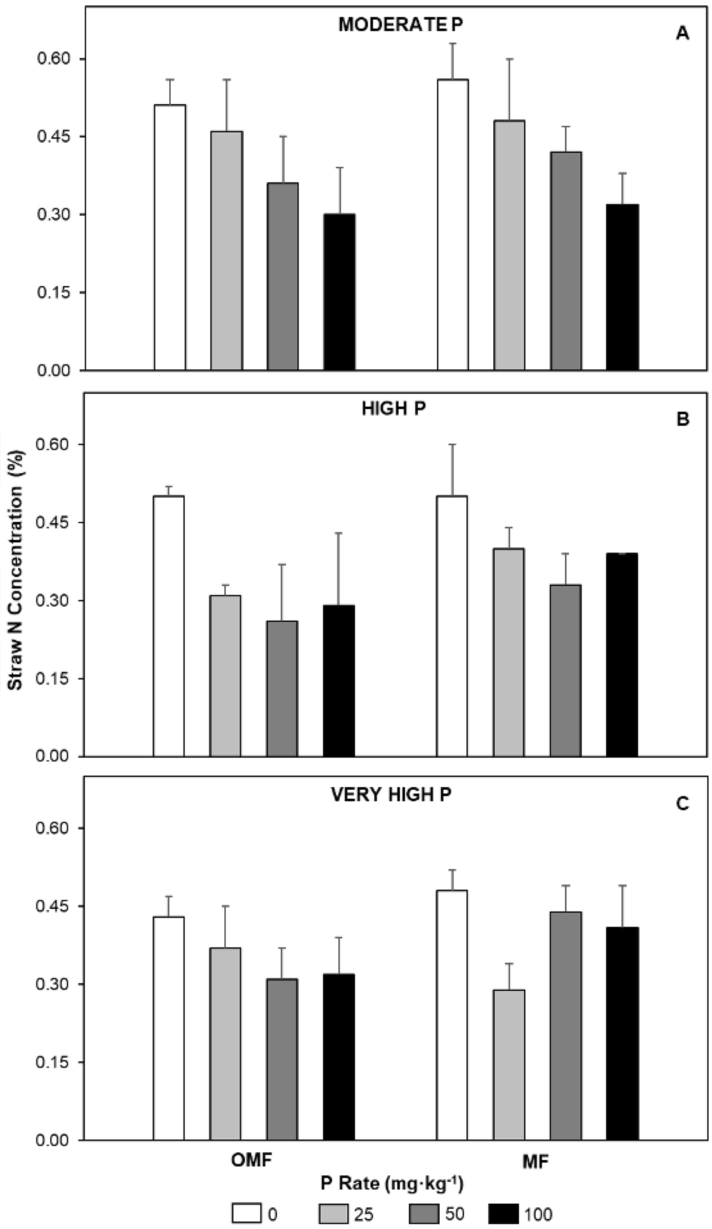

Figure 4.17. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw N concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 86, 87, and 88). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 89).

Grain Nitrogen Concentration: A group of two-way and one-way ANOVA analyses, as shown in Figure 4.18, analyze the effects of two P-containing fertilizers (OMF and MF) applied at increasing application rates on wheat grain N concentrations (%) in soils with increasing P fertility levels. Regardless of distinct soil P fertility statuses, neither the type of fertilizer nor the application rate affected grain N concentration (Figure 4.18A, B, C).

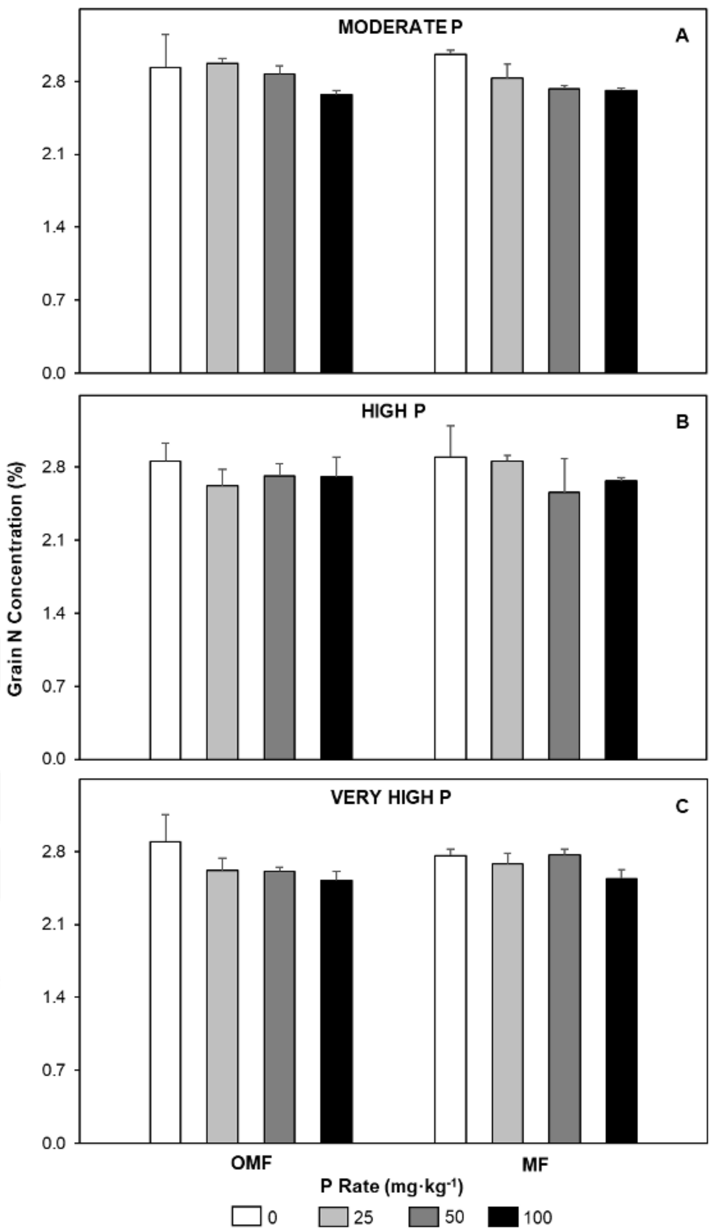

Figure 4.18. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain N concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 90, 91, and 92). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 93).

Nitrogen Content and Uptake

Straw N Content: Figure 4.19 outlines the effects of two P-containing fertilizers, P-OMF and -MF, and their application rates on wheat straw N content, as determined across soils with varying levels of plant-available P through ANOVA analyses (both two-way and one-way) . Increasing P application increased straw N content compared to control treatments at the MODERATE-P fertility level, irrespective of the fertilizer type (Figure 4.19A). However, these differences were statistically insignificant. At all P fertility statuses, straw N content was not affected by either fertilizer type or P application rate (Figure 4.19A, B, C).

Grain N Content: Figure 4.20 illustrates the results of multiple ANOVA analyses (both two-way and one-way) assessing the impact of different P fertilizer types and application rates on the grain N content of wheat grown in soils with different P fertility statuses, harvested at the end of the ripening stage (103 days post-planting). The analyses indicate that the statistically significant effects of fertilizer types and P rates diminished as soil P fertility levels increased with higher P pre-incubation levels, showing a negative correlation between P fertility levels and these factors. Significant differences in grain N content were observed with increased P application compared to control treatments at the MODERATE-P fertility level, with P-OMF demonstrating higher effectiveness than P-MF (Figure 4.20A). At the HIGH-P level (Figure 4.20B), the effect of P application started to wane, and the significant differences between P-OMF and P-MF observed in MODERATE-P soil were no longer present. Nevertheless, minor yet statistically insignificant differences compared to control treatments (Figure 4.20B) were still noticeable. Concerning the VERY HIGH-P fertility level, although fertilizer sources had no effect on grain N content, subtle differences were observed as a function of P rates (Figure 4.20C).

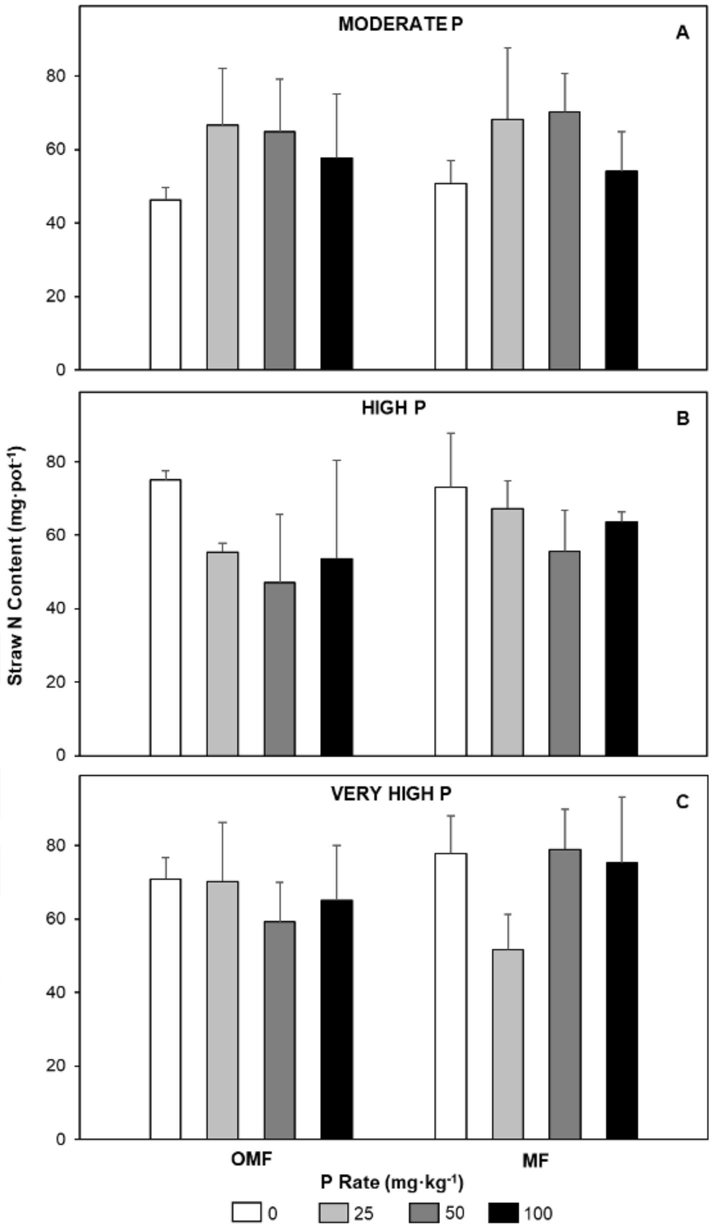

Figure 4.19. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw N content (mg. N·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 94, 95, and 96). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 97).

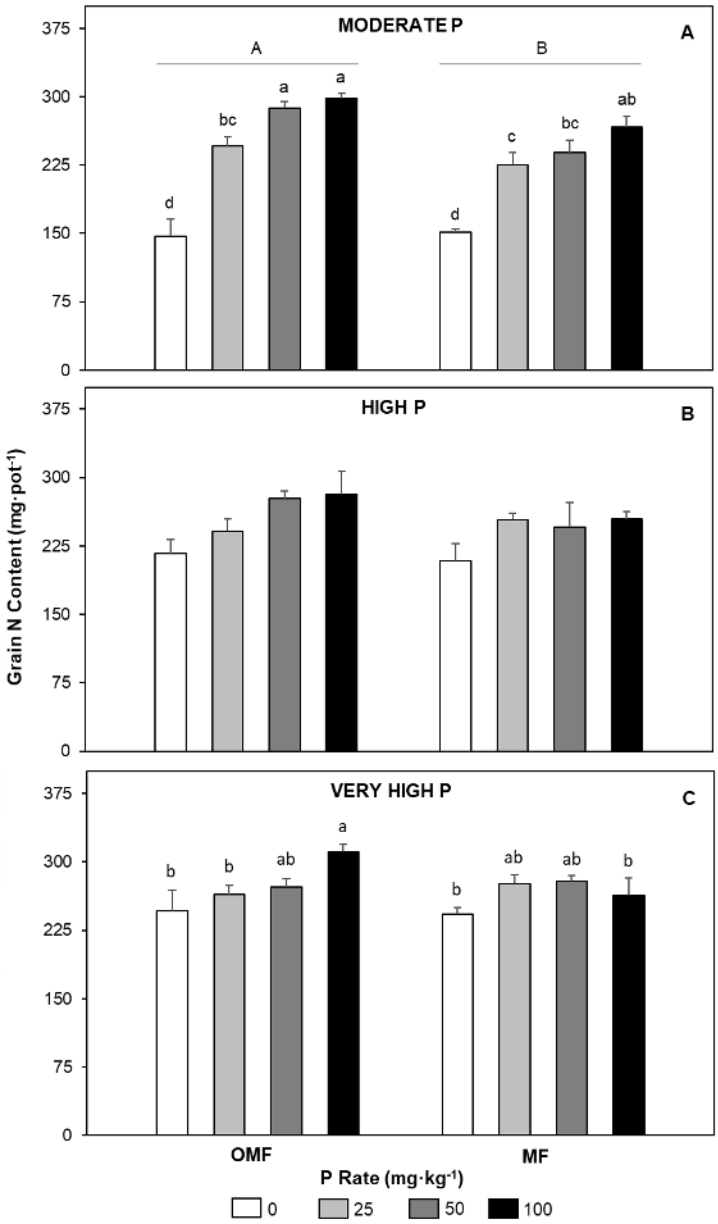

Figure 4.20. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain N content (mg. N·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 98, 99, and 100). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 101).

Total N Uptake: Figure 4.21 displays the results of ANOVA analyses (both two-way and one-way) evaluating the effects of different P fertilizer types and P rates on the total N uptake at each P fertility level at the end of the ripening stage. The results show that, although statistically insignificant, plants supplied with P-OMF tended to have higher total N uptake values than those provided with P-MF at the MODERATE-P fertility level (Figure 4.21A). Increasing P rates at the same fertility level enhanced the total N uptake irrespective of P fertilizer types (Figure 4.21A). However, the effect of P application disappeared in HIGH-P (Figure 4.21B) and VERY HIGH-P soils (Figure 4.21C).

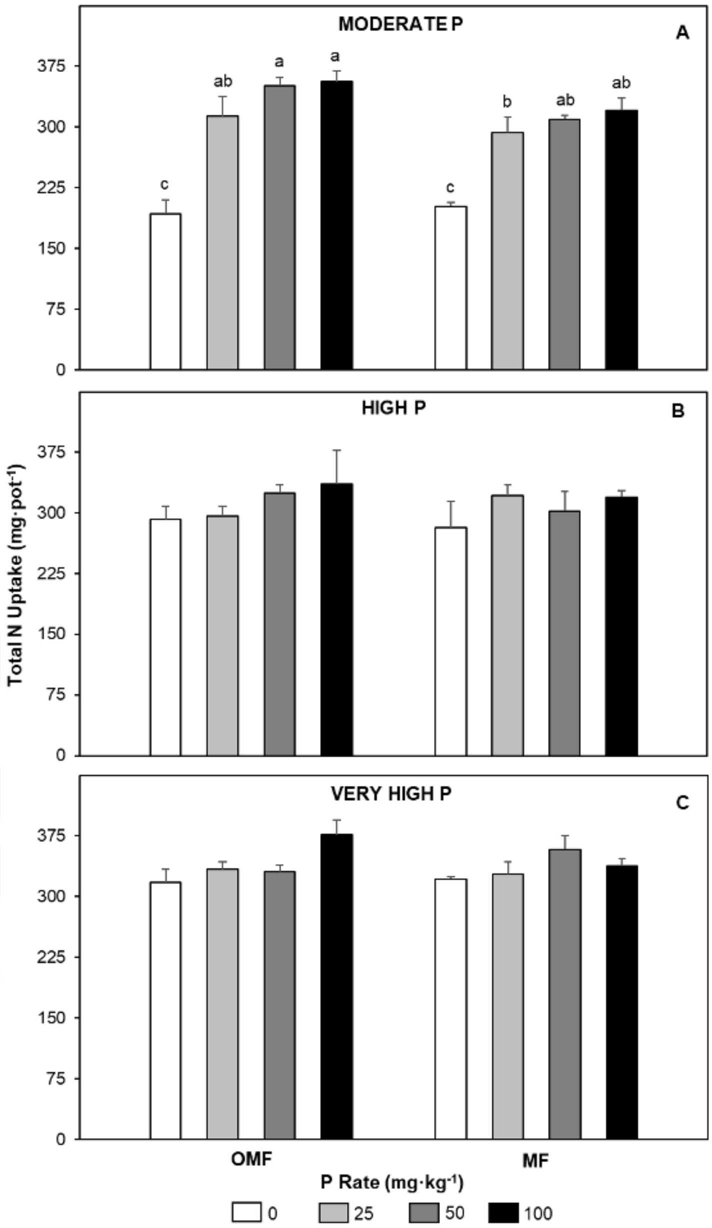

Figure 4.21. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total N uptake (mg. N·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 102, 103, and 104). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 105).

4.1.4. Potassium Nutrition and Uptake

4.1.4.1. Tillering Stage

Shoot K Concentration

Appendix 106 provides the details of a three-way ANOVA that investigated the effects of different P fertility levels, fertilizer types, P application rates, and their interactions on the shoot K concentrations (%) in wheat plants grown for 45 days and harvested at the end of the tillering stage. The analysis indicates that shoot K concentration in wheat was significantly affected only by soil P fertility level ($P<0.05$), with all other factors and their interactions showing no significant effects.

Across all soil P fertility status, neither the type of fertilizer nor the P rate impacted shoot K concentration (Figure 4.22A, B, C).

Shoot K Content (Uptake)

Appendix 111 summarizes the findings of a three-way ANOVA investigating the impact of various soil P fertility levels, P fertilizer types, P rates, and their interactions on the shoot K content in wheat grown for 45 days (at the end of the tillering stage) under greenhouse conditions. The findings show that soil P fertility and P rates had statistically significant effects. Among the interactions, only the interaction between pre-incubation levels and fertilizer rate (SOIL P*RATE) was statistically significant. However, the independent impact of fertilizer types (FERTYPE) and all other interactions were statistically insignificant.

Figure 4.23 illustrates the results of ANOVA analyses (both two-way and one-way) examining the effects of different P fertilizer types and P rates on shoot K content in soils with varying P fertility levels at the end of the tillering stage. The analyses indicate that the statistically significant impact of P rates on shoot K content diminished as soil P fertility levels increased, eventually disappearing at the highest P fertility level, VERY HIGH-P. Regardless of P fertility levels, fertilizer types had no significant effect on shoot K content (Figure 4.23A, B, C).

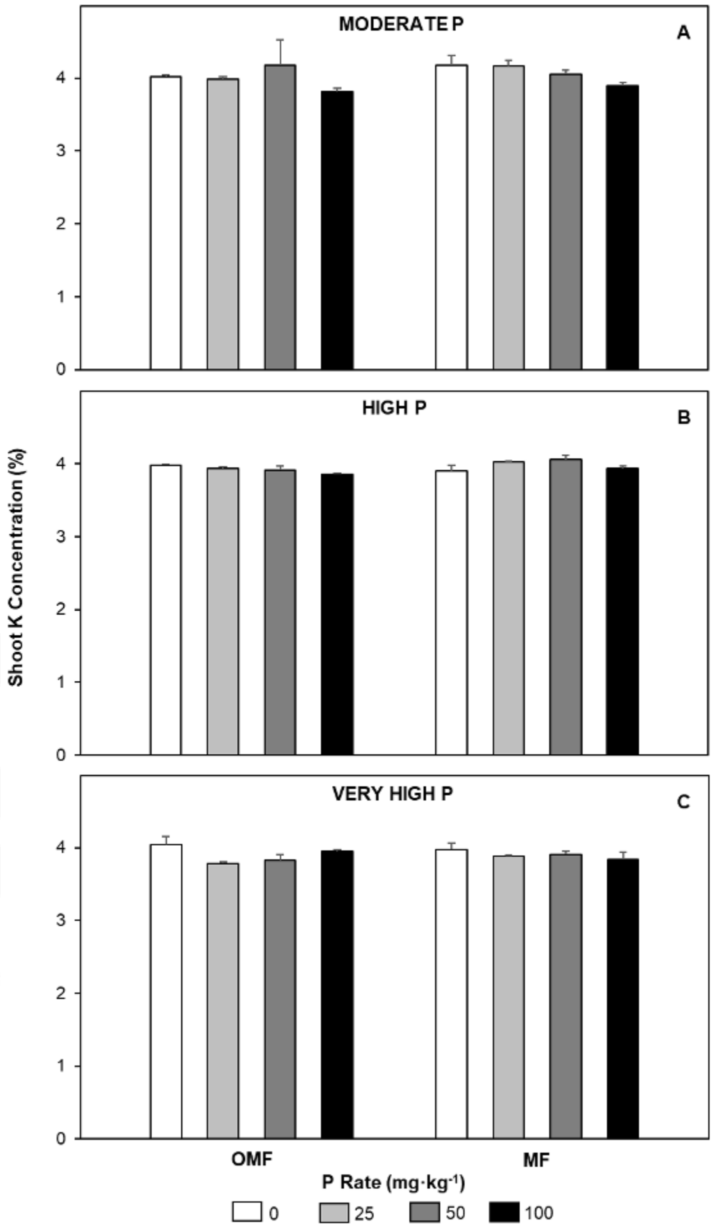

Figure 4.22. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot K concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 107, 108, and 109). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 110).

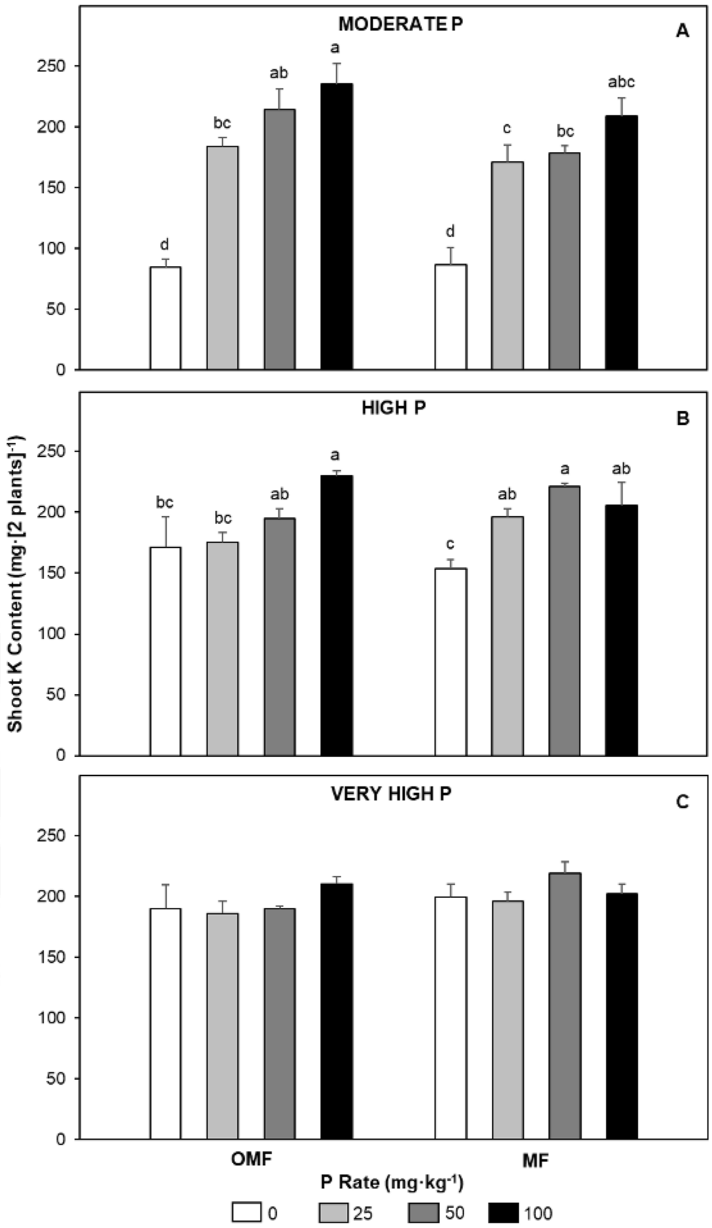

Figure 4.23. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot K content (mg·[2 Plants]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 112, 113, and 114). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 115).

4.1.4.2. Ripening stage

Table 4.5 presents multiple three-way ANOVA findings investigating the effects of various P fertility levels, fertilizer types, P rates, and their interactions on the wheat K nutritional parameters at the end of the ripening stage (103 days post-planting). Based on the findings, the three-way interaction among the independent variables (SOIL P*FERTYPE*RATE) did not significantly influence K nutritional parameters, except for straw K concentration. When considered individually, SOIL P significantly impacted straw K concentration, straw K content, grain K content, and total K uptake, but had no effect on grain K concentration. Moreover, the fertilizer type affected only straw K concentration significantly. The P application rate also caused statistically significant changes in all growth parameters. When binary interactions are considered, SOIL P*FERTYPE did not considerably affect any N nutritional parameter. At the same time, the SOIL P*RATE interaction caused substantial results, except for grain K concentration. With the exception of straw K content and total K uptake, the FERTYPE*RATE interaction was statistically insignificant for all other parameters.

Table 4.5. Results of multiple three-way ANOVA analyses for potassium nutritional status of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil P fertility levels (10.2, 16.4, and 24.1 mg P·kg^{-1} soil), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

	Individual Variables and Their Interactions							
K Nutritional Parameters	**SOIL P**	**FERTYPE**	**RATE**	**SOIL P* FERTYPE**	**SOIL P*RATE**	**FERTYPE*RATE**	**SOIL P* FERTYPE*RATE**	**APPENDIX No**
Ripening Stage								
Straw K Concentration	***	***	***	ns	*	ns	*	116
Grain K Concentration	ns	ns	***	ns	ns	ns	ns	117
Straw K Content	***	ns	***	ns	***	*	ns	118
Grain K Content	**	ns	***	ns	*	ns	ns	119
Total K Uptake	***	ns	***	ns	***	*	ns	120

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Potassium Concentration

Straw K Concentration: The results of several ANOVA analyses (both two-way and one-way), conducted to reveal the contribution of increasing rates of P-containing fertilizers (OMF and MF) in soils with varying P fertility levels to the straw K concentration of wheat plants harvested at the end of the ripening stage, are shown in Figure 4.24. As indicated, straw K concentration was affected by P sources; namely, P-MF applications resulted in significantly higher straw K concentrations than P-OMF treatments throughout all P fertility levels (Figure 4.24A, B, C; uppercase letters). Although not statistically significant in some cases, P application tended to decrease straw K concentration irrespective of the rate applied (Figure 4.24A, B, C; lowercase letters).

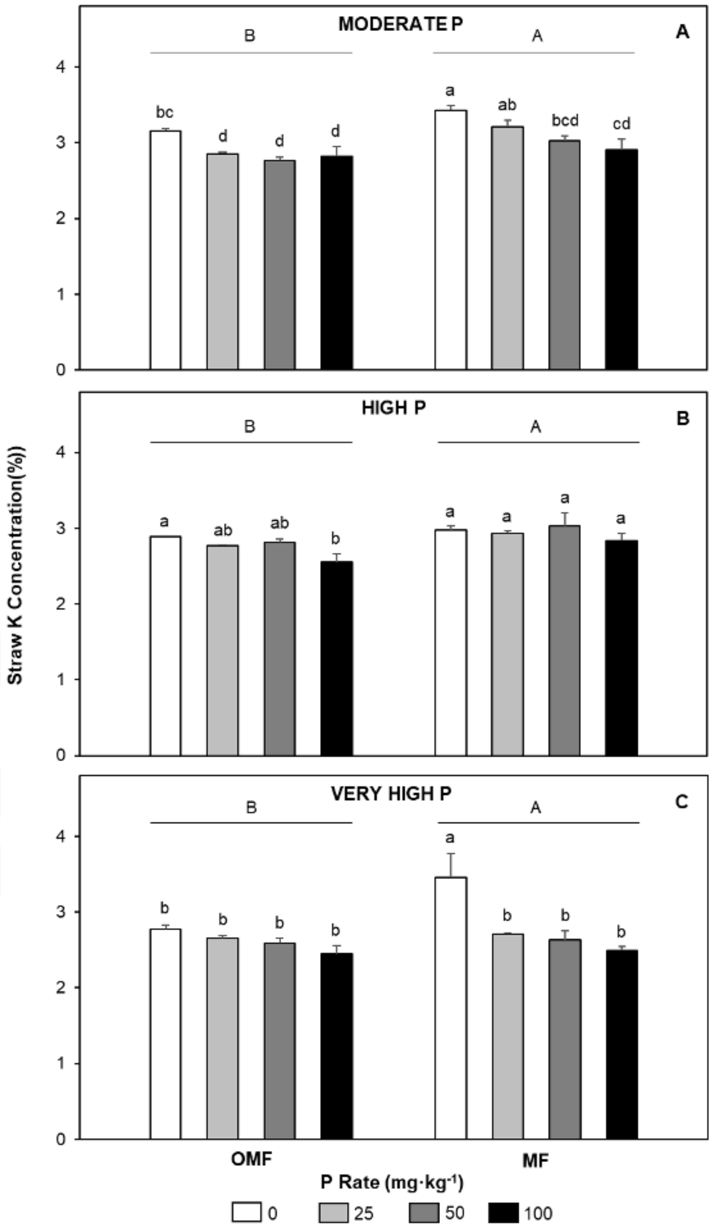

Figure 4.24. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw K concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 121, 122, and 123). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 124).

Grain K Concentration: Figure 4.25 depicts the ANOVA (both two-way and one-way) findings examining the effects of increasing P applications, as either OMF or MF, in soils with increasing soil P fertility levels on grain K concentration. Generally, fertilizer type did not affect grain K concentrations. However, increasing P application rates significantly affected grain K concentrations solely in the MODERATE-P fertility level (Figure 4.25A), where concentrations were lower than those in control treatments.

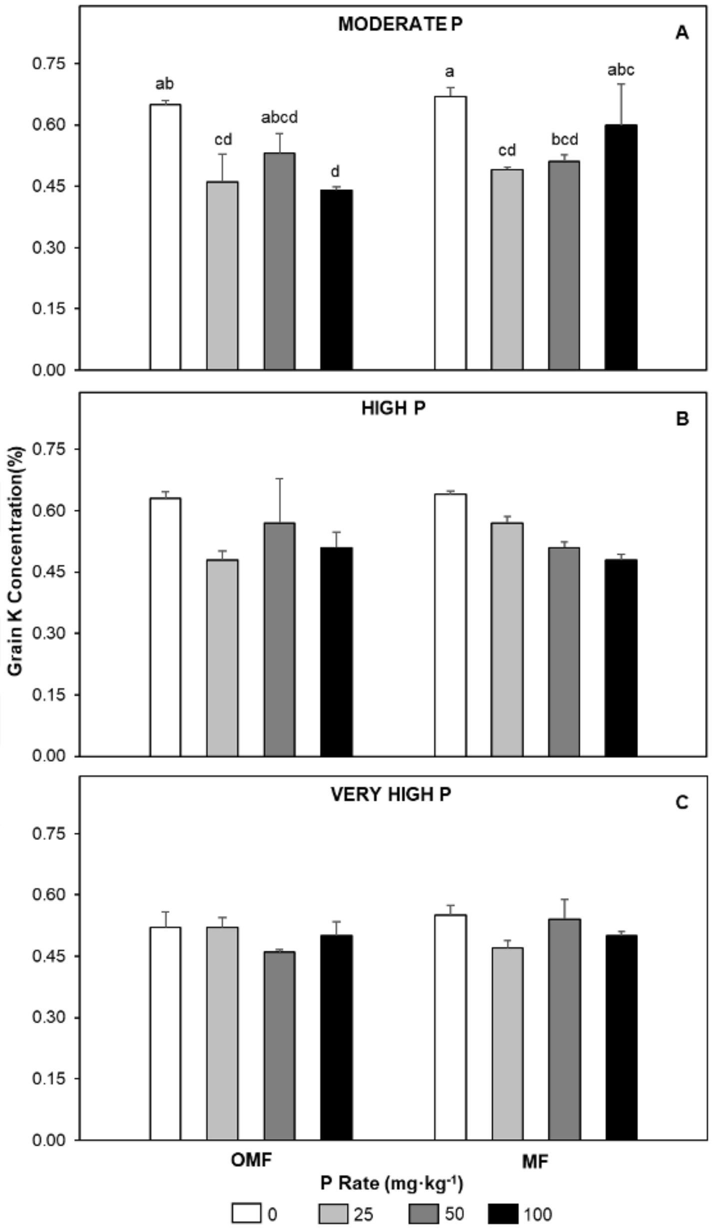

Figure 4.25. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain K concentration (%) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 125, 126, and 127). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 128).

Potassium Content and Uptake

Straw K Content: Figure 4.26 shows the findings of ANOVA analyses (both two-way and one-way) evaluating the effects of different P fertilizer types and P rates on straw K content at each soil P fertility level. The results reveal that the statistically significant impact of P rates on straw K content, noted in MODERATE-P and HIGH-P soils, diminished with higher soil P fertility levels, ultimately disappearing at the VERY HIGH-P level (Figure 4.26A, B, C). Regardless of P fertility levels, fertilizer types did not significantly affect K content (Figure 4.26A, B, C).

***Grain K Content*:**

The results of ANOVA analyses (both two-way and one-way) assessing the effects of different P fertilizer types and P rates on grain K content at varying P fertility levels (MODERATE-P, HIGH-P, and VERY HIGH-P) separately at the end of the ripening stage are shown in Figure 4.27. The analyses indicate no difference in grain K content between fertilizer types (Figure 4.27A, B, C). The P rates did not significantly affect grain K content, except at the MODERATE-P level (Figure 4.27A).

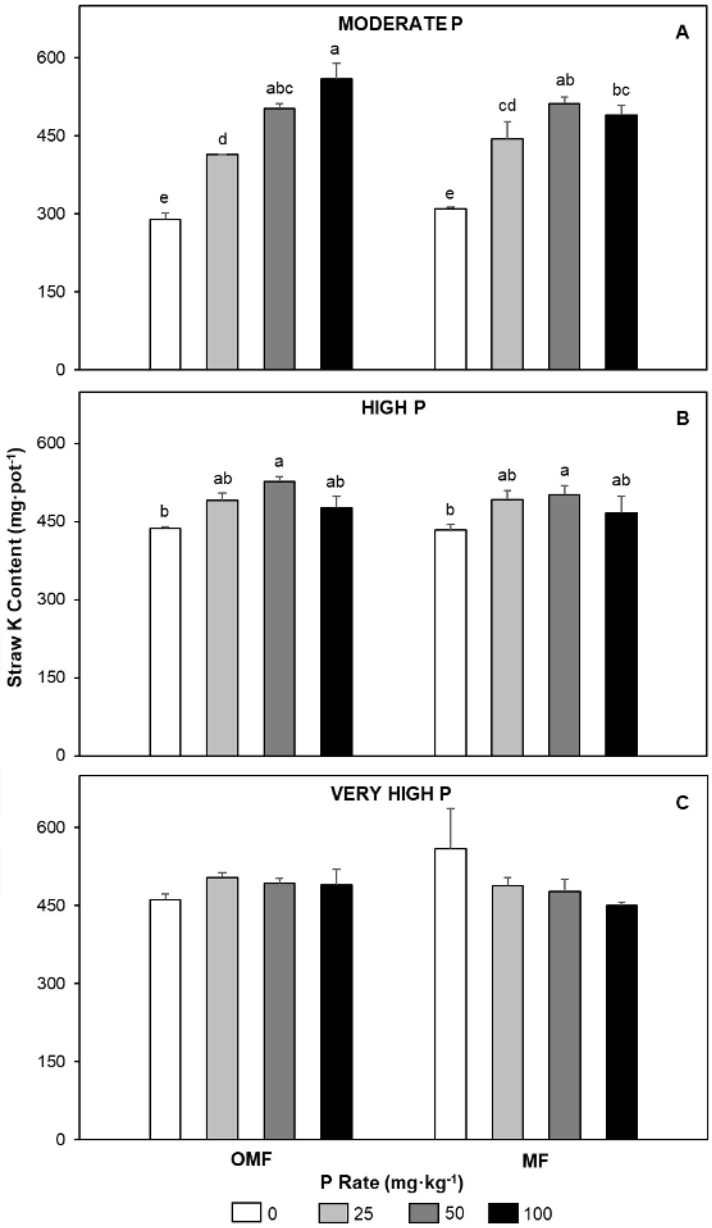

Figure 4.26. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw K content (mg K·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 129, 130, and 131). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 132).

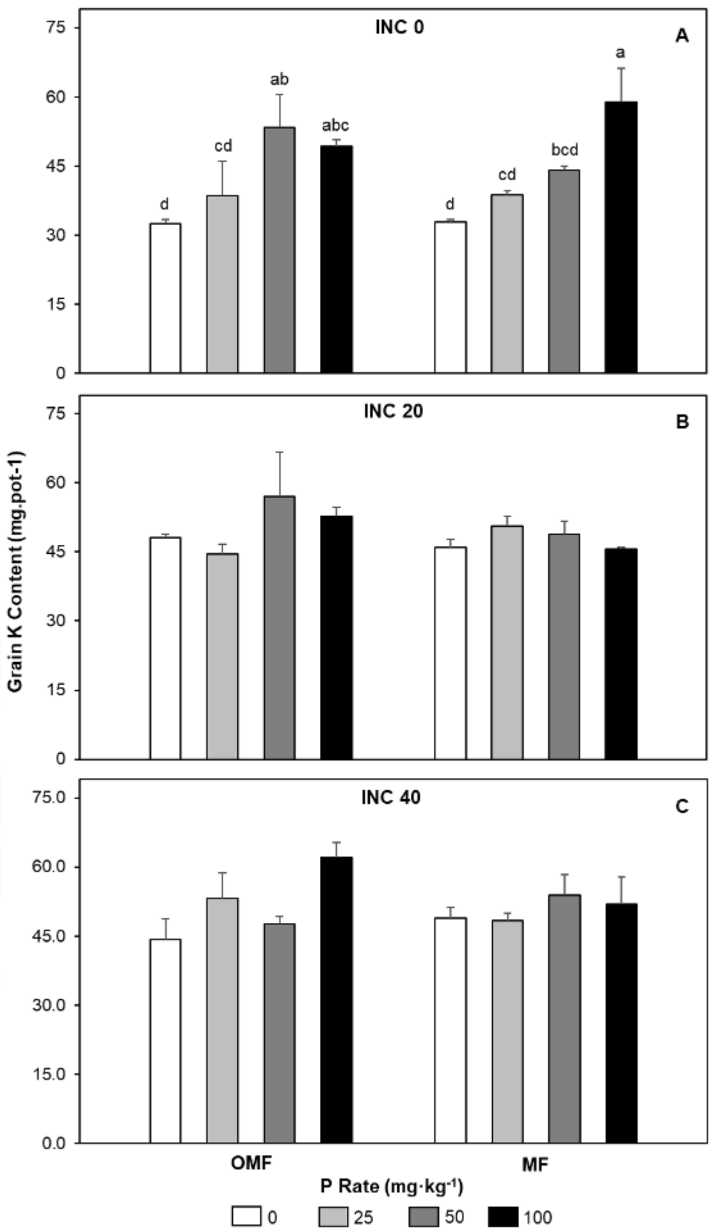

Figure 4.27. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain K content (mg K·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 133, 134, and 135). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 136).

Total K Uptake: Figure 4.28 illustrates the outcomes of ANOVA analyses (both two-way and one-way) evaluating the influence of different P fertilizer types and P rates on total K uptake in wheat plants grown in soils with varying P fertility statuses at the end of the ripening stage. The analyses demonstrate that the significant effect of P rates on total K uptake at the MODERATE-P level (Figure 4.28A) began to diminish as soil P fertility increased to the HIGH-P level (Figure 4.28B), eventually becoming non-significant in soil with the highest soil P fertility, VERY HIGH-P (Figure 4.28C). Across all incubation levels, using different fertilizer types did not significantly impact total K uptake (Figure 4.28A, B, C).

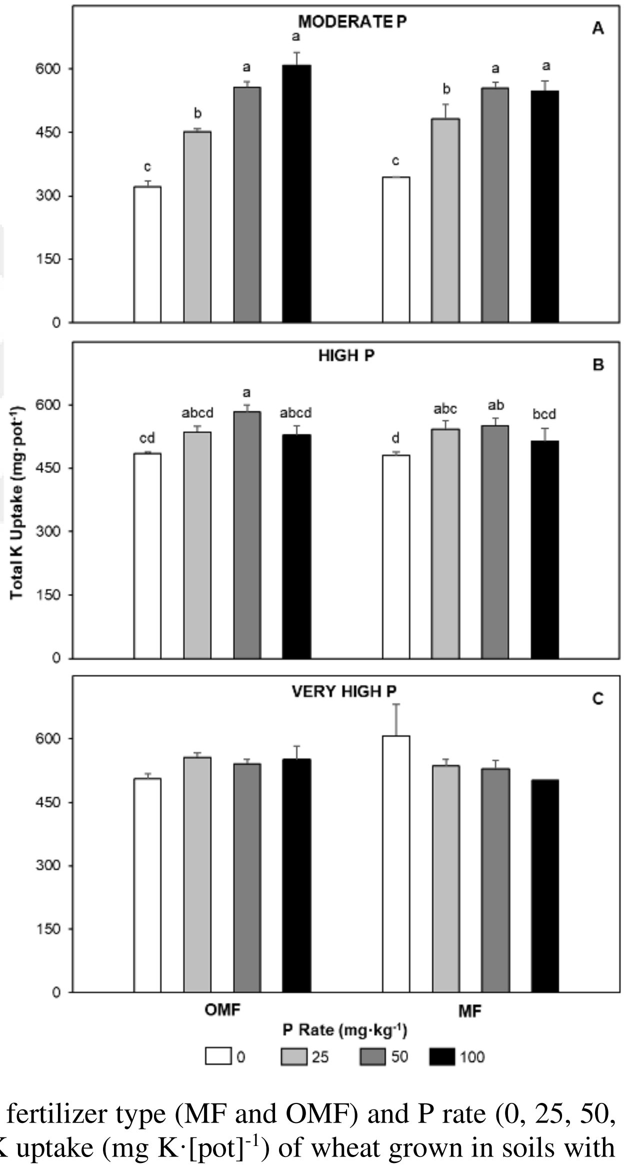

Figure 4.28. Effect of fertilizer type (MF and OMF) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total K uptake (mg K·[pot]$^{-1}$) of wheat grown in soils with different P levels (A, B, and C, respectively, pre-incubated with 0, 20, and 40 mg P·kg^{-1} soil) under greenhouse conditions for 103 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 137, 138, and 139). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 140).

4.2. Comparisons of Granular and Powdered P-Containing Organomineral Fertilizers for Growth and P Uptake of Wheat in a Calcareous Soil (*Experiment II*)

4.2.1. Plant Growth Parameters and Yield

4.2.1.1. Tillering Stage

Appendix 141 presents the results of a three-way ANOVA examining the effects of two different P-containing fertilizer types (P-OMF and P-MF), their two forms (granular and powdered), and four P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil) on the shoot dry weights ($g \cdot [2\ plants]^{-1}$) of wheat plants harvested 45 days after planting, at the end of the tillering stage. The analysis shows that P rates significantly affected shoot dry weight. However, the other individual effects and all interactions were not statistically significant.

The findings of a series of two-way and one-way ANOVA analyses examining the effects of different fertilizer types applied in different forms and P rates on the shoot development of wheat grown for 45 days are depicted in Figure 4.29. A separate test was conducted for each fertilizer form. As demonstrated, shoot dry weight increased with increasing P application, regardless of the fertilizer types (OMF and MF) or forms (granular and powdered), compared to control treatments (no P applied). Although there was no difference between the efficiencies of fertilizers in granular form (Figure 4.29A), P-MF exhibited superior performance over P-OMF when applied in powdered form (Figure 4.29B).

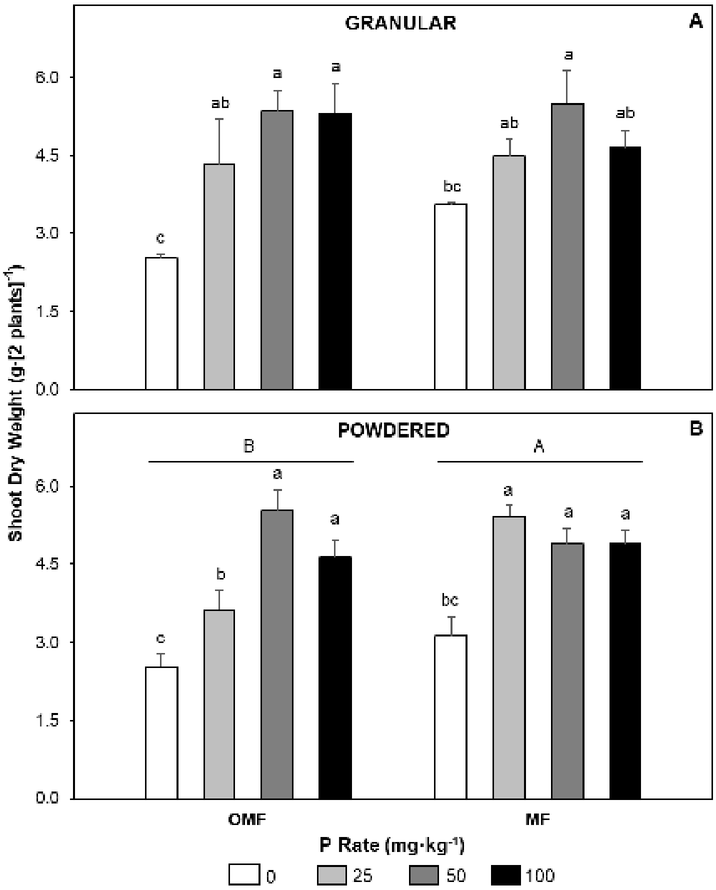

Figure 4.29. Effect of fertilizer type (MF and OMF), their forms (granular and powdered) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot dry weights (g·[2 plants]$^{-1}$) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 142 and 143). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 144).

4.2.1.2. Ripening Stage

Table 4.6 reports the results of multiple three-way ANOVA analyses examining the impact of two P-containing fertilizer types (FERTYPE: P-OMF and P-MF), two forms (FERTFORM: granular and powdered), and four application rates (RATE: 0, 25, 50 and 100 mg P·kg^{-1} soil), along with their interactions, on growth parameters of wheat plants grown for 128 days under greenhouse conditions. Based on the results, the three-way interaction of all independent variables (FERTYPE*FERTFORM*RATE) had no significant effect on wheat growth parameters. The main objective of this greenhouse experiment was to investigate the role of different fertilizer forms (granular and powdered) in the effectiveness of P-OMF and P-MF, focusing on plant growth parameters and the nutritional status of primary macronutrients (N, P, and K). In this regard, it is evident that FERTFORM significantly influenced plant height, biological yield, straw yield, and grain yield. In contrast, its influence on spike length, number of spikes per pot, SPAD reading, and harvest index was insignificant. Additionally, while the type of fertilizer had a statistically significant effect on all parameters except the number of spikes per pot, the P rate affected all parameters. When binary interactions are considered, the FERTYPE*FERTFORM combination did not have statistically significant effects on any growth parameter. Likewise, the FERTFORM*RATE combination demonstrated no statistically meaningful results. Yet, the FERTYPE*RATE interaction produced statistically significant results for all parameters, except the number of spikes..

Table 4.6. Results of multiple three-way ANOVA analyses for growth parameters of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

	Individual Variables and Their Interactions							
Growth Parameters	**FERTYPE**	**FERTFORM**	**RATE**	**FERTYPE* FERTFORM**	**FERTYPE*RATE**	**FERTFORM* RATE**	**FERTYPE* FERTFORM*RATE**	**APENDIX No**
Ripening Stage								
Plant Height	***	*	***	ns	***	ns	ns	145
Spike Length	***	ns	***	ns	*	ns	ns	146
Number of Spikes	ns	ns	***	ns	ns	ns	ns	147
Biological Yield	***	**	***	ns	***	ns	ns	148
Straw Yield	***	**	***	ns	***	ns	ns	149
Grain Yield	***	**	***	ns	***	ns	ns	150
SPAD Reading	***	ns	***	ns	***	ns	ns	151
Harvest Index	***	ns	***	ns	***	ns	ns	152

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Plant Height: Figure 4.30 shows the results obtained from ANOVA analyses (both two-way and one-way) testing the effects of fertilizer types, P rates, and their interactions on wheat plant height, with separate analyses conducted for granular and powdered P-containing fertilizers. In general, P applications significantly increased plant height compared to control treatments, regardless of fertilizer type or form, with P-OMF consistently demonstrating superior performance to P-MF (Figure 4.30; uppercase letters). Notably, plants supplied with the lowest rate of P-OMF (25 mg P·kg^{-1} soil) reached plant heights that were either comparable to (Figure 4.30A; lowercase letters) or higher than those treated with the highest rate (100 mg P·kg^{-1} soil) of P-MF (Figure 4.30B; lowercase letters). When factoring in the RATE, there were no statistically significant differences in plant height among plants treated with P-OMF. In contrast, plants treated with P-MF showed statistically significant differences only when applied in granular form (Figure 4.30A).

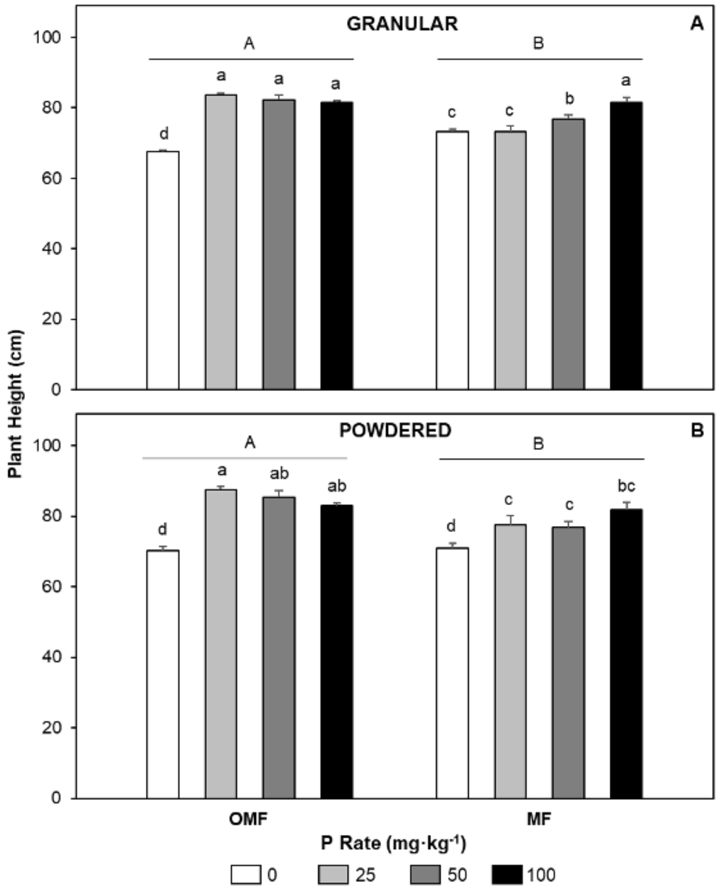

Figure 4.30. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on plant height (cm) of wheat grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 153 and 154). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 155).

Spike Length: The outcomes of ANOVA analyses (both two-way and one-way) conducted to examine the effects of increasing P applications as either OMF or MF, as well as their interactions, on the spike length of wheat plants, are presented in Figure 4.31, where granular and powdered forms of P-OMF and P-MF were evaluated separately. The analyses indicate that P applications significantly increased spike length compared to control treatments, regardless of the fertilizer type or form, with OMF consistently outperforming MF (Figure 4.31; uppercase letters).

Regarding the RATE, no statistically significant differences were found in the spike length of wheat plants supplied with either P-OMF or P-MF (Figures 4.31A, B; lowercase letters). In addition, the spike length of plants treated with the lowest rate of P-OMF (25 mg P·kg^{-1} soil) was statistically similar to that of plants treated with the highest rate of P-MF (100 mg P·kg^{-1} soil), irrespective of fertilizer form (Figures 4.31A, B; lowercase letters), highlighting the superiority of P-OMF over P-MF (Figures 4.31A, B; uppercase letters).

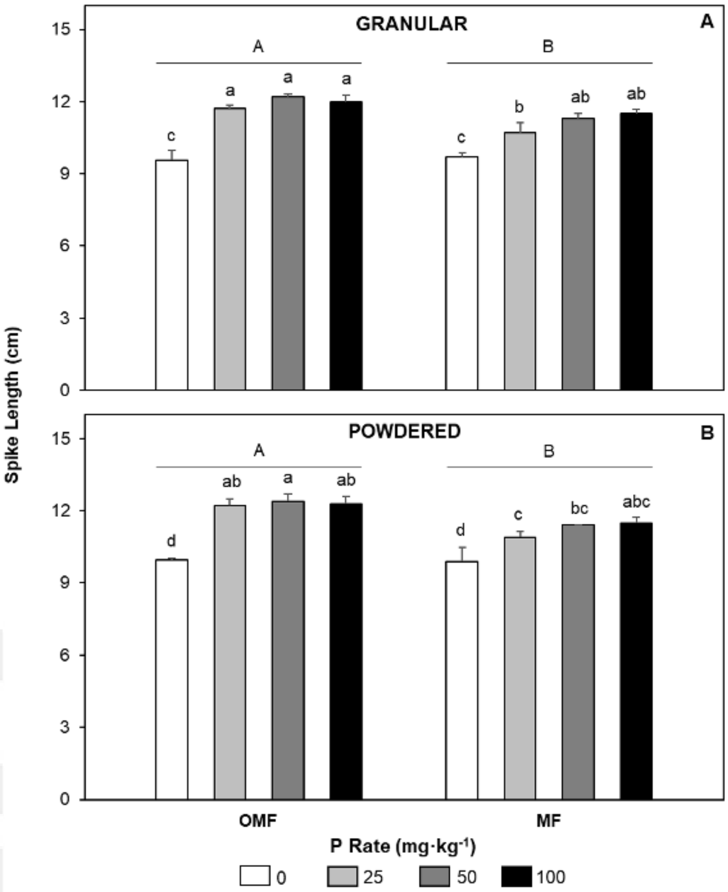

Figure 4.31. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on spike length (cm) of wheat grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 156 and 157). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 158).

Spike Count: Figure 4.32 expands on ANOVA analyses (both two-way and one-way) evaluating the efficiency of increasing P applications using P-OMF and -MF, applied in either powdered or granular form, on the spike numbers of wheat plants in each pot at the end of the ripening stage. Generally, P application in either granular or powdered form did not result in significant differences between P-OMF and -MF (FERTYPE), indicating that both fertilizers performed similarly regarding spike count (Figure 4.32A, B).

Biological yield (Straw + Grains): Figure 4.33 displays the results of ANOVA analyses (both two-way and one-way) investigating the impact of fertilizer types, P rates, and their interactions on the biological yield of wheat, with results provided independently for granular and powdered forms. The results show that P application significantly increased biological yield compared to control treatments, regardless of fertilizer type or form, with OMF consistently outperforming MF (Figure 4.33A, B). In this regard, plants treated with P-OMF yielded total biomass equal to or greater than that of plants supplied with P-MF across all application rates (Figure 33A, B). In particular, plants treated with the lowest rate of P-OMF (25 mg P·kg⁻¹ soil) exhibited comparable dry weights to those treated with the highest rate (100 mg P·kg⁻¹ soil) of P-MF (Figure 4.33A, B). Concerning the RATE, although all types and forms of P-containing fertilizers caused a nearly linear increase in biological yield as rates increased, only powdered P-OMF showed no statistically significant difference between the lowest and highest P rates; all values remained in the highest range (Figure 4.33A, B).

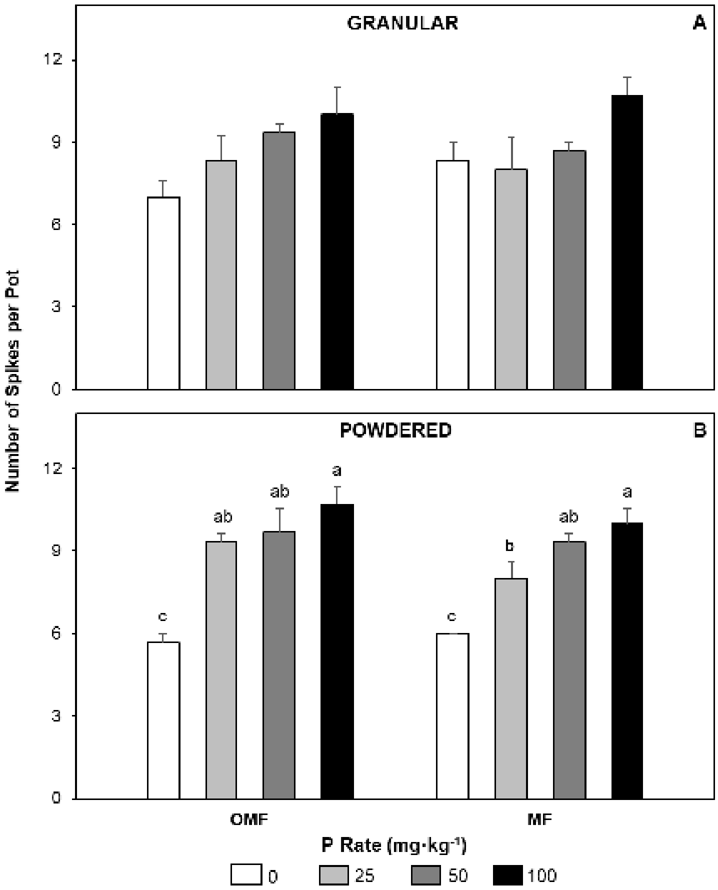

Figure 4.32. Effect of fertilizer type (MF and OMF), their forms (granular and powdered) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on spike count (number of spikes per pot) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 159 and 160). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 161).

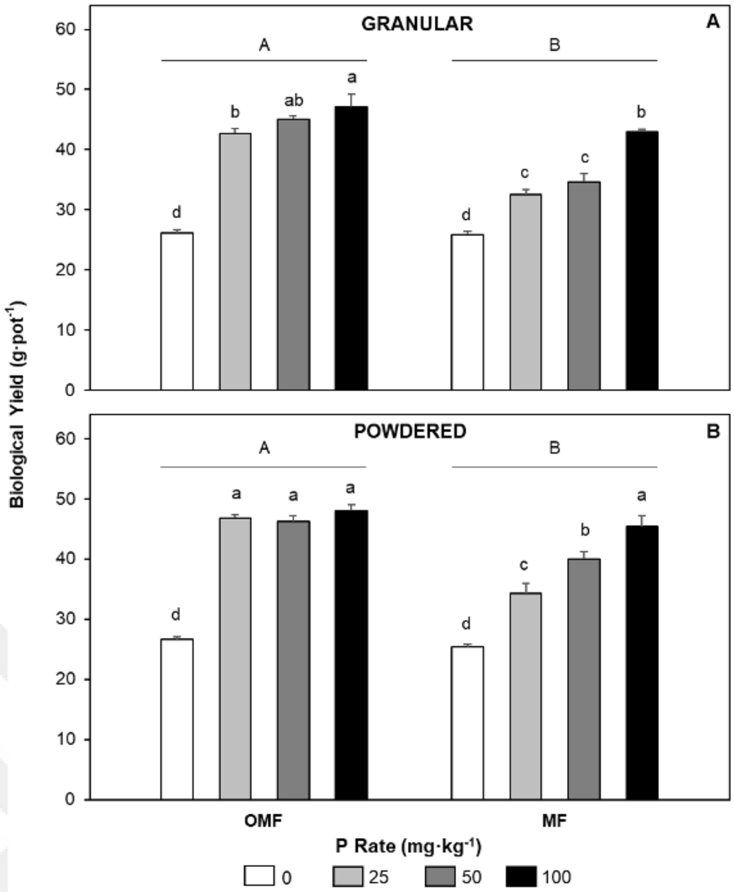

Figure 4.33. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on biological yield of wheat plants (g ·pot^{-1}) grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 162 and 163). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 164).

Straw yield: Figure 4.34 demonstrates the findings of ANOVA analyses (both two-way and one-way) revealing the effects of P-containing fertilizer types, P rates, as well as their interactions on wheat straw yield, with analyses conducted separately for granular and powdered forms of each fertilizer. It is evident that P application significantly increased straw yield compared to control treatments, regardless of fertilizer type or form (Figure 4.34A, B). Furthermore, in line with the biological yield results, the P-OMF consistently outperformed the P-MF (Figure 4.34A, B; uppercase letters).

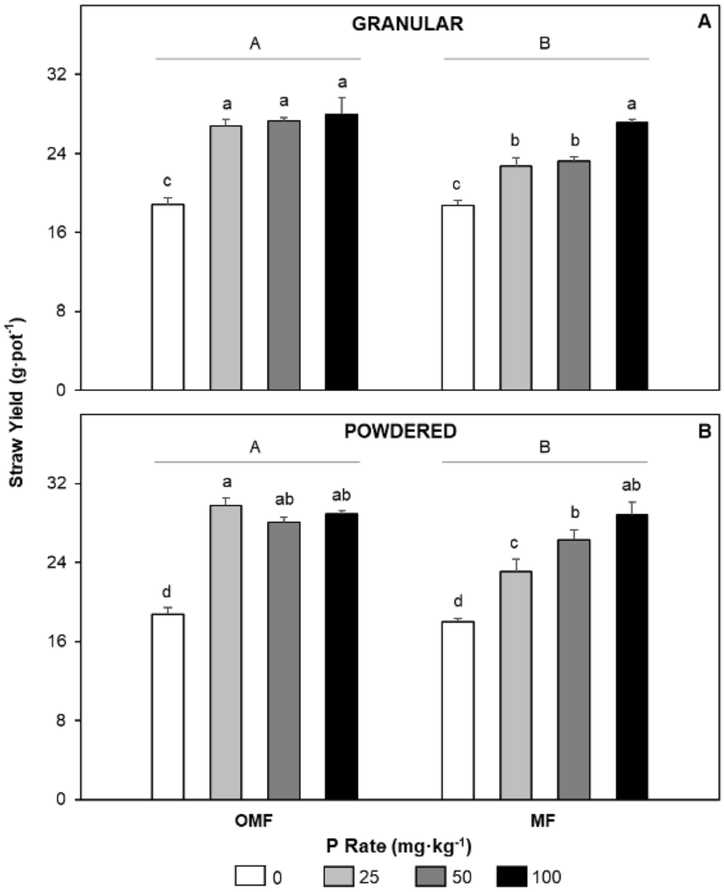

Figure 4.34. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw yields of wheat plants (g·pot^{-1}) grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 165 and 166). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 167).

Grain yield: The findings of ANOVA analyses (both two-way and one-way) on grain yield, showing the effects of P-containing fertilizer types, P rates, and their interactions, are presented in Figure 4.35, with granular and powdered forms of each fertilizer analyzed individually. Overall, P applications significantly increased grain yield compared to control treatments, regardless of fertilizer type (OMF and MF), or form (powdered and granular), with OMF consistently outperforming MF (Figure 4.35A, B). In addition, it is worth noting that plants treated with P-OMF regularly produced grain yields equal to or greater than those observed in plants supplied with P-MF across all application rates (Figure 4.35A, B; lowercase letters). When considering the P rate, the types and forms of P-containing fertilizers caused significant increases (nearly linear) in grain yield with increasing rates.

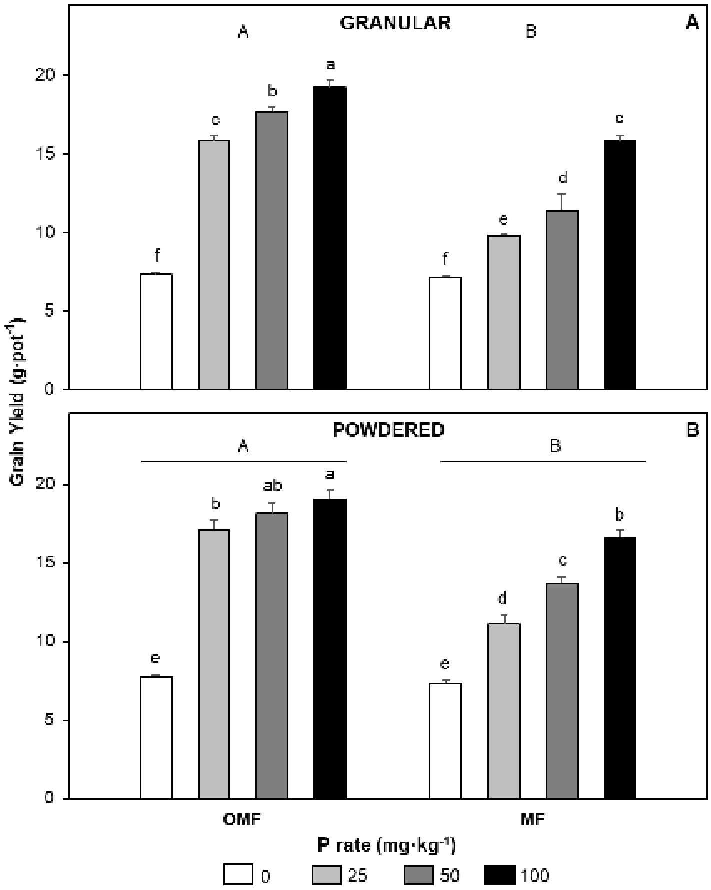

Figure 4.35. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain yield of wheat plants (g·pot^{-1}) grown in a calcareous soil under greenhouse conditions for 126 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 168 and 169). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 170).

SPAD Reading: The outcomes of ANOVA analyses (both two-way and one-way) revealing the effects of two types of P-containing fertilizers, P application rates, and their interactions on SPAD reading values are illustrated in Figure 4.36. The analyses were performed separately for granular and powdered P-containing fertilizers. Increasing P-OMF treatments consistently yielded higher SPAD reading values than P-MF, irrespective of fertilizer form. For P-OMF, increasing P applications led to higher SPAD reading values than control treatments, with no significant differences observed among the escalating rates. In contrast, P-MF applications initially resulted in slight decreases in SPAD reading values at 25 mg P·kg^{-1} soil compared to the control, regardless of fertilizer form (Figures 4.36 A, B). However, it is essential to note that values began to increase at 50 mg P·kg^{-1} soil and eventually reached statistically significant levels at 100 mg P·kg^{-1} soil for both fertilizer forms (Figures 4.36 A, B).

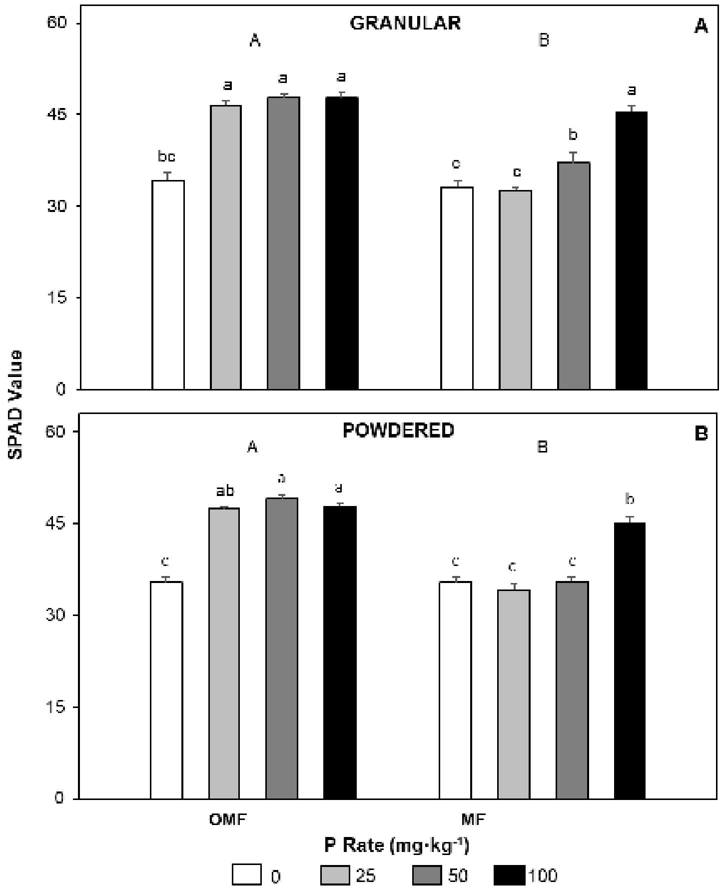

Figure 4.36. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on SPAD reading of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 171 and 172). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 173).

Harvest Index: Figure 4.37 presents the findings of ANOVA analyses (both two-way and one-way) that examined the impact of different P-containing fertilizers, two fertilizer forms, P application rates, and their interactions on the harvest index values of wheat plants. The analyses were conducted separately for granular and powdered forms. It appears that P-OMF treatments consistently yielded higher harvest index values than P-MF, regardless of fertilizer form. Increasing P applications using both fertilizer types and forms led to enhanced harvest index values (Figure 4.37A, B). In all cases, the lowest rate of P-OMF had harvest index values similar to those of the highest rate of P-MF.

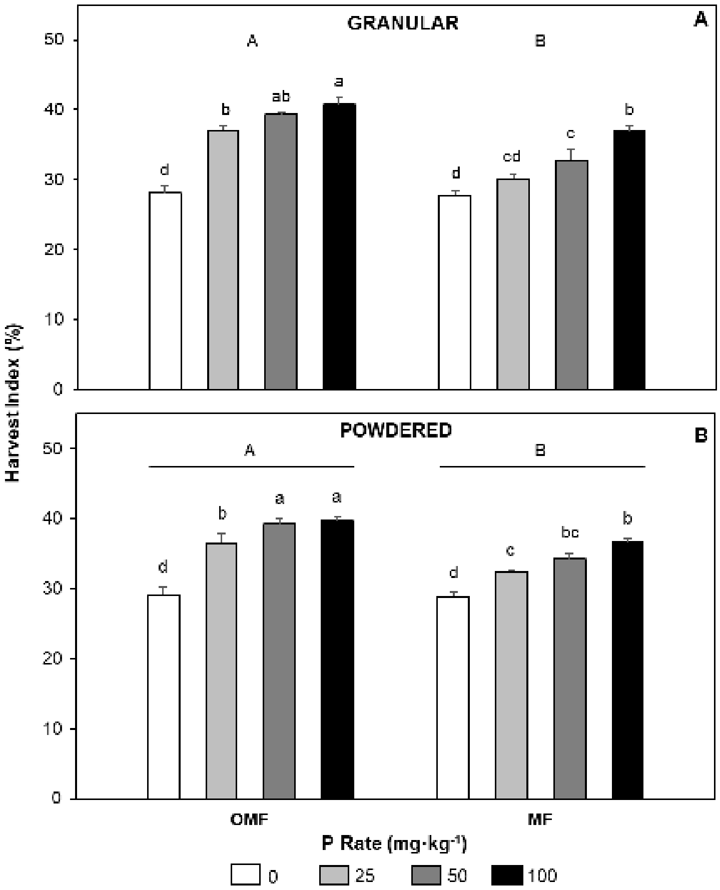

Figure 4.37. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on harvest index (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 174 and 175). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 176).

4.2.2. Phosphorus Nutrition and Uptake

4.2.2.1. Tillering Stage

Shoot P Concentration

Appendix 177 presents a three-way ANOVA investigating the effects of P-based fertilizer types (OMF and MF), fertilizer forms (granular and powdered), P rates, and their interactions on shoot P concentrations in wheat plants harvested at the end of the tillering stage, 45 days after planting. As seen, fertilizer type (P<0.001), fertilizer form (P<0.001), and P rate (P<0.001) had a statistically significant impact on shoot P concentration. Concerning interactions, all interactions except FERTYPE*RATE and FERTYPE*FERTFORM*RATE significantly affected shoot P concentration.

The results of ANOVA analyses (both two-way and one-way) evaluate the contribution of fertilizer type, P application rates, and their interactions to the shoot P concentration of wheat are presented in Figure 4.38. The analyses were conducted separately for each fertilizer form. Irrespective of fertilizer form or type, increasing P application rates resulted in significant increments in shoot P concentration (Figure 4.38A, B). The P concentration in control plants was significantly lower than those supplied with fertilizers (Figure 4.38). When fertilizers were applied in granular form, it was evident that P-OMF at all three application levels resulted in higher shoot P concentrations than P-MF (Figure 4.38A). However, in the case of the powdered form, no statistical differences were observed at any of the three P rates (Figure 4.38B). As demonstrated visually in Figure 4.38 and numerically in the appendices related to this figure, the powdered form consistently resulted in higher shoot P concentrations than the granular form (Appendix 180).

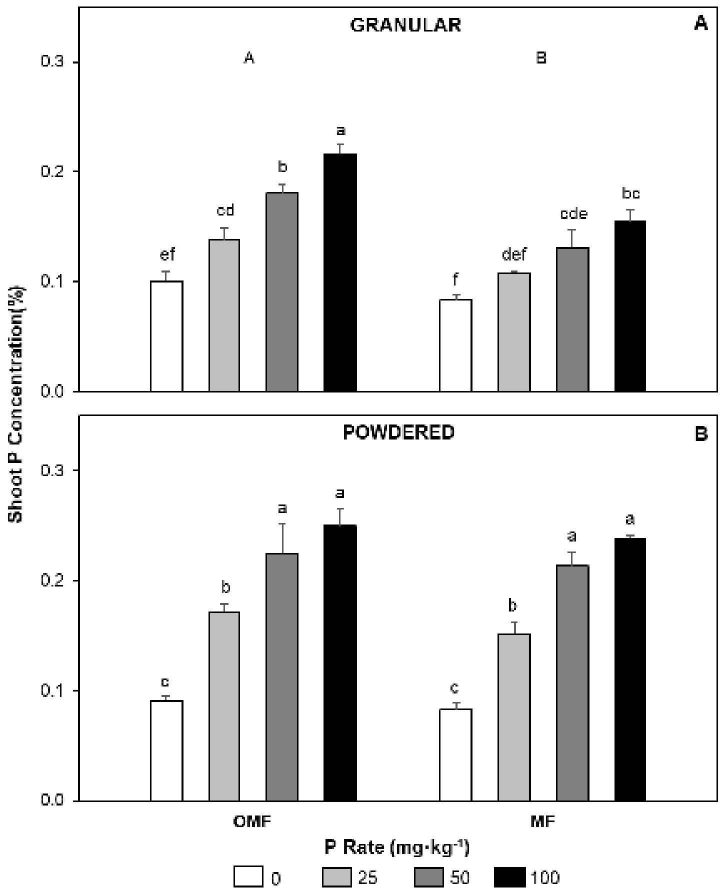

Figure 4.38. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot P concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 178 and 179). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 180).

Shoot P Content

The findings of a three-way ANOVA, detailed in Appendix 181, examine the effects of different types of fertilizers, fertilizer forms, phosphorus (P) rates, and their interactions on shoot P content in wheat plants harvested at the end of the tillering stage (45 days post-planting). The analysis revealed that fertilizer type ($P<0.05$), fertilizer form ($P<0.001$), and P rate ($P<0.001$) were statistically significant factors influencing shoot P content. Regarding interactions, all interactions except FERTYPE*FERTFORM*RATE significantly impacted shoot P concentration, each exhibiting varying levels of statistical sensitivity.

As illustrated in Figure 4.39, shoot P content mirrored the trend observed in shoot P concentration (Figure 4.38A, B). Notably, the P content in shoots increased with rising P application rates, regardless of the fertilizer type or form. Additionally, control plants demonstrated significantly lower P content than those supplied with fertilizers. In granular form, P-OMF was more effective than P-MF in enhancing the shoot P content (Figure 4.39A). However, when applied in powdered form, the overall efficiency of the fertilizers improved, showing no significant difference between OMF and MF (Figure 4.39B).

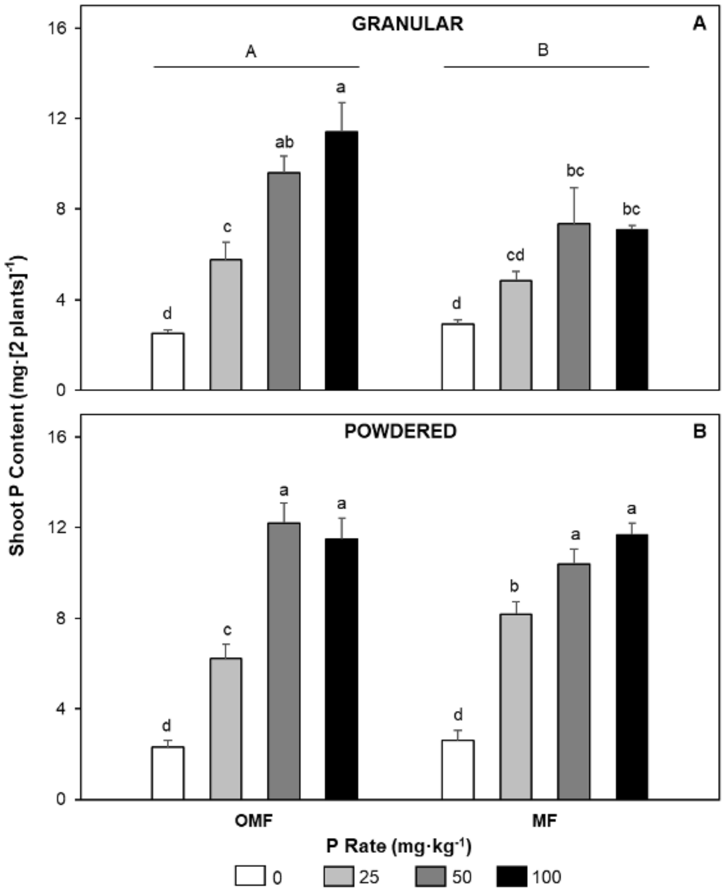

Figure 4.39. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot P content (mg P·[2 plants]$^{-1}$) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 182 and 183). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 184).

4.2.2.2. Ripening Stage

Table 4.7 presents the findings from a series of three-way ANOVA analyses exploring the influence of two phosphorus-based fertilizers, phosphorus application rates, fertilizer forms, and their interactions on the P nutritional parameters of wheat plants harvested at the end of the ripening stage (128 days post-planting). As shown, the three-way interaction among independent variables (FERTYPE*FERTFORM*RATE) did not affect the phosphorus nutritional status of wheat. Concerning FERTFORM, the main focus of this trial, it significantly influenced all parameters related to wheat P nutritional status. Similarly, fertilizer type and form individually caused statistically significant results in all parameters related to P nutrition. Regarding the binary interactions among the variables analyzed in the study, FERTYPE*FERTFORM yielded statistically significant results for grain P concentration, grain P content, and total P uptake. In contrast, straw P concentration, straw P content, and P harvest index exhibited no significant effects. Both

FERTYPE*RATE and FERTFORM*RATE interactions were shown to have statistically significant effects on all parameters related to P nutrition, except for straw P content.

Table 4.7. Results of multiple three-way ANOVA analyses for phosphorus nutritional status of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

P Nutritional Parameters	Individual Variables and Their Interactions							
	FERTYPE	FERTFORM	RATE	FERTYPE* FERTFORM	FERTYPE*RATE	FERTFORM* RATE	FERTYPE* FERTFORM*RATE	APENDIX No
Ripening Stage								
Straw P Concentration	***	***	***	ns	***	**	ns	185
Grain P Concentration	***	*	***	**	***	**	ns	186
Straw P Content	***	**	***	ns	ns	ns	ns	187
Grain P Content	***	***	***	*	**	**	ns	188
Total P Uptake	***	***	***	*	*	*	ns	189
P Harvest Index	***	***	***	ns	*	**	ns	190

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

P Concentration

Straw P Concentration: Figure 4.40 analyzes the ANOVA results (both two-way and one-way) showing the effects of P-containing fertilizers, P application rates, and their interactions on the concentration of P in wheat straw, with results presented separately for granular and powdered forms. As observed, P applications did not produce any statistically significant effect on the straw P concentration of wheat plants when compared to control treatments. Regardless of the type or form of fertilizers, the straw P concentrations in control plants were either higher or comparable to those supplied with P fertilizers, with P-MF outperforming P-OMF (Figure 4.40A, B). While increasing P application of P-OMF in the granular form led to a significant decrease in straw P concentration compared to control treatments, no difference was recorded among all P-MF treatments (Figure 4.40A). Conversely, applying either P-OMF or P-MF in powdered form resulted in a significant reduction in straw P concentration compared to control treatments (Figure 4.40B).

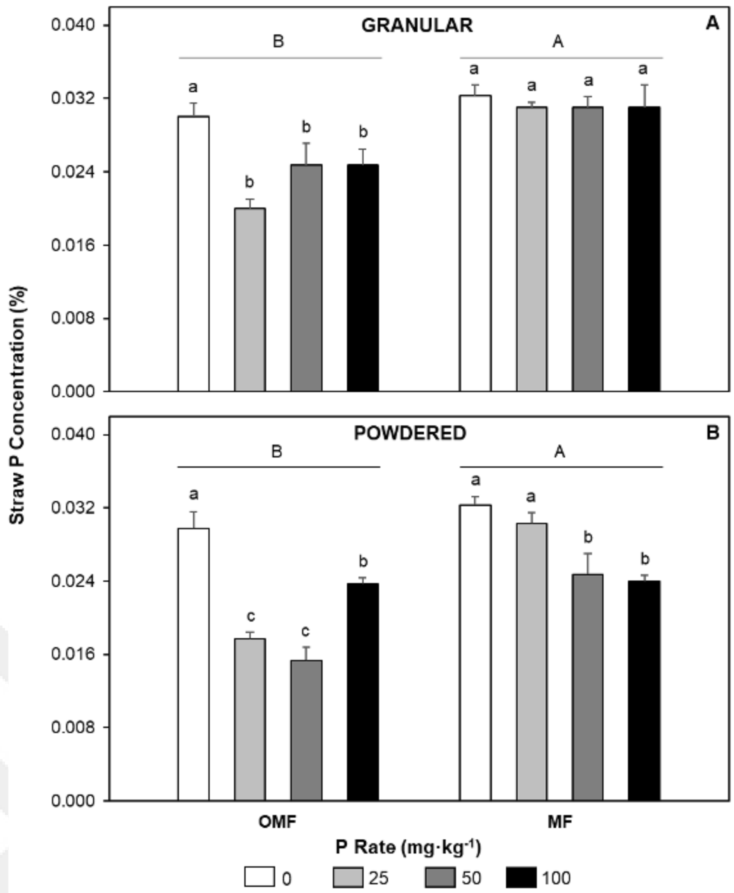

Figure 4.40. Effect of fertilizer type (MF and OMF), their forms (granular and powdered) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw P concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 191 and 192). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 193).

Grain P Concentration: Figure 4.41 illustrates the findings from ANOVA analyses (both two-way and one-way) that assessed the effects of two fertilizer types (OMF and MF) applied in either granular or powdered form, P application rates, and their interactions on grain P concentration. These effects were evaluated separately for each fertilizer form. The P-MF showed statistically better performance in the granular form than the P-OMF (Figure 4.41A). However, these differences do not appear highly significant in the context of the experimental subjects. In the case of powdered fertilizer applications, no significant difference was found between P-OMF and P-MF regarding grain P concentration (Figure 4.41B).

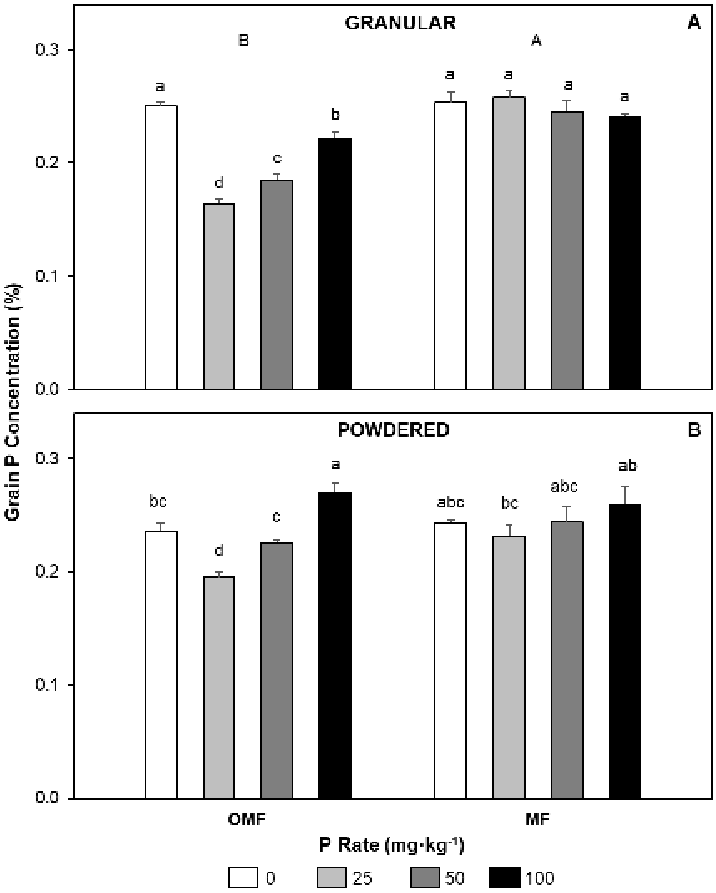

Figure 4.41. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain P concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 194 and 195). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 196).

P Content and Uptake

Straw P Content: The results obtained from ANOVA analyses (both two-way and one-way) in Figure 4.42 examine the impact of P-based fertilizers (OMF and MF) applied in either granular or powdered forms, P application doses, and their interactions on wheat straw P content, with tests conducted separately for each fertilizer form. Consistent with the straw P concentration (%) results (Figure 4.40), P-MF demonstrated statistically significant superiority over P-OMF, regardless of the fertilizer form (Figure 4.42A, B). While both fertilizer sources (FERTYPE) and P application rates (RATE), which were the experimental subjects used in the two-way ANOVA, displayed significant effects on straw P content, no data related to the general interpretation of the experimental results could be obtained for either fertilizer form (Figure 4.42A, B).

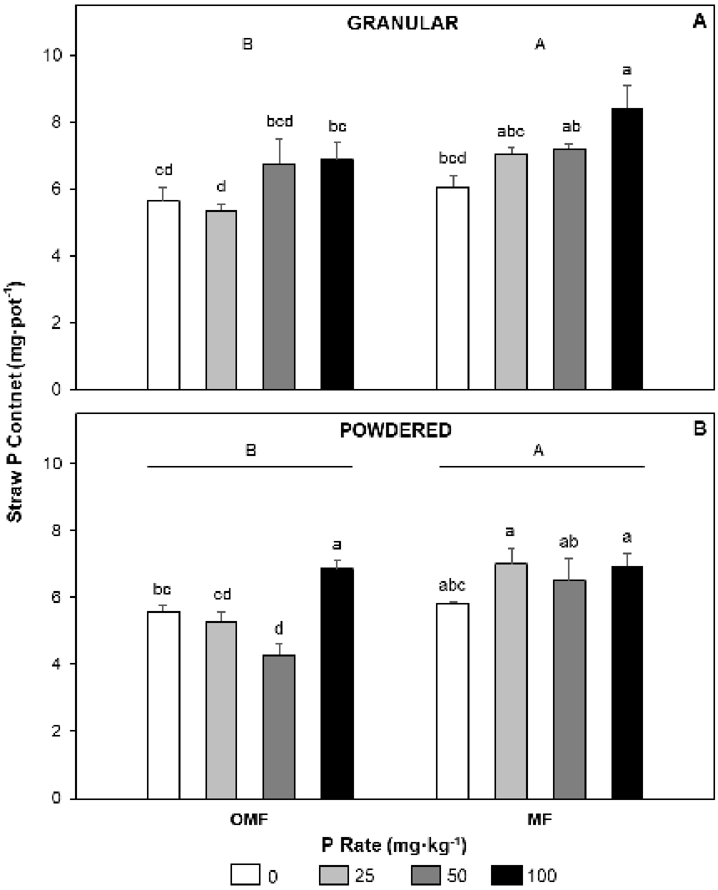

Figure 4.42. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw P content (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 197 and 198). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 199).

Grain P Content: Figure 4.43 shows the results of comprehensive statistical analyses (both two-way and one-way ANOVA) aimed at determining the effects of increasing rates of phosphorus-containing fertilizers, the type and form of fertilizers, and their interaction on the grain P content of wheat plants. The analyses were performed separately for each fertilizer form. The results indicate that higher P treatments significantly increased grain P content, regardless of fertilizer type or form. Moreover, grain P contents in control plants were significantly lower than those in plants receiving increasing amounts of phosphorus-containing fertilizers in granular and powdered forms (Figure 4.43A, B). Notably, the P-OMF consistently outperformed the P-MF; generally, grain P contents were higher with powdered treatments than granular applications (Figure 4.43A, B).

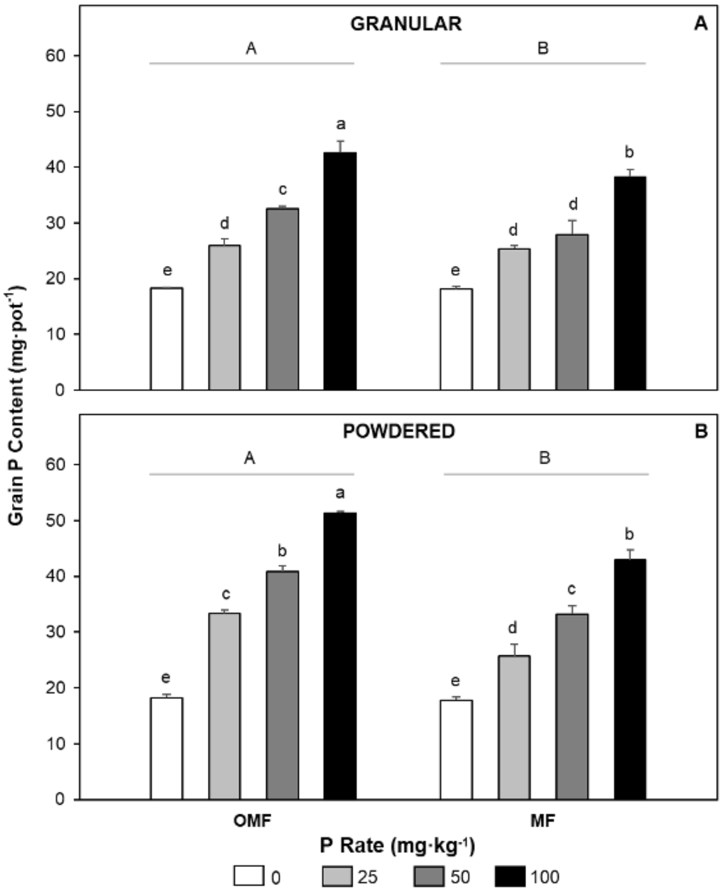

Figure 4.43. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain P content (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 200 and 201). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 202).

Total P Uptake: Figure 4.44 depicts the ANOVA (both two-way and one-way) findings examining the effects of P-containing fertilizers in either granular or powdered form, P application rates, and their interactions on total P uptake by wheat plants. In summary, analyses conducted separately for each fertilizer form indicate that increasing P applications boosted total P uptake by wheat plants at statistically significant levels, regardless of the fertilizer type or form.

Moreover, total P uptake was significantly lower in control treatments (no P) compared to plants treated with increasing amounts of P-containing fertilizers in granular (Figure 4.44 A) and powdered forms (Figure 4.44B). It is important to emphasize that P-OMF outperformed P-MF only in plants supplied with powdered fertilizers (Figure 4.44B), while both fertilizers exhibited similar performance when applied as granules. Total P contents were higher with powdered forms than with granular applications (Figure 4.44A, B).

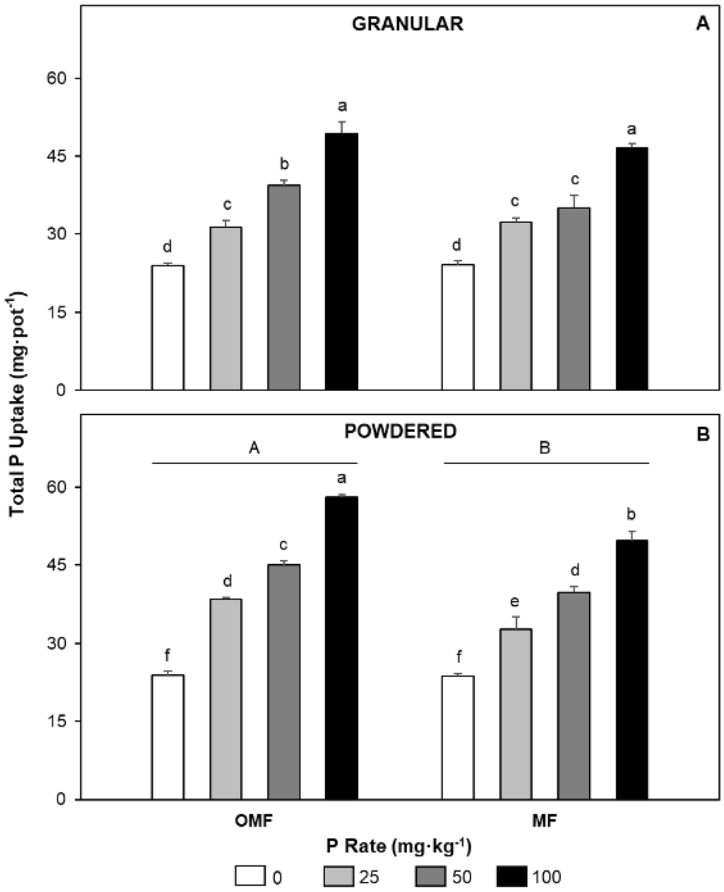

Figure 4.44. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total P uptake (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 203 and 204). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 205).

P Harvest Index (%): Figure 4.45 displays the results of multiple ANOVA analyses (both two-way and one-way) evaluating the effects of various fertilizer types (used in either granular or powdered forms), P application rates, and their interactions on P Harvest Index values. The analyses were carried out separately for each fertilizer form. Regardless of fertilizer type or form, increased P applications resulted in higher P Harvest Index values compared to control treatments, with P-OMF applications consistently producing higher P Harvest Index values than P-MF applications.

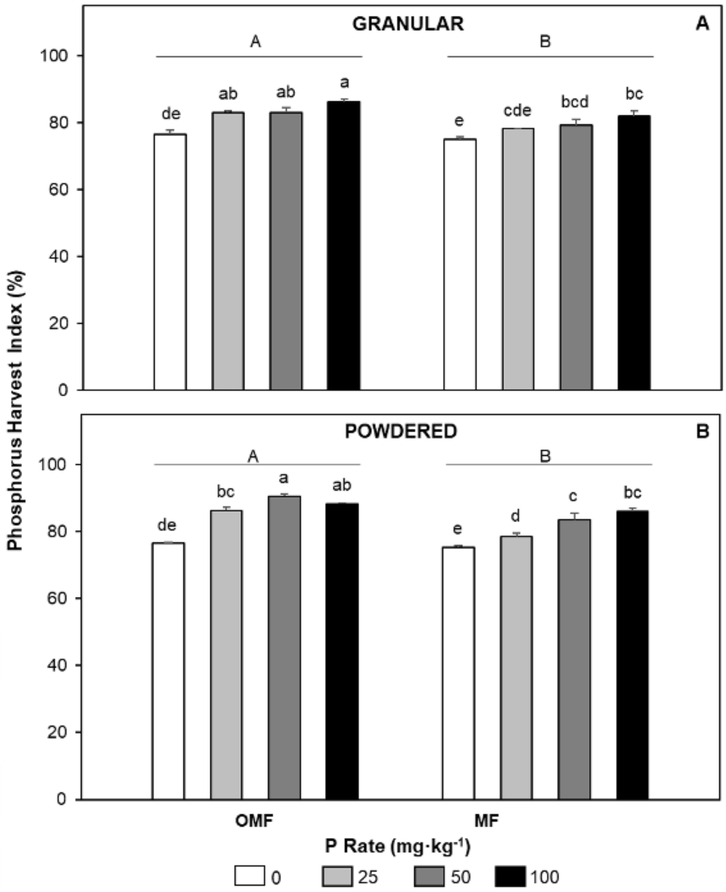

Figure 4.45. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on phosphorus harvest index (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 206 and 207). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 208).

4.2.3. Nitrogen Nutrition and Uptake

4.2.3.1. Tillering Stage

Shoot N Concentration

The outcomes of a three-way ANOVA for shoot N concentration in wheat plants harvested 45 days after planting, at the end of the tillering stage, are shown in Appendix 209. The analysis revealed that fertilizer type, P application rate, and their combined effect significantly influenced shoot N concentration. In contrast, the individual impact of fertilizer form and all other interactions among the factors were insignificant.

Figure 4.46 illustrates the findings of ANOVA analyses (both two-way and one-way) expanding on the impact of different forms of two phosphorus-containing fertilizers, increasing phosphorus application rates, and their interactions on nitrogen concentration in shoots. The analyses were conducted separately for each fertilizer form. According to the findings, plants treated with P-

OMF had statistically higher nitrogen concentration in their shoots than those supplied with P-MF, regardless of fertilizer form. However, when examining the average values of the P rates for each fertilizer type, no significant effects related to the trial subjects were found.

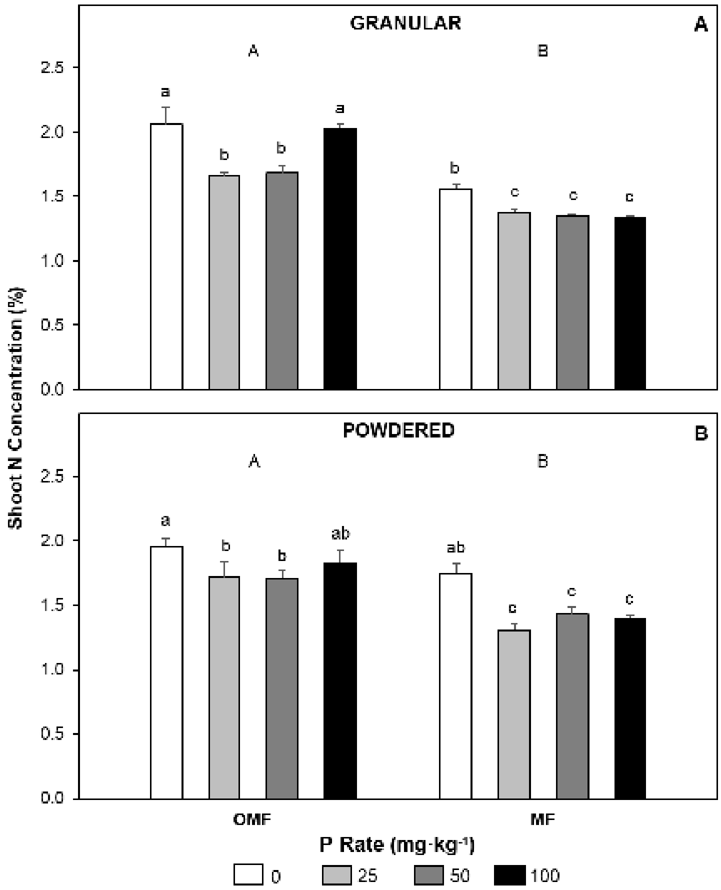

Figure 4.46. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot N concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 210 and 211). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 212).

Shoot N Content

Appendix 213 details a three-way ANOVA test examining the effects of various factors - including P-containing fertilizer types, forms, and rates- on the shoot N content of wheat plants harvested at the end of the tillering stage (45 days after planting). As shown, the shoot N content was significantly affected by fertilizer type (FERTYPE), P rate (RATE), and their interaction (FERTYPE*RATE). However, the individual effect of fertilizer form (FERTFORM), as well as all interactions involving FERTFORM, was non-significant.

The outcomes of multiple ANOVA analyses (both two-way and one-way) in Figure 4.47 further detail the impact of increasing applications of P-containing OMF and MF, fertilizer forms, and their interaction on shoot N content, with the analyses conducted independently for each fertilizer form. Irrespective of fertilizer form, the P-OMF applications led to higher significant shoot N content values than the P-MF (Figure 4.47A, B). In granular form, shoot N contents increased with higher P-OMF treatments, showing substantial differences at the highest application rate (100 mg P·kg^{-1} soil). The shoot N content in the control treatment was considerably lower than in plants supplied with the P-OMF. However, increasing granular P-MF did not alter the shoot N content compared to the control treatment or among the varying fertilizer rates (Figure 4.47A). Increased powdered P-OMF or P-MF applications significantly enhanced the shoot N content compared to control treatments. In addition, while shoot N content increased with higher P-OMF applications, no differences were observed among the higher P-MF applications (Figure 4.47B).

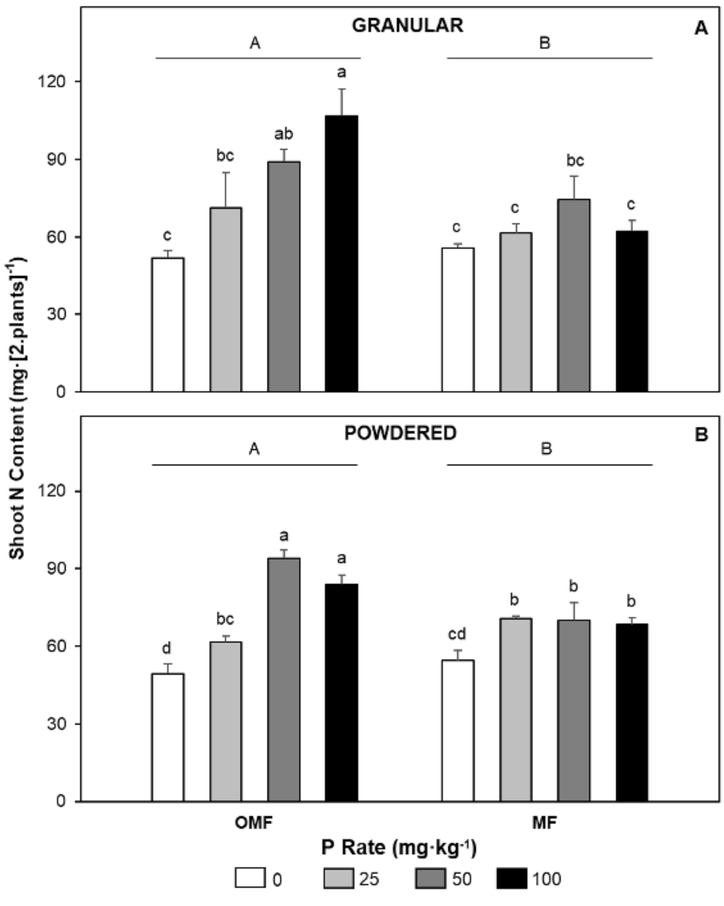

Figure 4.47. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot N content (mg N·[2 plants]$^{-1}$) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 214 and 215). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 216).

4.2.3.2. Ripening Stage

Table 4.8 presents the findings from multiple three-way ANOVA analyses examining the effects of P-based fertilizers (FERTYPE: P-OMF and P-MF), two fertilizer forms (FERTFORM: granular and powdered), and four application rates (RATE: 0, 25, 50, and 100 mg P·kg^{-1} soil), along with their combined effects (interactions) on the N nutritional parameters of wheat plants grown for 128 days under greenhouse conditions. The table indicates that the three-way interaction of FERTYPE*FERTFORM*RATE significantly influenced straw N concentration and content, whereas its effect on other parameters was insignificant. Regarding FERTFORM, the primary focus of this experiment, it significantly impacted only straw N concentration and grain N content. Considering the other two variables of the experiment—fertilizer type and P rate—, it was determined that while P rate significantly affected all N nutritional parameters, fertilizer type affected all parameters except for grain N concentration. Regarding binary interactions, FERTYPE*FERTFORM and FERTFORM*RATE are not significant for any parameter. Yet, the FERTYPE*RATE interaction showed significant effects on all parameters except total N uptake.

Table 4.8. Results of multiple three-way ANOVA analyses for nitrogen nutritional status of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

N Nutritional Parameters	Individual Variables and Their Interactions							
	FERTYPE	**FERTFORM**	**RATE**	**FERTYPE* FERTFORM**	**FERTYPE*RATE**	**FERTFORM* RATE**	**FERTYPE* FERTFORM*RATE**	**APENDIX No**
Ripening Stage								
Straw N Concentration	***	*	***	ns	***	ns	**	217
Grain N Concentration	ns	ns	***	ns	***	ns	ns	218
Straw N Content	***	ns	***	ns	***	ns	*	219
Grain N Content	***	**	***	ns	***	ns	ns	220
Total N Uptake	**	ns	***	ns	ns	ns	ns	221

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

N Concentration

Straw N Concentration: Figure 4.48 illustrates the results of ANOVA analyses (both two-way and one-way) that reveal the impact of P-containing fertilizers -P-OMF and -MF- applied as either powders or granules, the rates of P application, and their interactions on the straw N concentration in wheat plants. The analyses were performed separately for granular and powdered forms. Regardless of fertilizer type and form, P applications significantly lowered straw N concentrations in wheat plants compared to control treatments, with plants treated with P-MF showing significantly higher straw N concentrations than those treated with P-OMF (Figure 4.48A, B).

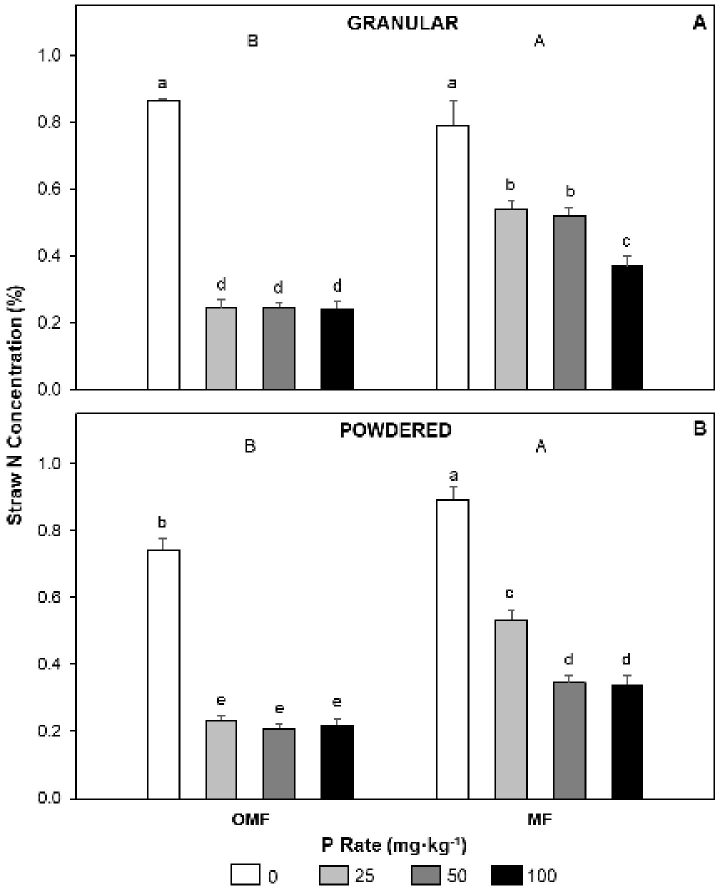

Figure 4.48. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw N concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 222 and 223). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 224).

Grain N Concentration: The findings from ANOVA analyses (both two-way and one-way), shown in Figure 4.49, examine the impact of two P-containing fertilizers applied at increasing rates and in different forms on the N concentration in the grain of wheat plants harvested at the end of the ripening stage (128 days post-planting). The analyses, performed independently for each fertilizer form (granular and powdered), indicated that higher N applications led to lower N concentrations in the grain compared to control treatments, regardless of fertilizer type (Figure 4.49A, B).

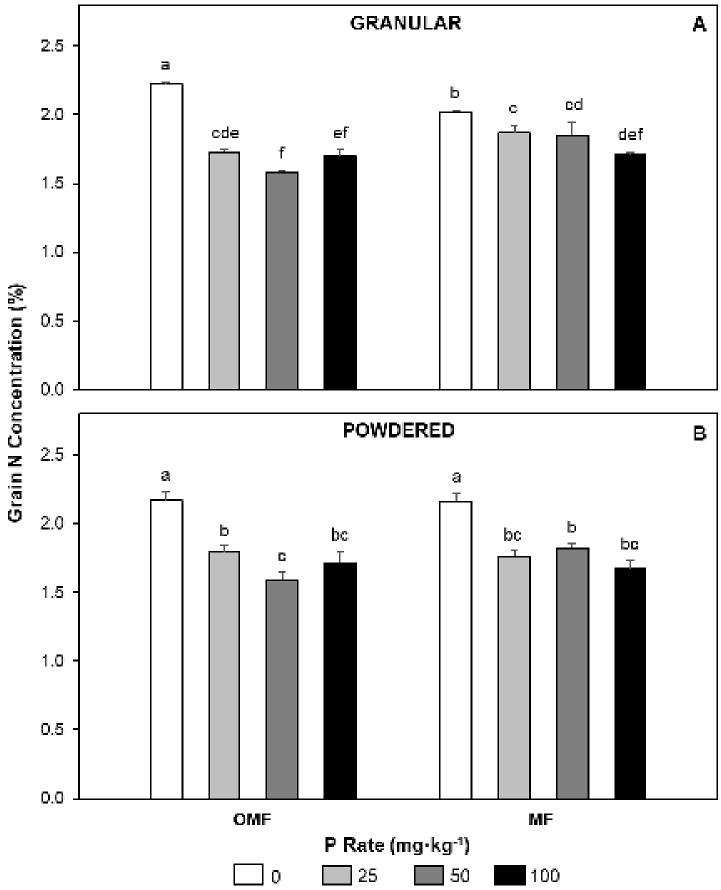

Figure 4.49. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain N concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 225 and 226). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 227).

N Content and Uptake

Straw N Content: Figure 4.50 presents the findings from ANOVA analyses (both two-way and one-way) examining the effects of P-OMF and P-MF, their forms, application rates, and their interaction on straw N content, with analyses conducted separately for each fertilizer form. Overall, the results for straw N content exhibited a similar trend to that of straw N concentration (Figure 4.48). Increasing P applications resulted in significantly lower straw N content compared to control treatments (no P), with plants receiving P-MF consistently showing superior performance over those provided with P-OMF at statistically significant levels, regardless of fertilizer form (Figure 4.50A, B).

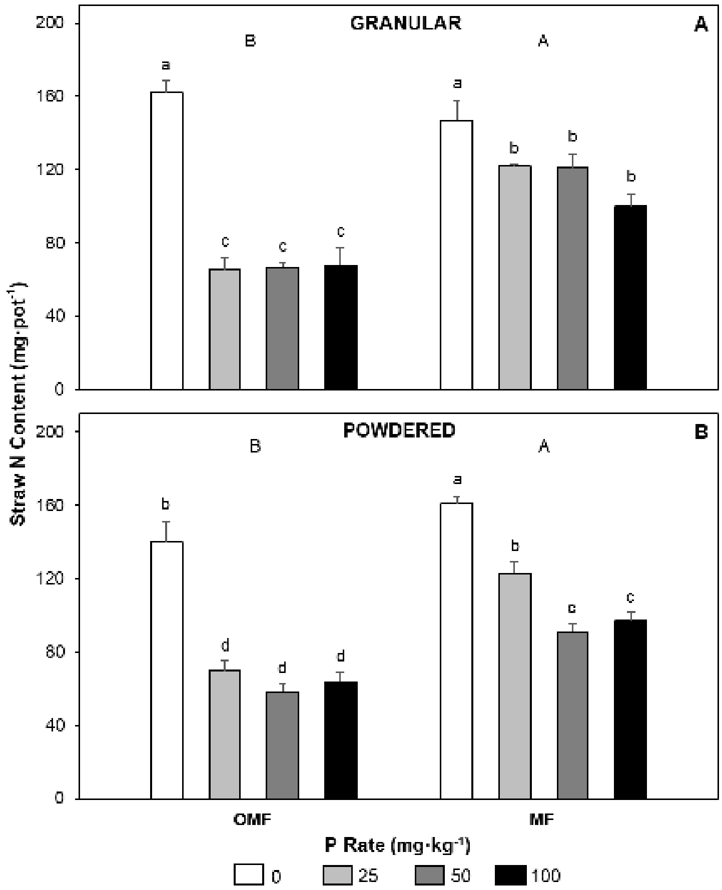

Figure 4.50. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw N content (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 228 and 229). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 230).

Grain N Content: Figure 4.51 shows ANOVA analyses (both two-way and one-way) examining the effects of increasing application rates of two P-based fertilizers applied in either granular or powdered form on the grain N content of wheat plants harvested at the end of the ripening stage (128 days post-planting), with analyses performed independently for each fertilizer form. Regardless of fertilizer form, grain N content increased with higher P doses relative to control treatments, with P-OMF applications yielding significantly higher grain N content than P-MF (Figure 4.51A, B). However, differences among P application rates were more pronounced for plants supplied with P-MF than for those treated with P-OMF.

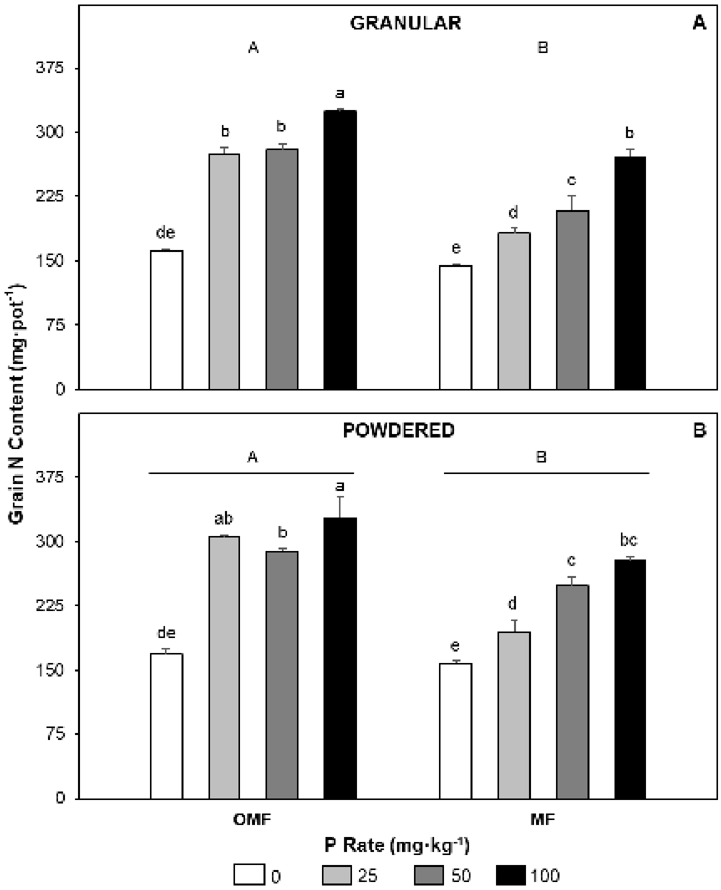

Figure 4.51. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain N content (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 231 and 232). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 233).

Total N Uptake: Figure 4.52 provides a detailed illustration of multiple ANOVA analyses (both two-way and one-way) examining the relationships among fertilizer types, fertilizer rates and fertilizer forms regarding total N uptake, with analyses conducted separately for each fertilizer form. Increasing P applications as OMF or MF, in either granular or powdered form, improved total N uptake to varying degrees. Among the fertilizer types, P-OMF applications in granular form resulted in significantly higher total N uptake compared to P-MF (Figure 4.52A). However, this difference was not present when P-containing fertilizers were applied in powdered form (Figure 4.52B).

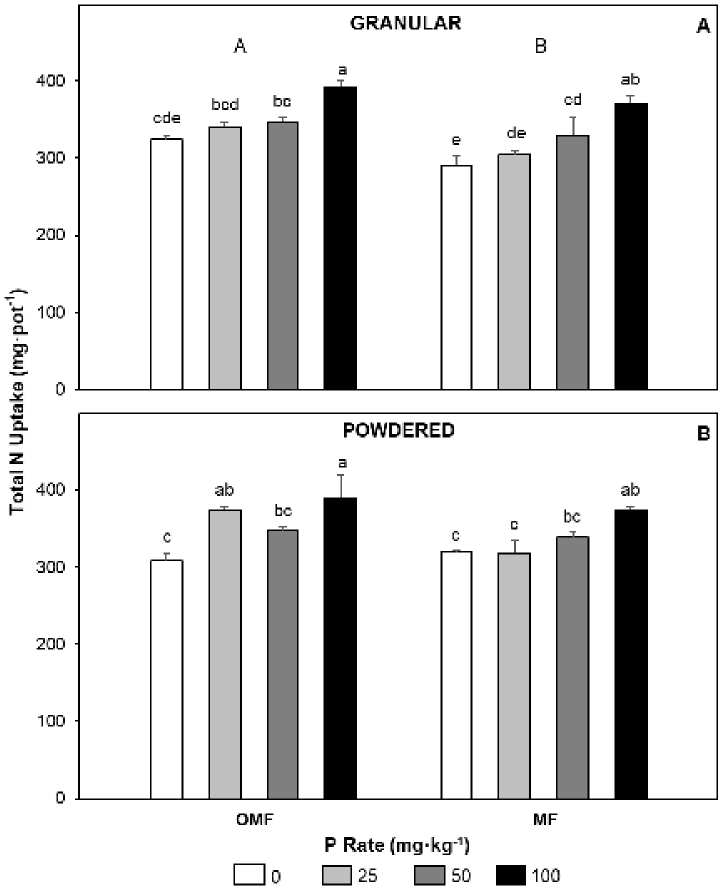

Figure 4.52. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total N uptake (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 234 and 235). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 236).

4.2.4. Potassium Nutrition and Uptake

4.2.4.1. Tillering Stage

Shoot K Concentration

Appendix 237 presents a three-way ANOVA analyzing the effects of fertilizer type, form, P application rate, and their interactions on shoot K concentrations in wheat plants cultivated for 45 days and harvested at the end of the tillering stage. The analysis revealed that shoot K concentration was significantly influenced only by fertilizer type and P rate individually. Concerning the interactions, only the FERTYPE*FERTFORM*RATE interaction was found to be significant.

As illustrated in Figure 4.53, which presents the results of ANOVA analyses (both two-way and one-way) of fertilizer type and P rate, performed separately for each fertilizer form (granular and powdered), statistically significant differences were observed. Specifically, plants treated with P-OMF exhibited significantly higher average shoot K concentrations than those treated with P-MF, regardless of fertilizer form. However, no explanatory results related to the trial subjects were identified when examining the average shoot K concentrations at each P rate for each fertilizer type.

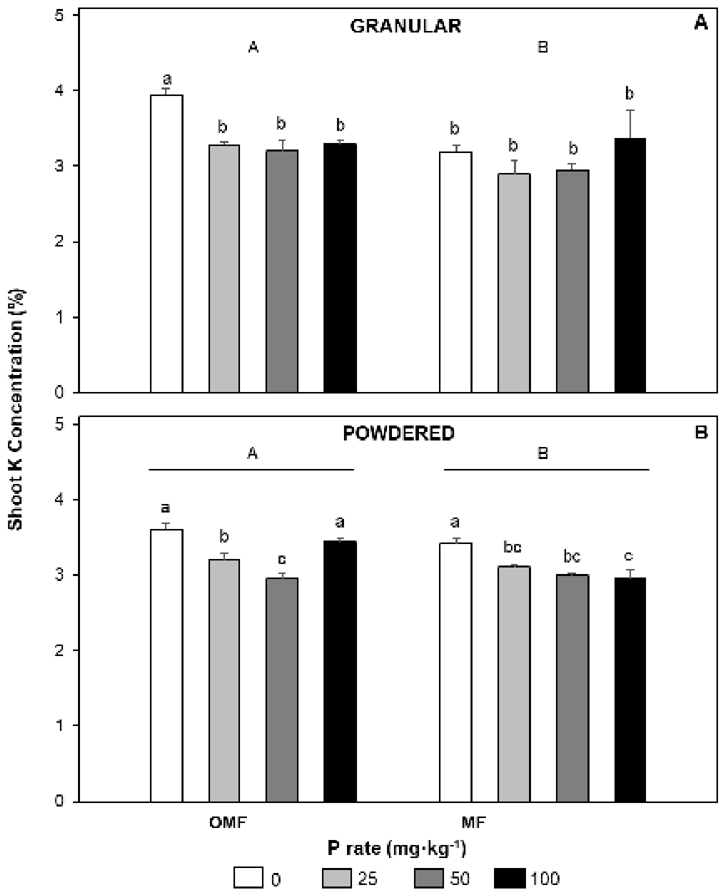

Figure 4.53. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot K concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 238 and 239). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 240).

Shoot K Content

The results of a three-way ANOVA analysis, reported in Appendix 241, show the effects of various factors, including types of P-containing fertilizers, their forms, and application doses on the shoot K content of wheat plants harvested at the end of the tillering stage (45 days post-planting). The analysis indicated that only the P rate (RATE) significantly impacted shoot K content.

Figure 4.54 further details the findings of ANOVA analyses (both two-way and one-way) examining the relationships among fertilizer types, fertilizer form, increasing application rates, and their interactions concerning shoot K content. Across all fertilizer forms, the type of fertilizer did not significantly affect shoot K content (Figure 4.54A, B).

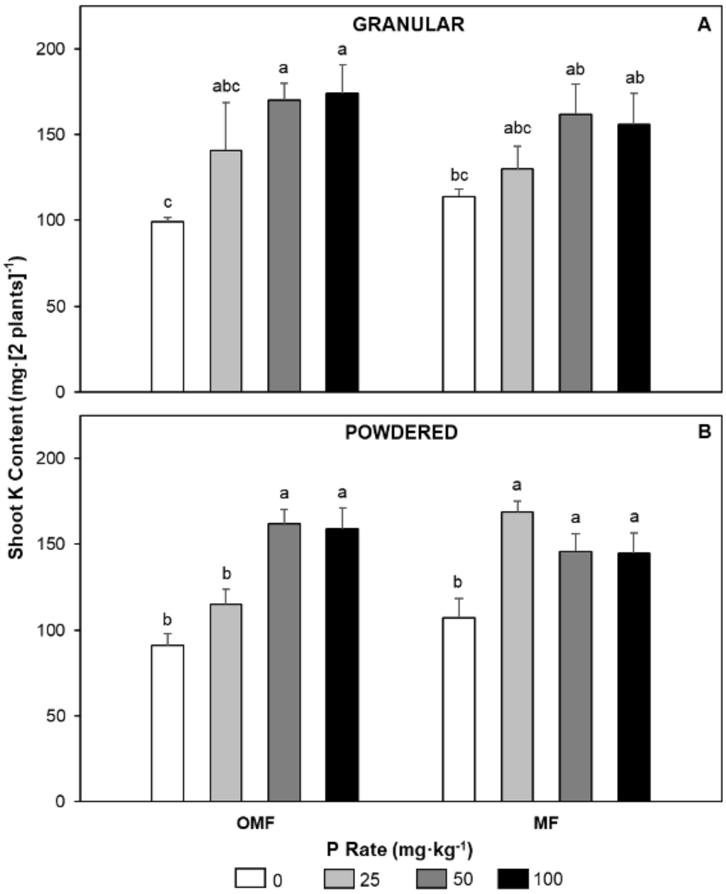

Figure 4.54. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on shoot K content (mg K·[2 plants]$^{-1}$) of wheat plants grown in a calcareous soil under greenhouse conditions for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 242 and 243). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 244).

4.2.4.2. Ripening Stage

Table 4.9 presents the results of multiple three-way ANOVA analyses assessing the effects of two P-containing fertilizers, various fertilizer forms, P application rates, and their interactions on the K nutritional parameters of wheat plants grown for 128 days under greenhouse conditions. The findings indicate that the three-way interaction of FERTYPE, FERTFORM, and RATE significantly affected straw K concentration, straw K content, and total K uptake, though it did not influence grain K nutritional status. Furthermore, FERTFORM, the primary focus of this experiment, significantly impacted all K nutritional parameters except for total K uptake. Regarding other experimental variables, the impact of FERTYPE was found to be significant for all parameters except for the straw K concentration and grain K concentration, whereas RATE had significant effects on all K nutritional parameters. When examining the impact of binary interactions between FERTYPE and RATE on the parameters related to K nutrition, it was determined that this interaction had statistically significant effects on all parameters.

Table 4.9. Results of multiple three-way ANOVA analyses for potassium nutritional status of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

	Individual Variables and Their Interactions							
K Nutritional Parameters	**FERTYPE**	**FERTFORM**	**RATE**	**FERTYPE* FERTFORM**	**FERTYPE*RATE**	**FERTFORM* RATE**	**FERTYPE* FERTFORM*RATE**	**APENDIX No**
Ripening Stage								
Straw K Concentration	ns	**	***	**	***	*	**	245
Grain K Concentration	ns	*	***	ns	*	ns	ns	246
Straw K Content	**	*	***	**	***	ns	*	247
Grain K Content	***	***	***	ns	***	ns	ns	248
Total K Uptake	***	ns	***	**	***	ns	*	249

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

K Concentration

Straw K Concentration: Figure 4.55 shows the outcomes of ANOVA analyses (both two-way and one-way) on wheat straw K concentration, exploring the impact of P-based fertilizers applied in granular and powdered forms at increasing application rates. Results are presented separately for each fertilizer form. Higher P application rates led to decreased straw K concentration in wheat plants compared to control treatments, except for the granular P-OMF application at 25 mg P·kg^{-1} soil. Although significant differences were observed between the fertilizer types, each type proved more effective in a different form. Specifically, P-OMF significantly outperformed P-MF in granular form (Figure 4.55A), while P-MF showed significant superiority over P-OMF when applied in powdered form(Figure 4.55B).

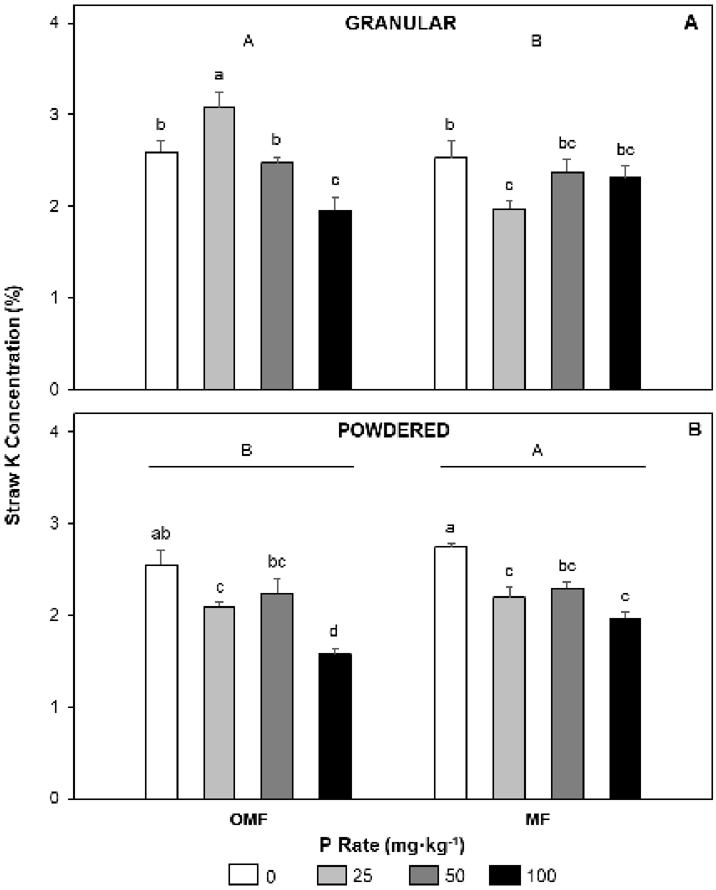

Figure 4.55. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw K concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 250 and 251). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 252).

Grain K Concentration: The results of several ANOVA analyses (both two-way and one-way) elaborating the effects of various P-based fertilizer types, forms, application rates, and their interactions on grain K concentration are shown in Figure 4.56, with analyses carried out separately for each form of fertilizer. Regardless of the fertilizer form, the type of fertilizer did not affect grain K concentration (Figure 4.56A, B).

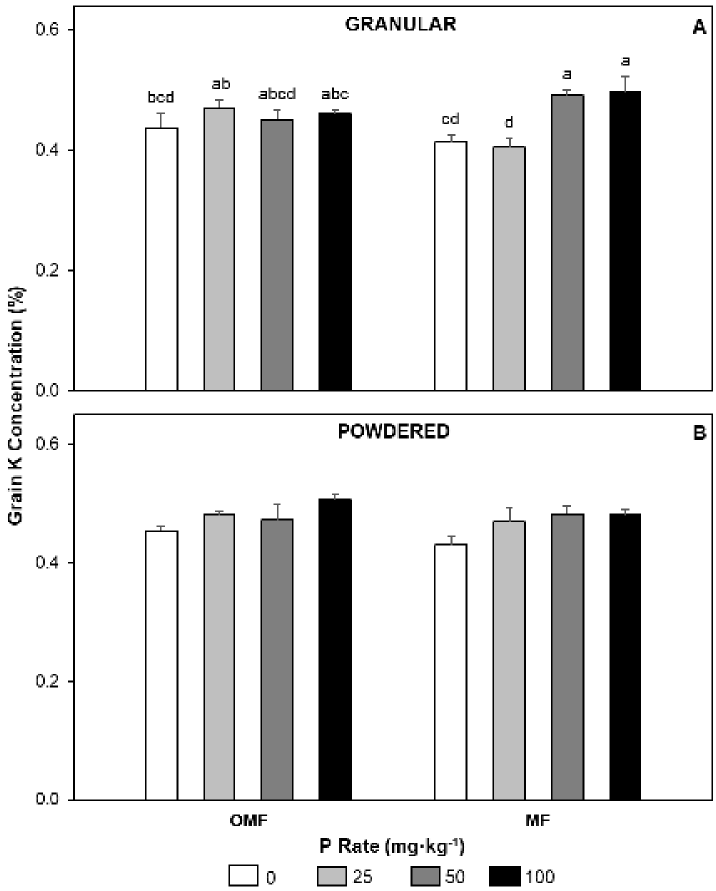

Figure 4.56. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on grain K concentration (%) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 253 and 254). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 255).

K Content and Uptake

Straw K Content: Figure 4.57 presents the findings from multiple ANOVA analyses (both two-way and one-way) examining how different types and forms of P-based fertilizers used in different forms, as well as P rates, and their interactions, affect straw K content. These analyses were conducted separately for granular and powdered forms of each fertilizer. Overall, the impact of fertilizers on straw K content was significantly influenced by the form of the fertilizer. Notably, increasing rates of granular applications of P-OMF showed significantly better performance compared to P-MF. In contrast, no significant difference was observed between the two fertilizers in powdered form. However, when looking at the average values of straw K content obtained at each P rate for each fertilizer type, no precise explanatory results regarding the experimental variables were identified.

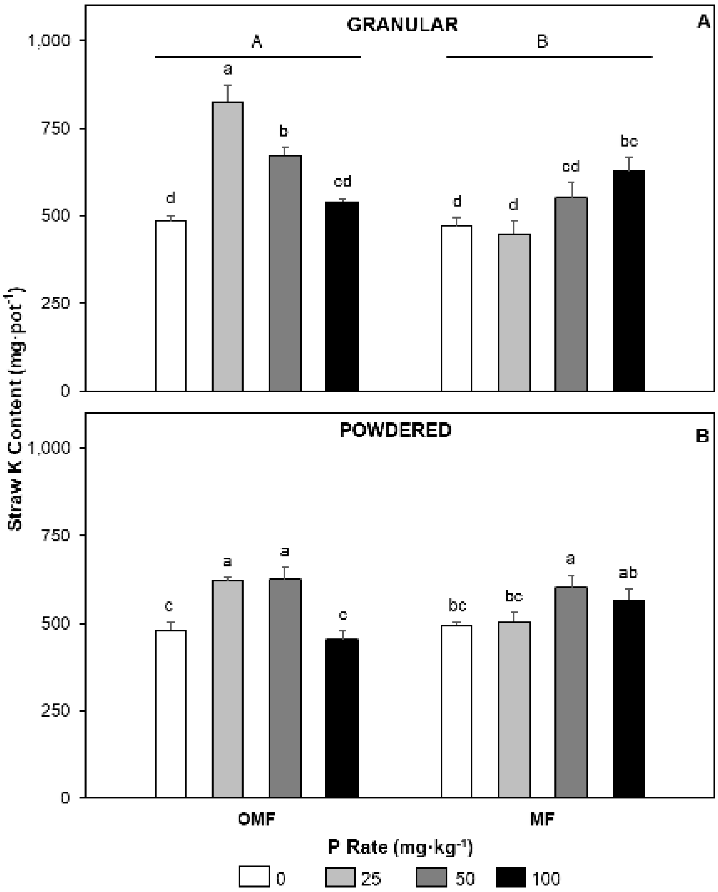

Figure 4.57. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on straw K content (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 256 and 257). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 258).

Grain K Content: The results of ANOVA analyses (both two-way and one-way), shown in Figure 4.58, depict the impacts of various P-containing fertilizers, fertilizer forms, P application rates, and their interactions on grain K content, with analyses performed independently for each form of P-containing fertilizers. Regardless of fertilizer form, plants treated with P exhibited higher grain K content compared to control treatments, with P-OMF applications consistently leading to greater grain K content than P-MF (Figure 4.58A, B).

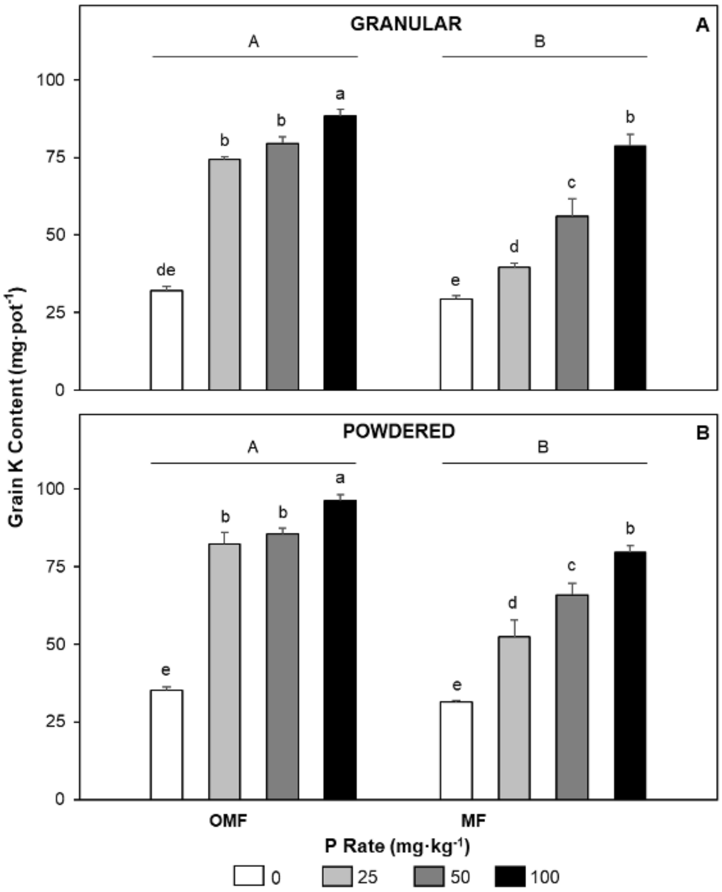

Figure 4.58. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil) on grain K content ($mg \cdot pot^{-1}$) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 259 and 260). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 261).

Total K Uptake: Figure 4.59 illustrates the outcomes of ANOVA analyses (both two-way and one-way), which evaluated the effects of different fertilizer types, P application rates, and their interactions on the total K uptake, with analyses conducted separately for granular and powdered P-containing fertilizers. Specifically, plants treated with P-OMF exhibited statistically higher average total K concentrations in granular form than those treated with P-MF (Figure 4.59A). However, when considering the average values of the P rates for each fertilizer type, no significant explanatory results related to experimental questions were observed.

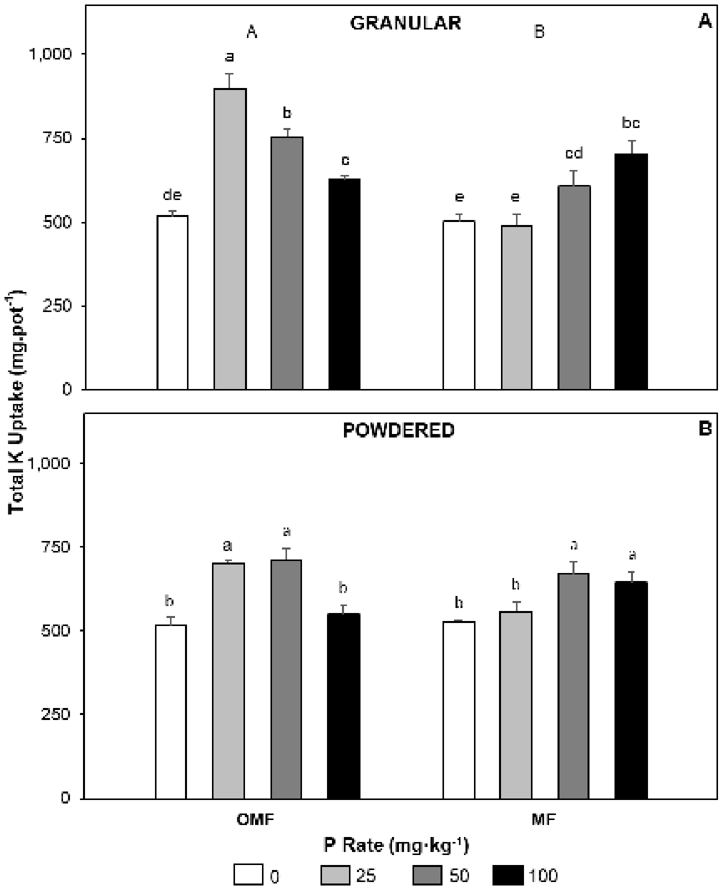

Figure 4.59. Effect of fertilizer type (MF and OMF), their forms (granular and powdered) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on total K uptake (mg·pot^{-1}) of wheat plants grown in a calcareous soil under greenhouse conditions for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 262 and 263). Columns with different letters significantly differ at P ≤ 5% according to ANOVA followed by Duncan's test (Appendix 264).

4.3. Organomineral Fertilizer Forms and Soil Available P Levels (*Experiment III*)

4.3.1. First Sampling (45-days Incubation)

The results of a three-way ANOVA analysis presented in Appendix 265 examined the effects of various P-containing fertilizer types, their forms, P application rates, and their interactions on the Olsen P concentrations in experimental soil incubated for 45 days under laboratory conditions. As observed, soil Olsen P levels were significantly influenced by fertilizer type and application rate, while the effect of fertilizer form was not significant. Among the interactions, only the combination of fertilizer type and fertilizer form showed a significant effect.

Overall, Olsen P levels increased with higher P application rates, regardless of fertilizer type or form (Figure 4.60). For granular applications, P-OMF resulted in significantly higher Olsen P levels compared to P-MF (Figure 4.60A). In contrast, P-OMF and P-MF applications in powdered form produced similar results (Figure 4.60B) underlining the greater efficiency of MF when applied in powdered form compared to OMF.

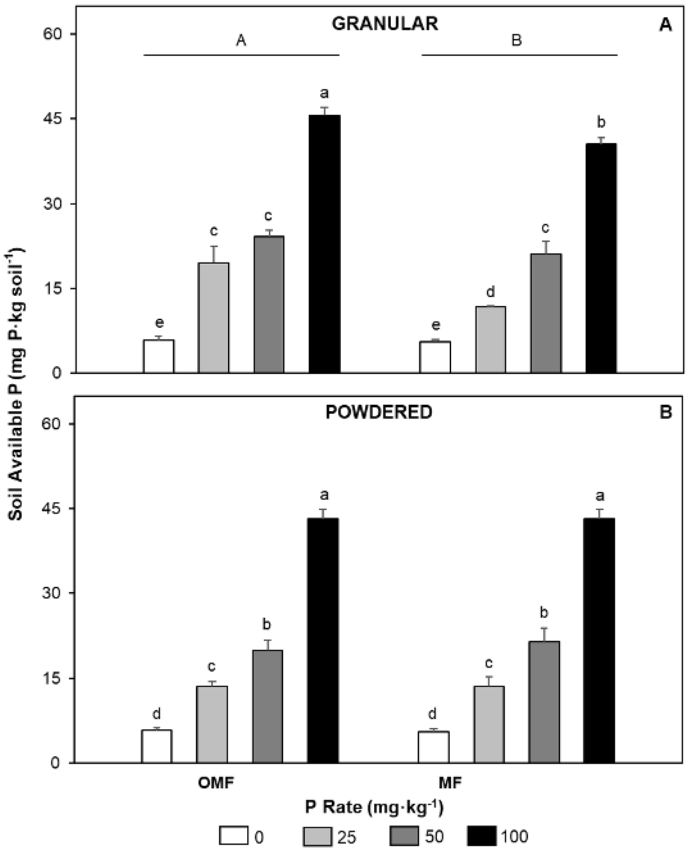

Figure 4.60. Effect of fertilizer type (MF and OMF), their forms (granular and powdered), and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on Soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 45 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 266 and 267). Columns with different letters significantly differ at P≤5% according to ANOVA followed by Duncan's test (Appendix 268).

4.3.2. Second Sampling (128-days Incubation)

Appendix 269 presents the findings of a three-way ANOVA that assesses the impact of various fertilizer types, forms, P application rates, and their interactions on Olsen P concentrations in experimental soil incubated for 128 days under laboratory conditions. The results showed that fertilizer type, P rate, and their interaction (FERTYPE*RATE) significantly affected Olsen P, while fertilizer form and all related interactions did not have a notable impact.

In general, Olsen P levels increased with higher P applications, regardless of the fertilizer type or form (Figure 4.61). Unlike the results from the first sampling, both fertilizer forms resulted in greater Olsen P levels for P-OMF compared to P-MF (Figure 4.61A, B). Irrespective of fertilizer form, P-OMF demonstrated statistically significant superiority over P-MF only at the highest P rate (100 mg $P \cdot kg^{-1}$ soil), whereas at the two lower rates, no significant differences were observed (Figure 4.61A, B).

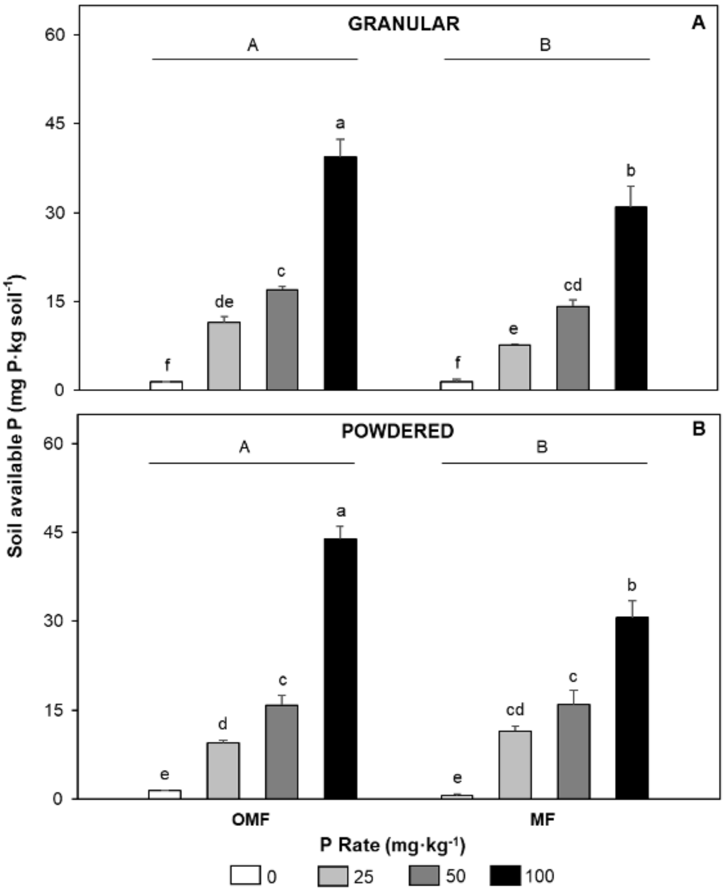

Figure 4.61. Effect of fertilizer type (MF and OMF), their forms (granular and powdered) and P rate (0, 25, 50, and 100 mg P·kg^{-1} soil) on Soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 128 days. Values are the means of three independent replicates ± SE. Capital letters show the significant differences between fertilizer types according to data obtained with two-way ANOVA of fertilizer type and P rate followed by Duncan's test using R statistical software (Appendices 270 and 271). Columns with different letters significantly differ at $P \leq 5\%$ according to ANOVA followed by Duncan's test (Appendix 272).

4.4. Discussion

4.4.1. Effectiveness of P-Containing Organomineral Fertilizers in Growth and P Uptake of Wheat in a Calcareous Soil Differing in P Availability (*Experiment I*)

Plant-available P concentrations in the experimental soil, pre-incubated with MF applications at 0, 20, and 40 mg P·kg soil^{-1} over a 42-day period, differed significantly in such a way that 10.2, 16.4, and 24.1 mg P·kg soil^{-1}, respectively (Table 4.1). According to Defra (2010), these values fall within the lower limit of P Index 1 (10-15 ppm), and lower and upper boundaries of P Index 2 (16-25 ppm), which is the target index for arable crops. In this context, crops grown on soils at Index 1 are expected to show a positive response to higher P fertilizer applications, whereas those on soils at Index 2 are less likely to respond to minor variations between P rates. Hence fertilization at this stage is recommended to be done when convenient. On the other hand, according to Havlin et al. (2016), the obtained Olsen P values of 10.2, 16.4, and 24.1 mg P·kg soil^{-1} representing soils with medium (8-11 ppm), high (12-20 ppm) and very high (>20 ppm) fertility statuses, respectively. So, the plants grown in soils with high and very high Olsen P would not respond to further P fertilization. Considering this information, this discussion section will delve into the impact of increasing Olsen P levels on fertilizer effectiveness with regard to the agronomic performance and the mineral nutritional status of wheat plants.

Under field conditions, the number of spikes·ha^{-1} is considered as a significant yield component for wheat yield and is dependent on the number of tillers·plant^{-1} produced between the tiller development stage and the initiation of jointing (Klepper et al., 1982; Tilley et al., 2019). Considering this greenhouse pot trial was conducted under controlled conditions, the number of spikes per pot is assumed to represent a key yield component. The present study found that the number of spikes·pot^{-1} and shoot dry weight obtained at the end of the tillering stage (g·[2 plants]$^{-1}$), 45 days post-planting, followed the same trend. Notably, both parameters were significantly affected by the application of increasing rates of P applied as either OMF or MF at MODERATE-P soil fertility level (10.2 ppm Olsen P) (Figure 4.1A and 4.4A) compared to control treatment, with OMF demonstrating a significantly superior performance. In a comparable study using the same fertilizers in powdered form and soil type, Erenoğlu et al. (2023) reported the superiority of OMF over MF concerning shoot growth at the end of the tillering stage (45 days post-planting). They attributed this to the significantly higher P uptake of plants as a positive consequence of OMF. Also, a greenhouse trial conducted by Erenoglu and Haciruestemoglu (2022) showed that application of increasing amounts of organic fertilizer derived from a biogas plant along with fixed rates of N, P, and K increased shoot dry weight of wheat grown for 45 days up to 15% relative to plants treated solely with mineral N, P, and K. Likewise, the increments recorded in the present study can be partly explained by the higher, yet statistically non-significant P uptake of plants supplied with P-OMF at the end of the tillering stage in MODERATE-P soil (Figure 4.9A). However, with increments in

Olsen P levels, the effectiveness of fertilizers with regard to shoot dry weight and spike count became comparable (Figures 4.1B, C and 4.4B, C), highlighting the reduced crop responsiveness to fertilizers at high Olsen P levels/fertility statuses (Defra, 2010; Havlin et al., 2016).

Based on the results of the current PhD thesis, increasing rates of OMF or MF in the soil with the MODERATE P fertility level resulted in taller plants and longer spikes compared to the control treatment (Figure 4.2A and Figure 4.3A), with both fertilizers producing similar results across all levels of incubation (Figure 4.2A, B, and C, Figure 4.3A, B, C). These improvements over the control treatment could be attributed to the rising application rates of P (Ahmad et al., 2013; Izhar Shafi et al., 2020), rendering the effect of organic fertilizer (OF) present in the OMF non-significant. However, these findings contrast with the second experiment, where granular OMF significantly outperformed MF for plant height and spike length. This incongruity may be associated with the shorter duration of the first experiment, which was 23 days shorter than the second, causing plants to experience higher temperatures during the rapid growth stage, thereby inhibiting the growth-promoting effects of organic substances such as humic and fulvic acids found in the OF as extensively cited by several authors (Vaughan et al., 1985; Tahir et al., 2011; Canellas and Olivares, 2014; Canellas et al., 2015; Izhar Shafi et al., 2020).

Enhanced crop agronomic performance in soils with high P-fixing capacity following the addition and/or presence of humic substances via organic fertilizers, organomineral fertilizers, or the co-application of organic and inorganic fertilizers (OF+IF) is a well-established phenomenon (Frazão et al., 2019; Izhar Shafi et al., 2020; Frazão et al., 2021; Khan et al., 2022; Erenoğlu et al., 2023). As demonstrated in Figure 4.5 and Figure 4.6, plants supplied with OMF-P led to significantly higher wheat biological yield (straw+grain) and straw yield (straw) compared to MF throughout all levels of incubation. Moreover, control plants' biological and straw yields were significantly lower than those treated with P regardless of the fertilizer source. Regarding the influence of soil P fertility levels on fertilizer effectiveness, it is evident that at moderate P fertility level, biological (Figure 4.5A) and straw yields (Figure 4.6A) significantly increased with increasing P applications, except for MF application at 100 P·kg soil^{-1} which was statistically comparable to the MF rate of 50 P·kg^{-1} soil. Although OMF-P consistently demonstrated better performance than MF-P, the findings clearly state that the effectiveness of both fertilizers in biological yield and straw yield began to diminish as soil fertility level rose to HIGH-P. This decline became more pronounced at the VERY HIGH-P fertility level (Figure 4.5B, C and Figure 4.6B, C).

Findings regarding grain yield (Figure 4.7) revealed that increasing P applications as either OMF or MF produced significantly higher grain yields compared to control treatments at the lower soil P fertility statuses (MODERATE-P and HIGH-P), with OMF leading to statistically more significant grain yield relative to MF. Although OMF outperformed MF when the soil P fertility level was high, increasing P application levels led to more minor differences compared to MODERATE P fertility highlighting an overall decrease in the effectiveness of fertilizers. Following this, the decline in fertilizer effectiveness became more pronounced, removing the superiority between both fertilizer types when the P fertility level was VERY HIGH. The higher grain, straw, and biological yields achieved with OMF over MF in soils with moderate P fertility levels corroborate the findings revealed by several authors (Haroon et al., 2010; Izhar Shafi et al., 2020) and confirms the positive role of organic fertilizers or substances such as humic acids and fulvic acids in improving crop agronomic performance. Such increases in plant growth and yield may be attributed to the growth-stimulating effects of humic substances such as promoting plant root growth (increasing root biomass, root hair, root branching, and inducing lateral roots), which is critical to water and nutrient acquisitions (Canellas and Olivares, 2014). Other combined beneficial effects of HAs and FAs and P affecting plant growth include improving soil physical, chemical, and biological properties, enzyme activation and/or inhibition, changes in membrane permeability, and protein synthesis (Canellas and Olivares, 2014; Canellas et al., 2015). The diminishing return on fertilizer investments concerning straw yield and grain yield at high and very high P fertility levels are in close agreement with the hypothesis put forward by Defra (2010) that soils with Olsen P levels between 16-25 ppm are less responsive to further fertilizer additions.

It is widely recognized that P availability to plants is low due to its reactive nature causing high fixation and precipitation and other unfavorable characteristics such as low mobility and slow diffusion (Havlin et al., 2016; Brady and Weil, 2017), therefore it is considered one of the predominant yield-limiting nutrients for plant growth (Shen et al., 2011; Balemi and Negisho, 2012). As demonstrated in Figure 4.8 and Figure 4.9, at the end of the tillering stage, plants treated with increasing P applications as either OMF or MF had similar shoot P concentrations and shoot P contents regardless of the soil P fertility statuses. Although plants treated with increasing amounts of P-OMF produced higher P uptake compared to those supplied with P-MF at the MODERATE-P fertility level, with P-OMF demonstrating similar performance to P-MF in P uptake, P-OMF produced more biomass (Figure 4.1A). This phenomenon underscores the contribution of organic matter (OM) in OMF to P utilization and plant growth. Our findings align with the work of Erenoğlu et al. (2023), which reported that increasing OMF applications led to higher shoot P contents and shoot dry weight than MF treatments at the end of the tillering stage.

When considering harvesting at maturity, there was no difference between the efficiency of fertilizer sources in increasing straw P concentrations (Figure 4.10A) and grain P concentrations (Figure 4.11A) in soils with the MODERATE-P fertility. Yet, P-OMF applied pots yielded higher straw P content (Figure 4.12A) and grain P contents (Figure 4.13A). Considering higher straw yields (Figure 4.6A) and grain yield (Figure 4.7A) of plants supplied with P-OMF, this outcome can be justified by the phenomenon that the straw P concentrations and grain P concentrations in the OMF-treated plants were affected by the dilution effect. These results are consistent with the total P uptake of wheat (Figure 4.14A) plants grown in soils containing the same soil P fertility level. There was also good accordance with several studies in the literature (Sharif et al., 2013; Izhar Shafi et al., 2020;

Erenoğlu et al., 2023). Increases in soil P fertility level from moderate to high and very high correlated with substantial decreases in P content in straw (Figure 4.12B, C) and grains (Figure 4.13B, C) of wheat plants leading to similar effectiveness of fertilizers. Although P-OMF applications resulted in significantly higher total wheat P uptake than P-MF at HIGH-P (Figure 4.14B), it was only due to the highest application dose of 100 mg P·kg soil^{-1}.

The fertilizer type significantly affected shoot N concentration in wheat plants harvested 45 days post-planting, with OMF outperforming MF across all soil P fertility levels (Figure 4.15). In addition, shoot N content was higher only in soils with moderate P fertility, with plants treated with P-OMF showing higher N content than P-MF (4.16A). This shows the ameliorating effect of organic matter on optimum plant growth and nutrient uptake in the initial growth stages. However, as soil P fertility level increased, the effectiveness of both fertilizers regarding shoot N content became similar (4.16B, C).

At the ripening stage, the application of increasing rates of P fertilizers, regardless of fertilizer types, did not affect straw N concentrations (Figure 4.17) and straw N contents (Figure 4.19). Although grain N concentrations were not affected by either fertilizer types or fertilizer application rates regardless of soil P fertility levels (Figure 4.18), applications of P-OMF at higher rates caused greater grain N content compared to P-MF when soil P fertility was at moderate (Figure 4.20A). However, with increments in soil P fertility, the effect of both fertilizers on grain N content became similar, highlighting a diminishing effect exerted by soil P fertility levels (Figure 4.20B, C). These findings are consistent with the hypothesis argued by Defra (2010) that soils with Olsen P levels between 16-25 ppm are less responsive to further P additions.

Concerning K uptake by wheat plants, although P-OMF applications effectively increased grain P and N contents at lower soil P fertility statuses (MODERATE-P and HIGH-P), it affected K nutrition at neither tillering stage (Figures 4.22 and Figure 4.23) nor ripening stage (Figures 4.26, Figure 4.27, and Figure 4.28); these findings were similar to those of recent studies (Erenoglu and Haciruestemoglu, 2022; Erenoğlu et al., 2023).

4.4.2. Comparisons of Granular and Powdered P-Containing Organomineral Fertilizers for Growth and P Uptake of Wheat in a Calcareous Soil (*Experiment II*)

Increasing P applications as either OMF or MF significantly increased shoot dry weights of wheat plants harvested at the end of the tillering stage (45 days after sowing) compared to control treatments, regardless of the application form (granular and powdered) (Figure 4.29). Although there was no difference between the performance of P-OMF and P-MF applied in granular form (Figure 4.29A), plants supplied with P-MF applications led to higher shoot dry weight than those treated with P-OMF when applied in powdered form (Figure 4.29B). These results reveal the promoting effect of increasing P applications on shoot growth in the initial growth stages. Compared to a granular form, the enhanced efficiency of P-MF when applied as powders can be associated with reduced precipitation, which is generally assumed to occur around the fertilizer granules (Holloway et al., 2001), indicating that powdered fertilizers are less prone to precipitation reactions. Contrary to our results, Erenoğlu et al. (2023) reported that powdered application of P-OMF led to statistically higher shoot dry weights relative to P-MF treatments at all P application rates at the end of the tillering stage. This discrepancy can be explained by the manufacturing process of OMF fertilizers used in the experiments. Although the OF and MF used in the manufacturing process of OMF were the same, the OMF adopted in our trials was manufactured as a single granular OMF, leading to a more stable product. In contrast, Erenoğlu et al. (2023) prepared the OMF by mixing and grounding biogas-based OF, TSP, and quartz sand.

Positive effects of increasing application rates of P as either MF or OMF on plant height and spike length over control treatments have been well-documented in various studies(Ahmad et al., 2013; Crusciol et al., 2020; Izhar Shafi et al., 2020; Khan et al., 2022). Likewise, in the present greenhouse trial, it was determined that irrespective of the type (OMF and MF) and form (powdered and granular) of fertilizers, increasing P applications significantly increased plant height and spike length compared to the control treatments (no P applied). It was also observed that OMF exhibited a statistically superior performance over MF (Figure 4.30 and Figure 4.31; uppercase letters). Moreover, plants supplied with the lowest amount of P-OMF (25 mg P·kg^{-1} soil) led to either similar or higher plant heights (Figure 4.30A, B) and spike lengths (Figure 4.31A, B) relative to those supplied with even the highest rate of MF-P (100 mg P·kg^{-1} soil). These results show that fertilizer applications can substantially decrease when applied as OMF. Similarly, Izhar Shafi et al. (2020) stated that the application of OMF (HA+SSP) increased plant height and spike length at statistically higher levels compared to the sole application of SSP and that the amount of fertilizers used can be reduced substantially. These results can be linked to the growth-promoting effects of organic substances such as humic and fulvic acids found in the OF (Vaughan et al., 1985; Tahir et al., 2011; Canellas and Olivares, 2014; Canellas et al., 2015; Izhar Shafi et al., 2020). Such effects of HA may be associated with the capability of HA to improve the biochemical environment of soil by promoting soil enzymatic activities, microbial activities and population, cation exchange capacity, and water retention of soil that ultimately enhance the plant growth and nutrient uptake (Izhar Shafi et al., 2020).

Commonly, the number of spikes·ha^{-1} is regarded as a significant yield component for wheat under field conditions and depends on the number of tillers·plant^{-1} produced between the tiller development stage and the initiation of jointing (Klepper et al., 1982; Tilley et al., 2019). Since this greenhouse study was conducted under controlled conditions, the number of spikes per pot is assumed to represent a key yield component. In this regard, the results show that increasing P applications in either granular or powdered forms did not cause any differences between P-OMF and P-MF, showing no superiority between the fertilizers concerning the spike count (Figure 4.32A, B). However, increasing P application in powdered form led to substantial increases in spike count compared to control treatments (Figure 4.32B), while increasing P treatments in granular form did not lead to any differences from control treatments (Figure 4.32A).

Plant P uptake and utilization are crucial in determining the final crop yield (Shen et al., 2011). With regards to crop agronomic performance, it has been documented that incorporation organic substances such as humic acids through organic matter containing fertilizers (organic fertilizer and organomineral fertilizers) and/or joint application of organic and inorganic fertilizers (OF+IF) result in improved biological (straw+grain), straw, and grain yields in soils with high P-sorption capacity (Frazão et al., 2019; Izhar Shafi et al., 2020; Frazão et al., 2021; Khan et al., 2022; Erenoğlu et al., 2023). Coherently, the present findings indicate that increasing P applications produced significantly higher biological yield (Figure 4.33A, B), straw yield (Figure 4.34A, B), and grain yield (Figure 4.35A, B) compared to control treatments, irrespective of fertilizer type (OMF and MF) and form (powdered and granular), with OMF consistently showing superior performance over MF. Moreover, plants supplied with P-OMF generated biological yield, straw yield, and grain yield comparable to or higher than those treated with P-MF across all application rates. This highlights that, in our experimental soil (Table 3.1), characterized by unfavorable properties such as high $CaCO_3$ (24.4%) and clay content (50%), which reduce P mobility and availability, the use of OMF presents an effective strategy to enhance crop agronomic efficiency. Numerous studies conducted on various crops grown in different soil types have recorded a superiority of OMF over MF in biological yield (straw yield + grain yield), straw yield, and grain yield (Grohskopf et al., 2019; Crusciol et al., 2020; Izhar Shafi et al., 2020; Khan et al., 2022). These results confirm the promoting effects of organic fertilizers or organic substances such as humic and fulvic acids on overall crop yield potential. The observed increases in plant growth and yield may be attributed to the growth-promoting properties of humic substances, which stimulate plant root growth by boosting root biomass, root hair, and root branching, and inducing lateral roots, releasing organic anions to increase rhizodeposition and enzyme secretion, all essential for water acquisition and nutrient uptake (Brown et al., 2013; Canellas and Olivares, 2014). Additionally, the combined positive influence of humic acids and fulvic acids, along with P, affecting plant growth include improving soil physical, chemical, and biological properties, enzyme activation and/or inhibition, changes in membrane permeability, protein synthesis (Canellas and Olivares, 2014; Canellas et al., 2015). Notably, the plants treated with the lowest P-OMF rate (25 mg $P \cdot kg^{-1}$ soil) exhibited similar performance to those receiving the highest P-MF rate (100 mg $P \cdot kg^{-1}$ soil). This implies that P application rates can be substantially reduced when using OMF, allowing farmers to lower the fertilizer input cost while sustaining both yield and crop productivity. Similarly, Izhar Shafi et al. (2020) stated that P applications can be reduced through the co-application of single superphosphate (SSP) and humic acid (HA) compared to the use of single superphosphate (SSP) alone. In addition, Khan et al. (2022) reported that the joint application of normal manure (unprocessed manure) with half the recommended dose of diammonium phosphate (DAP) resulted in a higher chickpea grain yield relative to the application of the recommended rates of DAP alone.

Concerning the results of SPAD reading (Figure 4.36) and harvest index parameters (Figure 4.37), it is apparent that they followed a similar pattern. Overall, plants treated with P-OMF applications significantly outperformed P-MF irrespective of fertilizer form (granular and powdered). Plants receiving the lowest P-OMF rate (25 mg $P \cdot kg^{-1}$ soil) demonstrated statistically comparable results to those receiving the highest P-MF rate (100 mg $P \cdot kg^{-1}$ soil). SPAD greenness is measured to predict leaf chlorophyll (Chl) status, which is an essential indicator of photosynthesis (Barutcular et al., 2015). Therefore, enhanced SPAD values following P-OMF applications compared to P-MF treatments could be attributed to higher N and P uptake of plants treated with OMF (Figure 4.44 and Figure 4.52). Findings of SPAD readings are in partial agreement with those of Silva et al. (2020), who reported no differences in corn SPAD readings with increasing P-containing OMF applications in two acidic soils with distinct textures (clayey and sandy) but differ in that both OMF and MF yielded similar results contrasting the results of the present study. Consistent with our results, Sitzmann et al. (2024) emphasized that OMF-fertilized tomato plants showed significantly higher SPAD readings than the control treatments (no P applied) but no differences between OMF and MF.

The harvest index is the ratio between the economic yield (grain) and the dry weight of the biological yield (grain yield + straw yield), which is influenced by the amount of photosynthates translocated to the generative part of the plant (Rahman et al., 2024). The higher harvest index indicates that the photosynthate in the canopy is translocated to the seeds, which will increase the grain yield produced. Therefore, in the current study, superior harvest index values obtained as a result of P-OMF treatments over P-MF applications (Figure 4.37A, B) can be linked to the higher SPAD reading values obtained with P-OMF applications leading to higher photosynthate translocation to wheat grains, hence greater grain yield (Figure 4.35A, B). An increase in wheat grain yield has been determined to be correlated with an enhanced harvest index (Shearman et al., 2005). Likewise, the present study's findings demonstrate a strong correlation between the harvest index and grain yield.

In terms of plant nutrition, P is well-known for its unfavorable characteristics such as low mobility, slow diffusion, and its reactive nature causing high fixation and precipitation; therefore, it stands out as a significant yield-limiting nutrient (Shen et al., 2011; Balemi and Negisho, 2012; Havlin et al., 2016; Brady and Weil, 2017). In this context, since P mobility is low, maintaining adequate P supply at the root zone can enhance the effectiveness of plant roots in mobilizing and acquiring P from the rhizosphere (Shen et al., 2011). As demonstrated in Figure 4.38A and Figure 4.39A, applying P-OMF yielded higher shoot P concentrations and shoot P content compared to P-MF when applied as granules at the end of the tillering stage (45 days post-planting). These results show good consistency between plant P concentration (4.38A) and Olsen P concentrations in soils incubated with granular P-OMF or P-MF for 45 days (Figure 4.60A). Based on these findings, it can be put forward that addition/presence of organic substances is an effective strategy to increase P availability in the soil (Delgado et al., 2002; Yan et al., 2016; Liu et al., 2017; Chen et al., 2018; Xing et al., 2020; M. Farid et al., 2021; Zhang et al., 2022) and provide plants with adequate P supply in the early growth stages. Parallel to the Olsen P concentration (Figure 4.60B), there was no difference between the performance of increasing P applications as either OMF or MF with regards to shoot P concentration (Figure 4.38B) and shoot P content (Figure 4.39B) when applied in powdered form. Considering the superior performance of P-OMF over P-MF in granular form, it is evident that powdered applications substantially increased the availability of P-MF rather than P-OMF (Figure 4.38B and Figure 4.39B).

Regarding wheat P nutrition at physiological maturity, irrespective of fertilizer form (granular and powder), plants treated with increasing rates of P-MF had higher straw P concentrations (Figures 4.40A, B) and straw P contents (Figures 4.42A, B) compared to those treated with P-OMF. Considering the higher straw yield obtained with P-OMF applied in either granular or powdered form, the lower P concentrations in straw treated with P-OMF can be attributed to enhanced P transport to the grains.

On the other hand, no meaningful relations were found between fertilizer forms, fertilizer types, and grain P concentrations (Figure 4.41). Regarding grain P contents, the higher grain P contents were obtained as a function of P-OMF applied in either granular or powdered forms compared to P-MF applications (Figure 4.43A, B), which is in good accordance with the results of Olsen P concentrations of incubated soils with P for 45 and 128 days. In addition, the grain P contents were higher with powdered forms than with granular applications (Figure 4.43A, B). Similarly, Lustosa Filho et al. (2019) reported that powder applications of a biochar-based slow-release fertilizer (BBF) prepared by combining poultry litter and Magnesium oxide (MgO) with TSP (PLB-TSP-MgO) and TSP led to higher P uptake by maize plants compared to their granular applications but stated that TSP applications recorded greater P uptake compared to biochar-based fertilizers regardless of application forms contradicting the findings of this study. This outcome can be explained by the formation of water-insoluble magnesium pyrophosphate ($Mg_2P_2O_7$) within the slow-release BBF and higher water-soluble P content of TSP. Moreover, the increased P availability and absorption from powdered mineral fertilizers (P-MF) relative to granular form may be due to the reduced precipitation, which is considered to occur in the solution surrounding granules (Holloway et al., 2001) and decreased fixation from powdered fertilizers (Bertrand et al., 2006). These hypotheses might also be true for OMF fertilizer used in our study. The greater grain P uptake (Figure 4.43) and grain yield (Figure 4.35) as a function of increasing P-OMF applications as either powder or granules demonstrate that the dilution effect impacted the grain P concentrations in plants supplied with OMF.

In the present experiment, up to 90% of the P in above-ground parts of wheat was translocated to and accumulated in the grains (Figure 4.45). Phosphorus Harvest Index (PHI), calculated as the ratio of grain P content to total above-ground P content, is regarded as a key efficiency metric that demonstrates a positive correlation with grain yield and a strong correlation with the harvest index (HI) (Batten, 1992). These relationships have been established in greenhouse pot experiments (Batten, 1986) and field studies (Batten and Khan, 1987). In low-yielding plants, the P proportion in grains of mature wheat plants is less than 30%, but it can reach 90% under favorable conditions (Batten, 1986; Batten and Khan, 1987; Jones et al., 1989; Batten, 1992). In this experiment, PHI ranged from 74.9% to 86.1% for granular applications and 75.4% to 90.5%, reflecting the high yield potential of the wheat cultivar used under favorable conditions (controlled environment). The findings indicate that P applications increased PHI compared to control treatments, with OMF significantly outperforming MF regardless of fertilizer form (Figure 4.45). Furthermore, P-OMF treatments led to higher PHI than P-MF across all application rates (Figure 4.45A, B). These findings highly correlate with grain yields (4.35A, B) and harvest index (4.37A, B), following the same trend.

Findings on the N and K nutritional status of wheat revealed that, regardless of fertilizer form, the harvest rests (straw) N concentration (Figure 4.48A, B) and contents (Figure 4.50A, B) were significantly lower than those of grain N concentration (Figure 4.49A, B) and contents (Figure 4.51A, B). In contrast, K nutrition followed the opposite trend (Figure 4.55, Figure 4.56, figure 4.57 and Figure 4.58). Regarding total N and K, plants fertilized with P-OMF showed higher N (Figure 4.52A, B) and K uptake (Figure 4.59A, B) than those supplied with P-MF. This difference was statistically significant, particularly with granular treatments.

4.4.3. Effect of P-Containing Organomineral Fertilizer Forms (granular and powdered) on Olsen-P Levels of a Calcareous Soil (*Experiment III*)

The addition of organic substances/organic-based fertilizers to soils has been reported to improve P availability and its uptake by plants through two major ways such as improved recovery (Delgado et al., 2002) and higher mobility (Zhen-Yu et al., 2013; Erenoğlu and Dundar, 2020) enabling its transport to further distances. In the present study, the results indicated that the soils treated with increasing rates of P as either OMF or MF significantly increased plant-available P concentrations in experimental soils sampled at the end of 45-day and 128-day incubation periods (Figures 4.60A and 4.61A).

When applied in granular form, Olsen P concentrations in the soils incubated with P-OMF were significantly greater than those treated with P-MF in both sampling periods. Consistent with the results of the present study, several authors reported that long-term and/or short-term applications of plant-based or animal-based organic amendments improve P mobility and decrease P fixation under calcareous (Guo et al., 2018; Zhang et al., 2022) and non-calcareous (Guo et al., 2018; Andriamananjara et al., 2019) conditions. These results corroborate the findings reported by Delgado et al. (2002), who underlined that the application of humic and fulvic acids plays a vital role in the recovery of P under calcareous conditions by slowing down the precipitation of Ca with phosphates, thereby preventing the formation of poorly soluble Ca-P precipitates. In the current study, the reason for the higher plant-available Olsen P in the soil incubated with granular OMF-P than the mineral fertilizer (MF-P) may also be the humic substances from the organic raw material, as indicated in Table 3.2. It has been reported that OM acts as a substrate (Andriamananjara et al., 2019) for microorganisms, increasing both their population and activity (Sellamuthu and Govindaswamy, 2003; Maji et al., 2017). As microorganisms break down the OM, P is slowly released into the soil which allows P uptake by plants before they are fixed by the soil (Liu et al., 2009; Brady and Weil, 2017; Andriamananjara et al., 2019). Several other scientists reported enhanced P activity following adding humic acids to the soils, which can increase Olsen P levels in the soils (Sellamuthu and Govindaswamy, 2003; Li et al., 2019). In addition, Yang et al. (2021) determined that humic acids improve the soil's physicochemical properties, ensuring adequate nutrient supply, appropriate pH range, and aeration, which create a conducive environment for the multiplication and growth of P-solubilizing bacteria. Another possible reason for increased plant-available P concentrations (Figures 4.60A and Figure 4.61A) could be due to the humic-like substances in the OM creating microsite acidification, which promotes the conversion of Ca-P to Al/Fe bound-P in a depth of 0–20 cm (Zhang et al., 2022). Application of mineral fertilizers and organic amendments may also improve P mobilization as a function of Fe (III) reduction. Recent studies confirmed that the mobilization of soil P was promoted by Fe(III) reduction, which is widely coupled with the decrease of poorly soluble Al/Fe-P (Zhang et al., 2021a; Zhang et al., 2021b) in both flooded (Maranguit et al., 2017) and well-drained soils (Warrinnier et al., 2020).

Regarding powder applications of OMF and MF, for Olsen P concentrations in the samples collected on the forty-fifth day after initiation (Figure 4.60B), there was no difference between the efficiency of fertilizer applications in powdered forms. Although P-OMF additions led to higher soil Olsen P concentrations than MF-P in samples collected at the end of the 128-day incubation period (Figure 4.61B), these increases were only significant at the highest application rate. In other words, there was no statistically significant difference between P-OMF and P-MF at lower application doses. Based on the results obtained, it can be concluded that P-MF availability significantly improved when applied as a powder. These outcomes can be explained by the phenomenon that precipitation reactions leading to the formation of Ca-P precipitates under calcareous conditions are more likely to occur around the granules of mineral fertilizers (Holloway et al., 2001) and by the hypothesis that precipitation reactions prevail when the soil solution P concentration are high, while at low concentrations, adsorption reactions are predominant (Castro and Torrent, 1998; Delgado et al., 2002). Therefore, it is assumed that using powder fertilizers decreases the rate of precipitation and fixation, allowing the P availability of highly water-soluble MF (TSP) to be maintained over more extended periods.

These findings are inconsistent with those of Erenoğlu et al. (2023). The authors used the powdered form of TSP and OMF. They reported that soils incubated with OMF showed greater Olsen P levels at the end of the 45-day and 90-day incubation periods, with significant differences observed at the 90-day incubation period. This may be due to the manufacturing processes of OMFs, as the single granular fertilizer was used in the present experiment. In contrast, Erenoğlu et al. (2023) prepared the OMF under laboratory conditions by grounding quartz sand, TSP, and OF obtained from the biogas plant and homogenously mixing them.

5. CONCLUSIONS

The current PhD dissertation aims to reveal the effectiveness of an organomineral fertilizer on the agronomic performance and mineral nutritional status of wheat grown under greenhouse conditions and the efficiency of OMF on the availability of P in the soil. For this purpose, initially, a pot experiment was conducted under greenhouse conditions to test the effects of P-OMF and P-MF fertilizers applied at increasing amounts on the mineral nutritional status, yield, and growth parameters of wheat plants in soils with different P fertility levels (Olsen P). Thereafter, the second pot trial and an incubation study under laboratory conditions were conducted simultaneously to investigate the effects of OMF and MF fertilizers applied at increasing rates and in different forms (powdered and granular) on the agronomic performance of wheat, growth, and yield parameters and Olsen P concentration in the soil.

The conclusions and recommendations of the current PhD thesis are given below:

- Overall, OMFs produced using an organic fertilizer originating from biogas facility waste positively affect plant growth and yield in soils with high P-sorption capacity.
- The adoption of P-enriched OMFs improves P efficiency and availability due to the contribution of organic substances in preventing the fixation/precipitation of P to the soil.

Effectiveness of P-Containing Organomineral Fertilizers in Growth and P Uptake of Wheat in a Calcareous Soil Differing in P Availability

- Regarding crop agronomic performance, it was determined that increasing soil P fertility status negatively influenced shoot growth at the tillering stage, grain yield, and number of spikes per pot. However, no significant impact was observed on plant height or spike length.
- Increasing applications of P-OMF resulted in a higher number of spikes per pot and enhanced shoot growth at the tillering stage under MODERATE-P fertility conditions compared to P-MF, yet this difference was not recorded at HIGH-P and VERY HIGH-P fertility.
- Concerning wheat grain yield (economic yield), increasing P-OMF rates led to statistically significant improvements compared to P-MF applications at both MODERATE-P and HIHG-P fertility. Nevertheless, this difference disappeared at VERY HIGH-P fertility.
- Regardless of soil P fertility status, increasing P-OMF treatments resulted in statistically higher biological and straw yields than P-MF applications.

- Although increasing P-OMF applications caused statistically higher total P uptake by plants at MODERATE-P and HIGH-P fertility, no significant differences in plant P uptake were observed at VERY HIGH-P fertility.

Comparisons of Granular and Powdered P-Containing Organomineral Fertilizers for Growth and P Uptake of Wheat in a Calcareous Soil

- P-OMF, applied in either powdered or granular form, shows superior agronomic performance relative to P-MF. Therefore, it might be utilized as a substitute for MF fertilizers.
  Irrespective of fertilizer form (granular and powdered), increasing applications of P-OMF outperformed P-MF with regards to plant height, spike length, harvest index, SPAD reading conducted on flag leaves in the middle of the boot stage, and biological, grain, and straw yields,
- In terms of plant P nutrition, it was found that independent of fertilizer form, P-OMF treatments led to statistically significant increases in grain P content and P harvest index compared to P-MF treatments. These findings followed the same trend as the grain yield results, further highlighting the superior performance of P-OMF in boosting wheat economic yield.
- As a natural consequence of enhanced crop growth and development driven by the improved P nutrition, total plant N and K uptake also improved. Specifically, when applied in powdered form, P-OMF applications showed significantly greater N and K uptake by wheat plants compared to P-MF applications. However, both fertilizers exhibited similar performance when applied as granules.

As a final word, previous field trials have revealed that organomineral fertilizers perform as well as or better than mineral fertilizers. When considered alongside this study's findings, these results underscore that organomineral fertilizers present a viable alternative to mineral fertilizers. The current study's findings should be tested under field conditions on a regional scale to fully investigate their applicability.

REFERENCES

Abadia Ventura, M. V., Braghiroli, R., Souchie, E. L., Miclos Baliza, L., and Figueredo Carvalho, V. D. 2020. Use of Organomineral Fertilizers in Agriculture: Potentiality, Production and Benefits. *Global Science & Technology* 13.

Ahmad, M., Khan, M., and Muhammad, D. 2013. Response of maize to different phosphorus levels under calcareous soil conditions. *Sarhad J. Agric* 29, 43-48.

Allam, M., Radicetti, E., Quintarelli, V., Petroselli, V., Marinari, S., and Mancinelli, R. 2022. Influence of organic and mineral fertilizers on soil organic carbon and crop productivity under different tillage systems: A meta-analysis. *Agriculture* 12, 464.

Andriamananjara, A., Rakotoson, T., Razafimbelo, T., Rabeharisoa, L., Razafimanantsoa, M.-P., and Masse, D. 2019. Farmyard manure improves phosphorus use efficiency in weathered P deficient soil. *Nutrient Cycling in Agroecosystems* 115, 407-425.

Antelo, J., Arce, F., Avena, M., Fiol, S., López, R., and Macías, F. 2007. Adsorption of a soil humic acid at the surface of goethite and its competitive interaction with phosphate. *Geoderma* 138, 12-19.

Antille, D. L., Sakrabani, R., and Godwin, R. J. 2014. Effects of biosolids-derived organomineral fertilizers, urea, and biosolids granules on crop and soil established with ryegrass (Lolium perenne L.). *Communications in soil science and plant analysis* 45, 1605-1621.

Antille, D. L., Sakrabani, R., Tyrrel, S. F., Le, M. S., and Godwin, R. J. 2013. Characterisation of organomineral fertilisers derived from nutrient-enriched biosolids granules. *Applied and Environmental Soil Science* 2013.

Araújo, M. D., Souza, H. A. d., Benites, V. M., Pompeu, R. C., Natale, W., and Leite, L. F. 2020. Organomineral phosphate fertilization in millet in sandy soil. *Revista Brasileira de Engenharia Agrícola e Ambiental* 24, 694-699.

Avery, B. W., and Catt, J. A.,1995. The soil at Rothamsted. Lawes Agricultural Trust,(LAT) Harpenden

Ayinla, A., Alagbe, I., Olayinka, B., Lawal, A., Aboyeji, O., and Etejere, E. 2018. Effects of organic, inorganic and organo-mineral fertilizer on the growth, yield and nutrient composition of Corchorus Olitorious (L). *Ceylon Journal of Science* 47, 13-19.

Aziz, M. Z., Yaseen, M., Naveed, M., Wang, X., Fatima, K., Saeed, Q., and Mustafa, A. 2020. Polymer-Paraburkholderia phytofirmans PsJN coated diammonium phosphate enhanced microbial survival, phosphorous use efficiency, and production of wheat. *Agronomy* 10, 1344.

Bai, Z., Li, H., Yang, X., Zhou, B., Shi, X., Wang, B., Li, D., Shen, J., Chen, Q., and Qin, W. 2013. The critical soil P levels for crop yield, soil fertility and environmental safety in different soil types. *Plant and Soil* 372, 27-37.

Balemi, T., and Negisho, K. 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. *Journal of soil science and plant nutrition* 12, 547-562.

Baligar, V., and Bennett, O. 1986. NPK-fertilizer efficiency—a situation analysis for the tropics. *Fertilizer research* 10, 147-164.

Baligar, V., Fageria, N., and He, Z. 2001. Nutrient use efficiency in plants. *Communications in soil science and plant analysis* 32, 921-950.

Barley, K., and Rovira, A. 1970. The influence of root hairs on the uptake of phosphate. *Communications in Soil Science and Plant Analysis* 1, 287-292.

Barutcular, C., Toptas, I., Turkten, H., Yıldırım, M., and Koc, M. 2015. SPAD greenness to estimate genotypic variation in flag leaf chlorophyll in spring wheat under Mediterranean conditions. *Turkish Journal of Field Crops* 20, 1-8.

Batten, G. 1986. The uptake and utilization of phosphorus and nitrogen by diploid, tetraploid and hexaploid wheats (Triticum spp.). *Annals of Botany* 58, 49-59.

Batten, G., and Khan, M. 1987. Uptake and utilisation of phosphorus and nitrogen by bread wheats grown under natural rainfall. *Australian Journal of Experimental Agriculture* 27, 405-410.

Batten, G. D. 1992. A review of phosphorus efficiency in wheat. *Plant and soil* 146, 163-168.

Beauregard, M., Hamel, C., and St-Arnaud, M. 2010. Long-term phosphorus fertilization impacts soil fungal and bacterial diversity but not AM fungal community in alfalfa. *Microbial ecology* 59, 379-389.

Benites, V. d. M., Dal Molin, S. J., Menezes, J. F. S., Guimarães, G. d. S., and Machado, P. d. A. 2022. Organomineral fertilizer is an agronomic efficient alternative for poultry litter phosphorus recycling in an acidic Ferralsol.

Bertrand, I., McLaughlin, M. J., Holloway, R. E., Armstrong, R. D., and McBeath, T. 2006. Changes in P bioavailability induced by the application of liquid and powder sources of P, N and Zn fertilizers in alkaline soils. *Nutrient Cycling in Agroecosystems* 74, 27-40.

Bolland, M. D., and Gilkes, R. J. 2017. The chemistry and agronomic effectiveness of phosphate fertilizers. *In* Nutrient use in crop production, pp. 139-163. CRC Press.

Borges, B. M., Strauss, M., Camelo, P. A., Sohi, S. P., and Franco, H. C. 2020. Re-use of sugarcane residue as a novel biochar fertiliser-Increased phosphorus use efficiency and plant yield. *Journal of Cleaner Production* 262, 121406.

Borges, B. M. M. N., Abdala, D. B., de Souza, M. F., Viglio, L. M., Coelho, M. J. A., Pavinato, P. S., and Franco, H. C. J. 2019. Organomineral phosphate fertilizer from sugarcane byproduct and its effects on soil phosphorus availability and sugarcane yield. *Geoderma* 339, 20-30.

Bot, A., and Benites, J.,2005. The importance of soil organic matter: Key to drought-resistant soil and sustained food production. Food & Agriculture Org.

Bouhia, Y., Hafidi, M., Ouhdouch, Y., Zeroual, Y., and Lyamlouli, K. 2023. Organo-Mineral Fertilization Based on Olive Waste Sludge Compost and Various Phosphate Sources Improves Phosphorus Agronomic Efficiency, Zea mays Agro-Physiological Traits, and Water Availability. *Agronomy* 13, 249.

Bouwman, A. F., Beusen, A. H., and Billen, G. 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970–2050. *Global biogeochemical cycles* 23.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils 1. *Agronomy journal* 54, 464-465.

Bradstreet, R. B. 1954. Kjeldahl method for organic nitrogen. *Analytical Chemistry* 26, 185-187.

Brady, N. C., and Weil, R. W.,2017. The Nature and Properties of Soils. Pearson Education Limited, England,DF-1.4 %âãÏÓ 69235 0 obj <</Linearized 1/L 139535596/O 69238/E 966175/N 1105/T 139499931/H [1637 41502]>> endobj 69247 0 obj <</DecodeParms<</Columns 5/Predictor 12>>/Filter/FlateDecode/ID[<652DDE5F036B60186931741843F96F17><65117B21F6E8474EA17F4AFBC75A1E58>]/Index[69235 418]/Info 69234 0 R/Length 105/Prev 139499932/Root 69236 0 R/Size 69653/Type/XRef/W[1 3 1]>>stream hÞbbd` ``b`XQ " ï€H 0{ ˜| ‰ ‘,-@’ï,'ˆÍ "ùšÁì0 ùÉ‡ƒ□‰‘“ï X= #:Éò »ø(9JRB2Î ‡Qr4]□’£éj” ¡äÿÿ?žÏ 0.

Brown, L., George, T., Dupuy, L., and White, P. 2013. A conceptual model of root hair ideotypes for future agricultural environments: what combination of traits should be targeted to cope with limited P availability? *Annals of botany* 112, 317-330.

Brown, L., George, T., Thompson, J., Wright, G., Lyon, J., Dupuy, L., Hubbard, S., and White, P. 2012. What are the implications of variation in root hair length on tolerance to phosphorus deficiency in combination with water stress in barley (Hordeum vulgare)? *Annals of Botany* 110, 319-328.

Brussaard, L. 1994. Interrelationships between biological activities, soil properties and soil management. *In* Soil resilience and sustainable land use, pp. 309-329.

Canellas, L. P., and Olivares, F. L. 2014. Physiological responses to humic substances as plant growth promoter. *Chemical and Biological Technologies in Agriculture* 1, 1-11.

Canellas, L. P., Olivares, F. L., Aguiar, N. O., Jones, D. L., Nebbioso, A., Mazzei, P., and Piccolo, A. 2015. Humic and fulvic acids as biostimulants in horticulture. *Scientia horticulturae* 196, 15-27.

Carson, P. L. 1980. Recommended potassium test. *North Dakota Agricultural Experiment Station Bulletin*, 17-18.

Castro, B., and Torrent, J. 1998. Phosphate sorption by calcareous Vertisols and Inceptisols as evaluated from extended P-sorption curves. *European Journal of Soil Science* 49, 661-667.

Chassapis, K., and 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, H., Chen, M., Li, D., Mao, Q., Zhang, W., and Mo, J. 2018. Responses of soil phosphorus availability to nitrogen addition in a legume and a non-legume plantation. *Geoderma* 322, 12-18.

Chen, J.-H. 2006. The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. *In* International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use, Vol. 16, pp. 1-11. Citeseer.

Chien, S., Prochnow, L., and Cantarella, a. H. 2009. Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Advances in agronomy* 102, 267-322.

Chowdhury, R. B., Moore, G. A., Weatherley, A. J., and Arora, M. 2014. A review of recent substance flow analyses of phosphorus to identify priority management areas at different geographical scales. *Resources, Conservation and Recycling* 83, 213-228.

Ciesielczuk, T., Rosik-Dulewska, C., and Wiśniewska, E. 2015. Possibilities of coffee spent ground use as a slow action organo-mineral fertilizer. *Rocznik Ochrona Środowiska* 17.

Colomb, B., Debaeke, P., Jouany, C., and Nolot, J. M. 2007. Phosphorus management in low input stockless cropping systems: Crop and soil responses to contrasting P regimes in a 36-year experiment in southern France. *European journal of agronomy* 26, 154-165.

Conijn, J., Bindraban, P., Schröder, J., and Jongschaap, R. 2018. Can our global food system meet food demand within planetary boundaries? *Agriculture, Ecosystems & Environment* 251, 244-256.

Coonan, E. C., Kirkby, C. A., Kirkegaard, J. A., Amidy, M. R., Strong, C. L., and Richardson, A. E. 2020. Microorganisms and nutrient stoichiometry as mediators of soil organic matter dynamics. *Nutrient Cycling in Agroecosystems* 117, 273-298.

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

Creamer, C. A., de Menezes, A. B., Krull, E. S., Sanderman, J., Newton-Walters, R., and Farrell, M. 2015. Microbial community structure mediates response of soil C decomposition to litter addition and warming. *Soil Biology and Biochemistry* 80, 175-188.

Crusciol, C. A. C., Campos, M. d., Martello, J. M., Alves, C. J., Nascimento, C. A. C., Pereira, J. C. d. R., and Cantarella, H. 2020. Organomineral fertilizer as source of P and K for sugarcane. *Scientific Reports* 10, 5398.

Daberkow, S., Isherwood, K., Poulisse, J., and Vroomen, H. 2000. Fertilizer requirements in 2015 and 2030. *FAO, Rome*.

Dai, X., Ouyang, Z., Li, Y., and Wang, H. 2013. Variation in yield gap induced by nitrogen, phosphorus and potassium fertilizer in North China Plain. *PLoS One* 8, e82147.

Dai, X., Wang, H., and Fu, X. 2017. Soil microbial community composition and its role in carbon mineralization in long-term fertilization paddy soils. *Science of the Total Environment* 580, 556-563.

Dawson, C. J., and Hilton, J. 2011. Fertiliser availability in a resource-limited world: Production and recycling of nitrogen and phosphorus. *Food Policy* 36, S14-S22.

Defra,2010. The Fertiliser Manual (RB209). Department of the Environment, Food and Rural Affairs, TSO (The Stationary Office), London, 252.

Degryse, F., Baird, R., Da Silva, R. C., and McLaughlin, M. J. 2017. Dissolution rate and agronomic effectiveness of struvite fertilizers–effect of soil pH, granulation and base excess. *Plant and Soil* 410, 139-152.

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

Delgado, A., Quemada, M., and Villalobos, F. J. 2016. Fertilizers. *Principles of agronomy for sustainable agriculture*, 321-339.

Ding, J., Jiang, X., Ma, M., Zhou, B., Guan, D., Zhao, B., Zhou, J., Cao, F., Li, L., and 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. *Applied soil ecology* 105, 187-195.

Dotaniya, M., and Datta, S. 2014. Impact of bagasse and press mud on availability and fixation capacity of phosphorus in an Inceptisol of north India. *Sugar Tech* 16, 109-112.

ECOFI.2020.www.ecofi.info.

Edmeades, D., Metherell, A., Waller, J., Roberts, A., and Morton, J. 2006. Defining the relationships between pasture production and soil P and the development of a dynamic P model for New Zealand pastures: a review of recent developments. *New Zealand Journal of Agricultural Research* 49, 207-222.

Eghball, B., Binford, G., and Baltensperger, D. D.,1996. Phosphorus movement and adsorption in a soil receiving long-term manure and fertilizer application, Rep. No. 0047-2425. Wiley Online Library.

Eghball, B., and Power, J. F. 1999. Phosphorus-and nitrogen-based manure and compost applications corn production and soil phosphorus. *Soil Science Society of America Journal* 63, 895-901.

Elka, E., and Laekemariam, F. 2020. Effects of organic nutrient sources and NPS fertilizer on the agronomic and economic performance of haricot bean (Phaseolus vulgaris L.) in Southern Ethiopia. *Applied and Environmental Soil Science* 2020, 8853552.

Elser, J., and Bennett, E. 2011. A broken biogeochemical cycle. *Nature* 478, 29-31.

Erenoğlu, E., and Dundar, S. 2020. Application of liquid phosphorus fertilizer improves the availability of phosphorus in calcareous soils. *Applied Ecology and Environmental Research* 18.

Erenoglu, E., and Haciruestemoglu, K. 2022. Biogas Facility-Based Organic Fertilizer Enhances Nutrient Uptake and Growth of Wheat (Triticum Aestivum). *APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH*.

Erenoğlu, E. B., MORSY MOHAMMED MORSY, M. E., and Dündar, Ş. 2023. The Effect of Organomineral Fertilizer Phosphorus on the Availability of Phosphorus in a Calcareous Soil. *Applied Ecology & Environmental Research* 21.

Erisman, J. W., Galloway, J. N., Seitzinger, S., Bleeker, A., Dise, N. B., Petrescu, A. R., Leach, A. M., and de Vries, W. 2013. Consequences of human modification of the global nitrogen cycle. *Philosophical Transactions of the Royal Society B: Biological Sciences* 368, 20130116.

Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., and Winiwarter, W. 2008. How a century of ammonia synthesis changed the world. *Nature geoscience* 1, 636-639.

Everaert, M., Degryse, F., McLaughlin, M. J., De Vos, D., and Smolders, E. 2017. Agronomic effectiveness of granulated and powdered P-exchanged Mg–Al LDH relative to struvite and MAP. *Journal of agricultural and food chemistry* 65, 6736-6744.

Fan, F., Li, Z., Wakelin, S. A., Yu, W., and Liang, Y. 2012. Mineral fertilizer alters cellulolytic community structure and suppresses soil cellobiohydrolase activity in a long-term fertilization experiment. *Soil Biology and Biochemistry* 55, 70-77.

FAO,2006. Fertilizer use by crop. FAO, Rome,114.

FAO,2009. How to feed the world in 2050. Report on FAO Expert Meeting 24-26 June 2009.

Fernandes, A. L. T., Rodrigues, G. P., and Testezlaf, R. 2003. Mineral and organomineral fertirrigation in relation to quality of greenhouse cultivated melon. *Scientia Agricola* 60, 149-154.

Fink, J. R., Inda, A. V., Tiecher, T., and Barrón, V. 2016. Iron oxides and organic matter on soil phosphorus availability. *Ciencia e agrotecnologia* 40, 369-379.

Frazão, J. J., de Melo Benites, V., Pierobon, V. M., Ribeiro, J. V. S., and Lavres, J. 2021. A poultry litter-derived organomineral phosphate fertilizer has higher agronomic effectiveness than conventional phosphate fertilizer applied to field-grown maize and soybean. *Sustainability* 13, 11635.

Frazão, J. J., de Melo Benites, V., Ribeiro, J. V. S., Pierobon, V. M., and Lavres, J. 2019. Agronomic effectiveness of a granular poultry litter-derived organomineral phosphate fertilizer in tropical soils: Soil phosphorus fractionation and plant responses. *Geoderma* 337, 582-593.

Gahoonia, T. S., Nielsen, N. E., Joshi, P. A., and Jahoor, A. 2001. A root hairless barley mutant for elucidating genetic of root hairs and phosphorus uptake. *Plant and Soil* 235, 211-219.

Ganetri, I., Essamlali, Y., Amadine, O., Danoun, K., Aboulhrouz, S., and Zahouily, M. 2021. Controlling factors of slow or controlled-release fertilizers. *In* Controlled release fertilizers for sustainable agriculture, pp. 111-129. Elsevier.

Garcıia-Gil, J., Ceppi, S., Velasco, M., Polo, A., and Senesi, N. 2004. Long-term effects of amendment with municipal solid waste compost on the elemental and acidic functional group composition and pH-buffer capacity of soil humic acids. *Geoderma* 121, 135-142.

Geisseler, D., and Scow, K. M. 2014. Long-term effects of mineral fertilizers on soil microorganisms–A review. *Soil Biology and Biochemistry* 75, 54-63.

Gerke, J. 2022. The central role of soil organic matter in soil fertility and carbon storage. *Soil Systems* 6, 33.

Gong, W., Yan, X., Wang, J., Hu, T., and Gong, Y. 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.

Grohskopf, M. A., Corrêa, J. C., Fernandes, D. M., Benites, V. d. M., Teixeira, P. C., and Cruz, C. V. 2019. Phosphate fertilization with organomineral fertilizer on corn crops on a Rhodic Khandiudox with a high phosphorus contente. *Pesquisa Agropecuária Brasileira* 54.

Guan, X.-H., Shang, C., and Chen, G.-H. 2006. Competitive adsorption of organic matter with phosphate on aluminum hydroxide. *Journal of Colloid and Interface Science* 296, 51-58.

Guignard, M. S., Leitch, A. R., Acquisti, C., Eizaguirre, C., Elser, J. J., Hessen, D. O., Jeyasingh, P. D., Neiman, M., Richardson, A. E., and Soltis, P. S. 2017. Impacts of nitrogen and phosphorus: from genomes to natural ecosystems and agriculture. *Frontiers in Ecology and Evolution* 5, 70.

Guo, Z., Han, J., Li, J., Xu, Y., and Wang, X. 2019. Effects of long-term fertilization on soil organic carbon mineralization and microbial community structure. *PLoS One* 14, e0211163.

Guo, Z., Liu, H., Hua, K., Wang, D., and He, C. 2018. Long-term straw incorporation benefits the elevation of soil phosphorus availability and use efficiency in the agroecosystem. *Spanish Journal of agricultural research* 16, e1101-e1101.

Hagin, J. 1957. Comparison of availability of phosphorus from granulated and powdered superphosphate by calculations of yield curves related to the phosphorus added and found in soil and plant tests. *Plant and Soil* 9, 114-130.

Haroon, H., Khattak, R., and Dost Muhammad, D. M. 2010. Seed cotton yield and nutrient concentrations as influenced by lignitic coal derived humic acid in salt-affected soils.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., and Beaton, J. D.,2016. Soil fertility and fertilizers. Pearson Education India

Hinsinger, P. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. *Plant and soil* 237, 173-195.

Hiradate, S., and Uchida, N. 2004. Effects of soil organic matter on pH-dependent phosphate sorption by soils. *Soil science and plant nutrition* 50, 665-675.

Hızalan, E., and Ünal, H. 1966. Topraklarda önemli kimyasal analizler. *AÜ Ziraat Fakültesi Yayınları* 278, 5-7.

Holford, I. 1997. Soil phosphorus: its measurement, and its uptake by plants. *Soil Research* 35, 227-240.

Holloway, R., Bertrand, I., Frischke, A., Brace, D., McLaughlin, M., and Shepperd, W. 2001. Improving fertiliser efficiency on calcareous and alkaline soils with fluid sources of P, N and Zn. *Plant and Soil* 236, 209-219.

Hu, A., and Lu, Y. 2015. The differential effects of ammonium and nitrate on methanotrophs in rice field soil. *Soil Biology and Biochemistry* 85, 31-38.

Hui, L., Feng, W.-t., He, X.-h., Ping, Z., Gao, H.-j., Nan, S., and XU, M.-g. 2017. Chemical fertilizers could be completely replaced by manure to maintain high maize yield and soil organic carbon (SOC) when SOC reaches a threshold in the Northeast China Plain. *Journal of integrative agriculture* 16, 937-946.

Ibrahim, K., Wang, Q., Wang, L., Zhang, W., Peng, C., and Zhang, S. 2021. Determining the optimum level of soil Olsen phosphorus and phosphorus fertilizer application for high phosphorus-use efficiency in Zea mays L. in black soil. *Sustainability* 13, 5983.

Ifansyah, H. 2014. Soil pH and solubility of aluminum, iron, and phosphorus in Ultisols: the roles of humic acid. *Journal of Tropical Soils* 18, 203-208.

Izhar Shafi, M., Adnan, M., Fahad, S., Wahid, F., Khan, A., Yue, Z., Danish, S., Zafar-ul-Hye, M., Brtnicky, M., and Datta, R. 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.

Jackson, M. 1958. Soil chemical analysis prentice Hall. *Inc., Englewood Cliffs, NJ* 498, 183-204.

Johnston, A., Lane, P., Mattingly, G., Poulton, P., and Hewitt, M. 1986. Effects of soil and fertilizer P on yields of potatoes, sugar beet, barley and winter wheat on a sandy clay loam soil at Saxmundham, Suffolk. *The Journal of Agricultural Science* 106, 155-167.

Johnston, A. E., Poulton, P. R., Fixen, P. E., and Curtin, D. 2014. Phosphorus: its efficient use in agriculture. *Advances in agronomy* 123, 177-228.

Johnston, A. E., Poulton, P. R., and White, R. P. 2013. Plant-available soil phosphorus. Part II: the response of arable crops to Olsen P on a sandy clay loam and a silty clay loam. *Soil Use and Management* 29, 12-21.

Jones, G., Blair, G., and Jessop, R. 1989. Phosphorus efficiency in wheat—a useful selection criterion? *Field Crops Research* 21, 257-264.

Karagöz, İ. 2021. Fertilization and Fertilizer Types. *Applied Soil Chemistry*, 123-148.

Khaliq, A., Abbasi, M. K., and Hussain, T. 2006. Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan. *Bioresource technology* 97, 967-972.

Khan, M. S., Naveed, M., Qadir, M. F., Bashir, M. A., Rafique, M., Siddiqui, M. H., Alamri, S., Brtnicky, M., Holatko, J., and Mustafa, A. 2022. Combined effect of animal manures and di-ammonium phosphate (DAP) on growth, physiology, root nodulation and yield of chickpea. *Agronomy* 12, 674.

Kiiski, H., Dittmar, H., Drach, M., Vosskamp, R., Trenkel, M. E., Gutser, R., and Steffens, G. 2016a. Fertilizers, 2. Types. *Ullmann's Encyclopedia of Industrial Chemistry, (Ed.).* 1-53.

Kiiski, H., Scherer, H. W., Mengel, K., Kluge, G., and Severin, K. 2016b. Fertilizers, 1. General. *Ullmann's Encyclopedia of Industrial Chemistry, (Ed.).* 1-30.

Klepper, B., Rickman, R., and Peterson, C. 1982. Quantitative characterization of vegetative development in small cereal grains 1. *Agronomy Journal* 74, 789-792.

Koch, M., Kruse, J., Eichler-Löbermann, B., Zimmer, D., Willbold, S., Leinweber, P., and Siebers, N. 2018. Phosphorus stocks and speciation in soil profiles of a long-term fertilizer experiment: Evidence from sequential fractionation, P K-edge XANES, and 31P NMR spectroscopy. *Geoderma* 316, 115-126.

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

Kopittke, P. M., Dalal, R. C., Finn, D., and Menzies, N. W. 2017. Global changes in soil stocks of carbon, nitrogen, phosphorus, and sulphur as influenced by long-term agricultural production. *Global change biology* 23, 2509-2519.

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., and Lombi, E. 2019. Soil and the intensification of agriculture for global food security. *Environment international* 132, 105078.

Kumar, R., Kumar, R., and Prakash, O. 2019. Chapter-5 the impact of chemical fertilizers on our environment and ecosystem. *Chief Ed* 35, 1173-1189.

Lal, R. 2006. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Land degradation & development* 17, 197-209.

Larramendy, M. L., and Soloneski, S.,2019. Organic fertilizers: history, production and applications. BoD–Books on Demand

Li, B., Song, H., Cao, W., Wang, Y., Chen, J., and 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 Biology* 27, 5356-5367.

Li, Y., Fang, F., Wei, J., Wu, X., Cui, R., Li, G., Zheng, F., and Tan, D. 2019. Humic acid fertilizer improved soil properties and soil microbial diversity of continuous cropping peanut: A three-year experiment. *Scientific reports* 9, 12014.

Lindsay, W. L., Vlek, P. L., and Chien, S. H. 1989. Phosphate minerals. *Minerals in soil environments* 1, 1089-1130.

Liu, J., Yang, J., Cade-Menun, B. J., Hu, Y., Li, J., Peng, C., and Ma, Y. 2017. Molecular speciation and transformation of soil legacy phosphorus with and without long-term phosphorus fertilization: Insights from bulk and microprobe spectroscopy. *Scientific reports* 7, 15354.

Liu, M., Hu, F., Chen, X., Huang, Q., Jiao, J., Zhang, B., and Li, H. 2009. Organic amendments with reduced chemical fertilizer promote soil microbial development and nutrient availability in a subtropical paddy field: The influence of quantity, type and application time of organic amendments. *Applied Soil Ecology* 42, 166-175.

Lombi, E., McLaughlin, M., Johnston, C., Armstrong, R., and Holloway, R. 2004. Mobility and lability of phosphorus from granular and fluid monoammonium phosphate differs in a calcareous soil. *Soil Science Society of America Journal* 68, 682-689.

Lombi, E., McLaughlin, M., Johnston, C., Armstrong, R., and Holloway, R. 2005. Mobility, solubility and lability of fluid and granular forms of P fertiliser in calcareous and non-calcareous soils under laboratory conditions. *Plant and Soil* 269, 25-34.

Lourenço, K. S., Ernani, P. R., Corrêa, J. C., Molin, S. J. D., and Lourenço, L. S. 2016. Addition of urease inhibitor has no effect on ammonia volatilization following soil application of poultry litter or organomineral fertilizer, unlike urea. *Revista Brasileira de Ciência do Solo* 40, e0150031.

Lu, F. 2015. How can straw incorporation management impact on soil carbon storage? A meta-analysis. *Mitigation and Adaptation Strategies for Global Change* 20, 1545-1568.

Lustosa Filho, J. F., Barbosa, C. F., da Silva Carneiro, J. S., and Melo, L. C. A. 2019. Diffusion and phosphorus solubility of biochar-based fertilizer: Visualization, chemical assessment and availability to plants. *Soil and Tillage Research* 194, 104298.

M. Farid, I., A. El-Ghozoli, M., HH Abbas, M., S. El-Atrony, D., Abbas, H. H., Elsadek, M., A. Saad, H., El Nahhas, N., and 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.

Maji, D., Misra, P., Singh, S., and Kalra, A. 2017. Humic acid rich vermicompost promotes plant growth by improving microbial community structure of soil as well as root nodulation and mycorrhizal colonization in the roots of Pisum sativum. *Applied soil ecology* 110, 97-108.

Manna, M., Ghosh, P., and Acharya, C. 2003. Sustainable crop production through management of soil organic carbon in semiarid and tropical India. *Journal of Sustainable Agriculture* 21, 85-114.

Maranguit, D., Guillaume, T., and 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.

Montalvo, D., Degryse, F., and McLaughlin, M. J. 2014. Fluid fertilizers improve phosphorus diffusion but not lability in Andisols and Oxisols. *Soil Science Society of America Journal* 78, 214-224.

Montalvo, D., Degryse, F., and McLaughlin, M. J. 2015. Agronomic effectiveness of granular and fluid phosphorus fertilizers in andisols and oxisols. *Soil Science Society of America Journal* 79, 577-584.

Morari, F., Vellidis, G., and Gay, P. 2011. Nitrogen Cycle. *Fertilizers, and N Loss Pathways*.

Motojima, H., Yamada, P., Irie, M., Ozaki, M., Shigemori, H., and Isoda, H. 2012. Amelioration effect of humic acid extracted from solubilized excess sludge on saline-alkali soil. *Journal of material cycles and waste management* 14, 169-180.

Mumbach, G. L., Gatiboni, L. C., de Bona, F. D., Schmitt, D. E., Corrêa, J. C., Gabriel, C. A., Dall'Orsoletta, D. J., and Iochims, D. A. 2020. Agronomic efficiency of organomineral fertilizer in sequential grain crops in southern Brazil. *Agronomy Journal* 112, 3037-3049.

Newman, E., and Andrews, R. E. 1973. Uptake of phosphorus and potassium in relation to root growth and root density. *Plant and soil* 38, 49-69.

Ning, C.-C., Gao, P.-D., Wang, B.-Q., Lin, W.-P., Jiang, N.-H., and Cai, K.-Z. 2017. Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. *Journal of integrative agriculture* 16, 1819-1831.

Noel, S., Mikulcak, F., Etter, H., and Stewart, N. 2015. Economics of Land Degradation Initiative: Report for policy and decision makers_ Reaping economic and environmental benefits from sustainable land management.

OECD, Food, and Nations, A. O. o. t. U.,2017. OECD-FAO Agricultural Outlook 2017-2026.

Olsen, S. R.,1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture

Papendick, R. I., and Parr, J. F. 1992. Soil quality—the key to a sustainable agriculture. *American Journal of Alternative Agriculture* 7, 2-3.

Pelá, A., Gonçalves, R. N., de Souza Pereira, F., Rodrigues, F., and Silva Cruz, S. J. 2017. Phosphorus use efficiency in maize as a function of different sources. *Australian Journal of Crop Science* 11, 71-75.

Poulton, P. R., Johnston, A. E., and White, R. P. 2013. Plant‐available soil phosphorus. Part I: the response of winter wheat and spring barley to Olsen P on a silty clay loam. *Soil use and management* 29, 4-11.

Qihua, W., Zhang, S., Gu, F., Ping, Z., Huang, S., Boren, W., and Minggang, X. 2020. Determining the optimum range of soil Olsen P for high P use efficiency, crop yield, and soil fertility in three typical cropland soils. *Pedosphere* 30, 832-843.

Rady, 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, 8-14.

Rahman, F. A., Sudirja, R., and Sofyan, E. T. 2024. Effect of NPK Bio-Organomineral Tablet Fertilizer on Harvest Index, Wet Weight, Dry Weight and Fertilization Efficiency in the Waste Contaminated Soil. *International Journal of Life Science and Agriculture Research* 3, 139-143.

Reddy, D. D., Rao, A. S., and Rupa, T. 2000. Effects of continuous use of cattle manure and fertilizer phosphorus on crop yields and soil organic phosphorus in a Vertisol. *Bioresource Technology* 75, 113-118.

Reetz, H. F.,2016. Fertilizers and their efficient use. International Fertilizer industry Association, IFA

Regelink, I., Weng, L., Lair, G., and Comans, R. 2015. Adsorption of phosphate and organic matter on metal (hydr) oxides in arable and forest soil: a mechanistic modelling study. *European Journal of Soil Science* 66, 867-875.

Rosolem, C. A., Almeida, D. S., Rocha, K. F., and Bacco, G. H. 2017. Potassium fertilisation with humic acid coated KCl in a sandy clay loam tropical soil. *Soil Research* 56, 244-251.

Rowe, H., Withers, P. J., Baas, P., Chan, N. I., Doody, D., Holiman, J., Jacobs, B., Li, H., MacDonald, G. K., and McDowell, R. 2016. Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy and water security. *Nutrient Cycling in Agroecosystems* 104, 393-412.

Roy, R. N., Finck, A., Blair, G., and Tandon, H. 2006. Plant nutrition for food security. *A guide for integrated nutrient management. FAO Fertilizer and Plant Nutrition Bulletin* 16.

Russo, R. O., and Berlyn, G. P. 1991. The use of organic biostimulants to help low input sustainable agriculture. *Journal of sustainable agriculture* 1, 19-42.

Sá, J. M. e., Jantalia, C. P., Teixeira, P. C., Polidoro, J. C., Benites, V. d. M., and Araújo, A. P. 2017. Agronomic and P recovery efficiency of organomineral phosphate fertilizer from poultry litter in sandy and clayey soils. *Pesquisa Agropecuária Brasileira* 52, 786-793.

Sakurada L, R., Batista, M., Inoue, T., Muniz, A., and Pagliari, P. 2016. Organomineral phosphate fertilizers: agronomic efficiency and residual effect on initial corn development. *Agronomy Journal* 108, 2050-2059.

Sellamuthu, K., and Govindaswamy, M. 2003. Effect of fertiliser and humic acid on rhizosphere microorganisms and soil enzymes at an early stage of sugarcane growth. *Sugar Tech* 5, 273-277.

Seyedbagheri, M.-M. 2010. Influence of humic products on soil health and potato production. *Potato research* 53, 341-349.

Shaji, H., Chandran, V., and Mathew, L. 2021. Organic fertilizers as a route to controlled release of nutrients. *In* Controlled release fertilizers for sustainable agriculture, pp. 231-245. Elsevier.

Shan, Y., Dong-jie, Z., Javkhlan, B., Lin, L., Ruo-nan, L., Jiang-xiang, Z., Shu-lan, Z., and Xue-yun, Y. 2018. Responses of phosphorus use efficiency to soil phosphorus fertility under winter wheat– summer maize cropping in loess soil. *Journal of Plant Nutrition and Fertilizers* 24, 1640-1650.

Sharif, M., Burni, T., Wahid, F., Khan, F., Khan, S., Khan, A., and Shah, A. 2013. Effect of rock phosphate composted with organic materials on yield and phosphorus uptake of wheat and mung bean crops. *Pak. J. Bot* 45, 1349-1356.

Shearman, V., Sylvester-Bradley, R., Scott, R., and Foulkes, M. 2005. Physiological processes associated with wheat yield progress in the UK. *Crop science* 45, 175-185.

Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., and Zhang, F. 2011. Phosphorus dynamics: from soil to plant. *Plant physiology* 156, 997-1005.

Silva, R., Lana, R. M. Q., Mageste, J., Oliveira, G. N., and Magela, M. L. M. 2020. Phosphate organomineral fertilizer usage compared to mineral phosphate in corn cultivation. *Journal of Agricultural Science* 12.

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

Singh, Y., Singh, B., Maskina, M., and Meelu, O. 1988. Effect of organic manures, crop residues and green manure (Sesbania aculeata) on nitrogen and phosphorus transformations in a sandy loam at field capacity and under waterlogged conditions. *Biology and Fertility of Soils* 6, 183-187.

Sitzmann, T. J., Alpigiano, A., Lerda, C., Moretti, B., Zavattaro, L., and Grignani, C. 2024. Response of tomato to innovative organo-mineral fertilizers. *Frontiers in Sustainable Food Systems* 8, 1385828.

Smith, R. G., Menalled, F. D., and Robertson, G. 2007. Temporal yield variability under conventional and alternative management systems. *Agronomy Journal* 99, 1629-1634.

Smith, W. B., Wilson, M., and Pagliari, P. 2020. Organomineral fertilizers and their application to field crops. *Animal Manure: Production, Characteristics, Environmental Concerns, and Management* 67, 229-243.

Spiertz, J. 2009. Nitrogen, sustainable agriculture and food security: a review. *Sustainable agriculture*, 635-651.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., de Macêdo, J. L. V., Blum, W. E., and 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 and soil* 291, 275-290.

Stewart, W., Dibb, D., Johnston, A., and Smyth, T. 2005. The contribution of commercial fertilizer nutrients to food production. *Agronomy journal* 97, 1-6.

Suge, J., Omunyin, M., and Omami, E. 2011. Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (Solanum Melongena L). *Archives of Applied Science Research* 3, 470-479.

Tahir, M., Khurshid, M., Khan, M., Abbasi, M., and Kazmi, M. 2011. Lignite-derived humic acid effect on growth of wheat plants in different soils. *Pedosphere* 21, 124-131.

Tan, Z.-X., Lal, R., and Wiebe, K. D. 2005. Global soil nutrient depletion and yield reduction. *Journal of sustainable agriculture* 26, 123-146.

Tang, X., Ma, Y., Hao, X., Li, X., Li, J., Huang, S., and Yang, X. 2009. Determining critical values of soil Olsen-P for maize and winter wheat from long-term experiments in China. *Plant and Soil* 323, 143-151.

Taxonomy, S. 2014. Keys to soil taxonomy. USDA-Natural Resources Conservation Service, Washington, DC.

Tilley, M. S., Heiniger, R. W., and Crozier, C. R. 2019. Tiller initiation and its effects on yield and yield components in winter wheat. *Agronomy Journal* 111, 1323-1332.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., and Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature* 418, 671-677.

Urrutia, O., Fuentes, M., Olaetxea, M., Garnica, M., Baigorri, R., Movila, M., De Hita, D., and Garcia-Mina, J. 2020. The effect of soil organic matter on plant mineral nutrition. *In* Achieving sustainable crop nutrition, pp. 291-306. Burleigh Dodds Science Publishing.

Urrutia, O., Guardado, I., Erro, J., Mandado, M., and García-Mina, J. M. 2013. Theoretical chemical characterization of phosphate-metal–humic complexes and relationships with their effects on both phosphorus soil fixation and phosphorus availability for plants. *Journal of the Science of Food and Agriculture* 93, 293-303.

Van Kauwenbergh, S. J.,2010. World phosphate rock reserves and resources. Ifdc Muscle Shoals

Vance, C. P., Uhde-Stone, C., and Allan, D. L. 2003. Phosphorus acquisition and use: critical adaptations by plants for securing a nonrenewable resource. *New phytologist* 157, 423-447.

Vaughan, D., Malcolm, R., and Ord, B. 1985. Influence of humic substances on biochemical processes in plants. *Soil organic matter and biological activity*, 77-108.

Vlek, P. L., Kühne, R. F., and Denich, M. 1997. Nutrient resources for crop production in the tropics. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 352, 975-985.

Wahba, M., Fawkia, L., and Zaghloul, A. 2019. Management of calcareous soils in arid region. *International Journal of Environmental Pollution and Environmental Modelling* 2, 248-258.

Walkley, A., and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science* 37, 29-38.

Wang, J., and Chu, G. 2015. Phosphate fertilizer form and application strategy affect phosphorus mobility and transformation in a drip-irrigated calcareous soil. *Journal of Plant Nutrition and Soil Science* 178, 914-922.

Wang, Y., Thorup-Kristensen, K., Jensen, L. S., and Magid, J. 2016. Vigorous root growth is a better indicator of early nutrient uptake than root hair traits in spring wheat grown under low fertility. *Frontiers in plant science* 7, 865.

Wang, Y., Zhu, Y., Zhang, S., and Wang, Y. 2018. What could promote farmers to replace chemical fertilizers with organic fertilizers? *Journal of cleaner production* 199, 882-890.

Warrinnier, R., Bossuyt, S., Resseguier, C., Cambier, P., Houot, S., Gustafsson, J. P., Diels, J., and Smolders, E. 2020. Anaerobic respiration in the unsaturated zone of agricultural soil mobilizes phosphorus and manganese. *Environmental Science & Technology* 54, 4922-4931.

Weil, R. R., and Magdoff, F. 2004. Significance of soil organic matter to soil quality and health. *Soil organic matter in sustainable agriculture*, 1-43.

Weng, L., Van Riemsdijk, W. H., and Hiemstra, T. 2012. Factors controlling phosphate interaction with iron oxides. *Journal of environmental quality* 41, 628-635.

Withers, P. J., Rodrigues, M., Soltangheisi, A., De Carvalho, T. S., Guilherme, L. R., Benites, V. d. M., Gatiboni, L. C., De Sousa, D. M., Nunes, R. d. S., and Rosolem, C. A. 2018. Transitions to sustainable management of phosphorus in Brazilian agriculture. *Scientific Reports* 8, 1-13.

WRB, I. 2015. FAO, World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps, World Soil Resour. Reports.

Wu, Q., Zhang, S., Ren, Y., Zhan, X., Xu, M., and Feng, G. 2018. Soil phosphorus management based on the agronomic critical value of Olsen P. *Communications in Soil Science and Plant Analysis* 49, 934-944.

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

Xu, L., Niu, H., Xu, J., and Wang, X. 2013. Nitrate-nitrogen leaching and modeling in intensive agriculture farmland in China. *The Scientific World Journal* 2013, 353086.

Yan, J., Jiang, T., Yao, Y., Lu, S., Wang, Q., and Wei, S. 2016. Preliminary investigation of phosphorus adsorption onto two types of iron oxide-organic matter complexes. *Journal of Environmental Sciences* 42, 152-162.

Yan, Z., Chen, S., Dari, B., Sihi, D., and Chen, Q. 2018. Phosphorus transformation response to soil properties changes induced by manure application in a calcareous soil. *Geoderma* 322, 163-171.

Yang, F., Sui, L., Tang, C., Li, J., Cheng, K., and Xue, Q. 2021. Sustainable advances on phosphorus utilization in soil via addition of biochar and humic substances. *Science of The Total Environment* 768, 145106.

Yang, K., Zhu, J., Gu, J., Yu, L., and Wang, Z. 2015. Changes in soil phosphorus fractions after 9 years of continuous nitrogen addition in a Larix gmelinii plantation. *Annals of Forest Science* 72, 435-442.

Zhang, S., Chen, S., Fenton, O., Li, Y., and Chen, Q. 2021a. Enhanced topsoil P leaching in a short term flooded calcareous soil with combined straw and ammonium nitrogen incorporation. *Geoderma* 402, 115322.

Zhang, S., Wang, L., Chen, S., Fan, B., Huang, S., and 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.

Zhang, S., Yang, X., Hsu, L.-C., Liu, Y.-T., Wang, S.-L., White, J. R., Shaheen, S. M., Chen, Q., and Rinklebe, 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. *Science of the Total Environment* 793, 148531.

Zhang Zhengqing, He Fang, Zhang YanLing, Yu RuJun, Li YaQi, Zheng ZhiLei, Gao ZhenQiang, and 2018. Experiments and modelling of potassium release behavior from tablet biomass ash for better recycling of ash as eco-friendly fertilizer.

Zhen-Yu, D., Qing-Hua, W., Fang-Chun, L., Hai-Lin, M., Bing-Yao, M., and Malhi, S. 2013. Movement of phosphorus in a calcareous soil as affected by humic acid. *Pedosphere* 23, 229-235.

Zhou, J., Zhang, Y., Wu, K., Hu, M., Wu, H., and Chen, D. 2021. National estimates of environmental thresholds for upland soil phosphorus in China based on a meta-analysis. *Science of the Total Environment* 780, 146677.

CURRICULUM VITAE

Şeyhmus DÜNDAR completed his primary, secondary and high school education in Mardin before enrolling at Çukurova University in 2009. He pursued his undergraduate studies in the Faculty of Agriculture, Department of Soil Science and Plant Nutrition, graduating in 2014 with the title of Agricultural Engineer. In the same year, he commenced a master's program at Çukurova University's Institute of Natural and Applied Sciences, specializing in Soil Science and Plant Nutrition, and successfully earned his MSc degree in 2017 in the same field. Building upon this foundation, he began doctoral studies in 2018 at the same institution, continuing his specialization in the Department of Soil Science and Plant Nutrition.

APPENDICES

Appendix 1. Results of three-way ANOVA analysis for shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (10.2, 16.4, and 24.1 mg P·kg^{-1} soil), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Tillering stage- Shoot dry weight (g·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	9.849	2	4.925	19.695	0.000	***
FERTYPE	0.157	1	0.157	0.629	0.432	ns
RATE	34.331	3	11.444	45.769	0.000	***
SOIL P*FERTYPE	1.857	2	0.928	3.713	0.032	*
SOIL P*RATE	17.797	6	2.966	11.863	0.000	***
FERTYPE*RATE	1.145	3	0.382	1.526	0.220	ns
SOIL P*FERTYPE*RATE	1.336	6	0.223	0.891	0.509	ns
Error	12.002	48	0.250			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 2. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot dry weight (g·[2 plants]$^{-1}$) at MODERATE-P.						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	43.604	3	14.535	63.463	0.000	***
FERTYPE	1.550	1	1.550	6.770	0.019	*
RATE*FERTYPE	0.524	3	0.175	0.763	0.531	ns
Error	3.664	16	0.229			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 3. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot dry weight (g·[2 plants]$^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	7.634	3	2.545	8.366	0.001	**
FERTYPE	0.013	1	0.013	0.042	0.840	ns
RATE*FERTYPE	1.551	3	0.517	1.699	0.207	ns
Error	4.867	16	0.304			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 4. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot dry weight (g·[2 plants]$^{-1}$) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.889	3	0.296	1.367	0.289	ns
FERTYPE	0.451	1	0.451	2.079	0.169	ns
RATE*FERTYPE	0.406	3	0.135	0.624	0.610	ns
Error	3.471	16	0.217			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 5. Shoot dry weights (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

RATE:TYPES	Shoot dry weight (g·[2 plants]$^{-1}$) MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:TSP	2.07	0.3092	e	3.95	0.1300	d	5.01	0.1900	
0:OMF	2.10	0.1817	e	4.29	0.6241	cd	4.70	0.4222	
25:TSP	4.10	0.3355	d	4.88	0.1607	bcd	5.07	0.2083	
25:OMF	4.61	0.1908	bcd	4.46	0.2233	bcd	4.90	0.2677	
50:TSP	4.41	0.1680	cd	5.46	0.0000	ab	5.63	0.2710	
50:OMF	5.12	0.1345	bc	5.00	0.2609	abcd	4.96	0.1258	
100:TSP	5.37	0.4048	ab	5.25	0.5007	abc	5.27	0.3584	
100:OMF	6.16	0.3507	a	5.97	0.1010	a	5.32	0.1770	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 6. Results of three-way ANOVA analysis for plant height (cm) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Plant height (cm)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	92.834	2	46.417	6.103	0.004	**
FERTYPE	2.347	1	2.347	0.309	0.581	ns
RATE	157.569	3	52.523	6.906	0.001	**
SOIL P*FERTYPE	5.229	2	2.614	0.344	0.711	ns
SOIL P*RATE	150.090	6	25.015	3.289	0.009	**
FERTYPE*RATE	60.505	3	20.168	2.652	0.059	ns
SOIL P*FERTYPE*RATE	49.079	6	8.180	1.076	0.390	ns
Error	365.067	48	7.606			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 7. Results of three-way ANOVA analysis for spike length (cm) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Spike length (cm)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.114	2	0.057	0.433	0.651	ns
FERTYPE	0.027	1	0.027	0.206	0.652	ns
RATE	7.408	3	2.469	18.695	0.000	***
SOIL P*FERTYPE	0.241	2	0.121	0.913	0.408	ns
SOIL P*RATE	1.432	6	0.239	1.807	0.118	ns
FERTYPE*RATE	0.067	3	0.022	0.170	0.916	ns
SOIL P*FERTYPE*RATE	1.061	6	0.177	1.339	0.259	ns
Error	6.340	48	0.132			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 8. Results of three-way ANOVA analysis for spike count (number of spikes per pot) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Spike count						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	46.361	2	23.181	20.354	0.000	***
FERTYPE	8.000	1	8.000	7.024	0.011	*
RATE	109.778	3	36.593	32.130	0.000	***
SOIL P*FERTYPE	4.750	2	2.375	2.085	0.135	ns
SOIL P*RATE	92.306	6	15.384	13.508	0.000	***
FERTYPE*RATE	9.111	3	3.037	2.667	0.058	ns
SOIL P*FERTYPE*RATE	5.472	6	0.912	0.801	0.574	ns
Error	54.667	48	1.139			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 9. Results of three-way ANOVA analysis for biological yield (straw + grain) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Biological yield (g·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	325.662	2	162.831	207.854	0.000	***
FERTYPE	61.162	1	61.162	78.073	0.000	***
RATE	765.440	3	255.147	325.694	0.000	***
SOIL P*FERTYPE	0.901	2	0.451	0.575	0.566	ns
SOIL P*RATE	224.459	6	37.410	47.754	0.000	***
FERTYPE*RATE	28.642	3	9.547	12.187	0.000	***
SOIL P*FERTYPE*RATE	2.799	6	0.466	0.595	0.732	ns
Error	37.603	48	0.783			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 10. Results of three-way ANOVA analysis for straw yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw yield (g·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	133.783	2	66.891	109.666	0.000	***
FERTYPE	29.070	1	29.070	47.660	0.000	***
RATE	265.435	3	88.478	145.057	0.000	***
SOIL P*FERTYPE	0.409	2	0.204	0.335	0.717	ns
SOIL P*RATE	110.815	6	18.469	30.280	0.000	***
FERTYPE*RATE	9.690	3	3.230	5.296	0.003	**
SOIL P*FERTYPE*RATE	2.087	6	0.348	0.570	0.752	ns
Error	29.278	48	0.610			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 11. Results of three-way ANOVA analysis for grain yield of wheat plants ($g \cdot pot^{-1}$) harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil).

Grain yield ($g \cdot pot^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	42.878	2	21.439	42.068	0.000	***
FERTYPE	5.913	1	5.913	11.602	0.001	**
RATE	130.987	3	43.662	85.675	0.000	***
SOIL P*FERTYPE	0.268	2	0.134	0.263	0.770	ns
SOIL P*RATE	21.137	6	3.523	6.913	0.000	***
FERTYPE*RATE	5.047	3	1.682	3.301	0.028	*
SOIL P*FERTYPE*RATE	1.978	6	0.330	0.647	0.692	ns
Error	24.462	48	0.510			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 12. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on plant height (cm) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Plant height (cm) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	201.238	3	67.079	10.751	0.00	***
FERTYPE	2.100	1	2.100	0.337	0.57	ns
RATE*FERTYPE	48.255	3	16.085	2.578	0.09	ns
Error	99.827	16	6.239			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 13. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on plant height (cm) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Plant height (cm) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	57.667	3	19.222	1.651	0.217	ns
FERTYPE	0.882	1	0.882	0.076	0.787	ns
RATE*FERTYPE	48.232	3	16.077	1.381	0.285	ns
Error	186.280	16	11.643			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 14. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on plant height (cm) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Plant height (cm) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	48.755	3	16.252	3.293	0.048	*
FERTYPE	4.594	1	4.594	0.931	0.349	ns
RATE*FERTYPE	13.098	3	4.366	0.885	0.470	ns
Error	78.960	16	4.935			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 15. Plant height (cm) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Plant height (cm)								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:TSP	70.5	0.7638	d	71.8	0.6667		72.6	1.14	
0:OMF	72.5	0.7638	cd	74.8	0.6009		73.9	0.3512	
25:TSP	77.4	1.58	ab	79.9	0.6360		74.8	0.7311	
25:OMF	77.6	0.3480	ab	75.5	0.6333		73.1	0.6064	
50:TSP	80.4	2.01	a	74.5	2.75		77.1	0.1202	
50:OMF	75.0	2.32	bc	75.8	0.6000		74.4	1.03	
100:TSP	78.5	1.45	ab	75.0	3.26		72.0	2.72	
100:OMF	79.4	1.15	ab	76.7	3.30		71.6	1.53	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 16. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike length (cm) of wheat plants harvested at the end of the ripening stage MODERATE-P fertility level.

	Spike length (cm) at MODERATE-P					
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	5.445	3	1.815	12.517	0.000	***
FERTYPE	0.060	1	0.060	0.414	0.529	ns
RATE*FERTYPE	0.253	3	0.084	0.582	0.635	ns
Error	2.320	16	0.145			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 17. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike length (cm) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

	Spike length (cm) at HIGH-P					
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1.408	3	0.469	2.602	0.088	ns
FERTYPE	0.007	1	0.007	0.037	0.850	ns
RATE*FERTYPE	0.443	3	0.148	0.819	0.502	ns
Error	2.887	16	0.180			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 18. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike length (cm) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

	Spike length (cm) at VERY HIGH-P					
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1.987	3	0.662	9.349	0.001	**
FERTYPE	0.202	1	0.202	2.847	0.111	ns
RATE*FERTYPE	0.432	3	0.144	2.031	0.150	ns
Error	1.133	16	0.071			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 19. Spike length (cm) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Spike length (cm)								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:TSP	8.30	0.2887	cd	8.60	0.3464		8.63	0.1764	d
0:OMF	8.13	0.0882	d	8.53	0.0333		8.73	0.1453	cd
25:TSP	8.80	0.2517	bcd	8.67	0.3383		9.13	0.1202	abc
25:OMF	9.10	0.3055	ab	9.03	0.2186		8.57	0.0333	d
50:TSP	8.90	0.2082	abc	9.40	0.1155		9.23	0.2963	ab
50:OMF	9.20	0.2000	ab	9.00	0.2646		8.93	0.1333	bcd
100:TSP	9.57	0.2333	a	9.10	0.2082		9.43	0.1202	a
100:OMF	9.53	0.0333	a	9.07	0.2667		9.47	0.0333	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 20. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike count (number of spikes per pot) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Spike count at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	175.500	3	58.500	52.000	0.000	***
FERTYPE	10.667	1	10.667	9.481	0.007	**
RATE*FERTYPE	8.333	3	2.778	2.469	0.099	ns
Error	18.000	16	1.125			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 21. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike count (number of spikes per pot) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Spike count at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	24.125	3	8.042	6.893	0.003	**
FERTYPE	2.042	1	2.042	1.750	0.204	ns
RATE*FERTYPE	4.792	3	1.597	1.369	0.288	ns
Error	18.667	16	1.167			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 22. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on spike count (number of spikes per pot) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Spike count at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	2.458	3	0.819	0.728	0.550	ns
FERTYPE	0.042	1	0.042	0.037	0.850	ns
RATE*FERTYPE	1.458	3	0.486	0.432	0.733	ns
Error	18.000	16	1.125			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 23. Spike count (number of spikes per pot) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Spike count								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	6.67	0.6667	d	10.3	0.3333	c	12.7	0.3333	
0:OMF	7.00	0.5774	d	11.0	0.5774	bc	13.3	0.3333	
25:MF	11.3	0.8819	c	13.3	0.6667	a	14.0	0.0000	
25:OMF	11.3	0.8819	c	13.0	0.0000	ab	13.3	0.6667	
50:MF	11.7	0.3333	c	12.0	0.5774	abc	12.7	0.8819	
50:OMF	14.3	0.3333	ab	14.0	0.5774	a	13.0	1.00	
100:MF	12.7	0.3333	bc	12.7	0.8819	ab	13.3	0.6667	
100:OMF	15.0	0.5774	a	12.7	0.8819	ab	13.3	0.3333	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 24. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on biological yield (straw + grain) of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at MODERATE-P fertility level.

Biological yield (g·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	781.345	3	260.448	280.012	0.000	***
FERTYPE	25.133	1	25.133	27.021	0.000	***
RATE*FERTYPE	15.456	3	5.152	5.539	0.008	**
Error	14.882	16	0.930			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 25. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on biological yield (straw + grain) of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at HIGH-P fertility level.

Biological yield (g·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	114.166	3	38.055	61.622	0.000	***
FERTYPE	22.854	1	22.854	37.007	0.000	***
RATE*FERTYPE	5.067	3	1.689	2.735	0.078	ns
Error	9.881	16	0.618			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 26. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on biological yield (straw + grain) of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Biological yield (g·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	94.387	3	31.462	39.206	0.000	***
FERTYPE	14.076	1	14.076	17.541	0.001	**
RATE*FERTYPE	10.917	3	3.639	4.535	0.017	*
Error	12.840	16	0.802			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 27. Biological yield (straw + grain) of wheat plants (g·pot^{-1}), harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Biological yield (g·pot^{-1})								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	14.0	0.2417	e	21.8	0.3641	c	24.9	0.7310	c
0:OMF	14.1	0.4035	e	22.7	0.0982	c	25.2	0.3386	c
25:MF	21.8	0.6626	d	25.7	0.6645	b	28.3	0.2892	b
25:OMF	22.8	0.4734	d	26.9	0.5600	b	29.0	0.5619	b
50:MF	25.6	0.1525	c	26.2	0.1805	b	28.2	0.4221	b
50:OMF	28.2	0.8712	b	28.9	0.5101	a	29.5	0.7127	b
100:MF	26.7	0.3760	bc	26.0	0.5490	b	28.5	0.4493	b
100:OMF	31.0	0.8200	a	29.0	0.3941	a	32.3	0.4512	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 28. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw yield (g·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	318.494	3	106.165	193.621	0.000	***
FERTYPE	10.179	1	10.179	18.564	0.001	**
RATE*FERTYPE	7.315	3	2.438	4.447	0.019	*
Error	8.773	16	0.548			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 29. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at HIGH-P fertility level.

Straw yield (g·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	32.219	3	10.740	23.548	0.00	***
FERTYPE	12.398	1	12.398	27.185	0.00	***
RATE*FERTYPE	3.234	3	1.078	2.363	0.11	ns
Error	7.297	16	0.456			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 30. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw yield (g·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	25.537	3	8.512	10.312	0.001	**
FERTYPE	6.902	1	6.902	8.361	0.011	*
RATE*FERTYPE	1.228	3	0.409	0.496	0.690	ns
Error	13.208	16	0.825			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 31. Straw yield (g·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the (MODERATE-P, HIGH-P and VERY HIGH-P) average of three independent replicates.

Straw yield (g·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	9.04	0.1610	e	14.6	0.3213	c	16.0	0.8058	d
0:OMF	9.16	0.2904	e	15.1	0.1484	c	16.7	0.1793	cd
25:MF	13.8	0.7377	d	16.8	0.3858	b	18.0	0.5116	bc
25:OMF	14.5	0.1184	d	17.7	0.4957	ab	18.9	0.1822	ab
50:MF	16.9	0.2794	c	16.6	0.4138	b	18.1	0.3782	bc
50:OMF	18.2	0.5871	b	18.7	0.4042	a	19.1	0.5312	ab
100:MF	16.8	0.1266	c	16.4	0.5997	b	18.1	0.6471	bc
100:OMF	19.9	0.5957	a	18.6	0.0462	a	19.9	0.6173	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 32. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain yield (g·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	103.394	3	34.465	104.616	0.000	***
FERTYPE	3.308	1	3.308	10.041	0.006	**
RATE*FERTYPE	1.871	3	0.624	1.893	0.172	ns
Error	5.271	16	0.329			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 33. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at HIGH-P fertility level.

Grain yield (g·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	25.995	3	8.665	34.388	0.000	***
FERTYPE	1.603	1	1.603	6.363	0.023	*
RATE*FERTYPE	0.269	3	0.090	0.356	0.785	ns
Error	4.032	16	0.252			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 34. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain yield of wheat plants (g·pot^{-1}) harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain yield (g·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	22.735	3	7.578	7.999	0.002	**
FERTYPE	1.270	1	1.270	1.340	0.264	ns
RATE*FERTYPE	4.885	3	1.628	1.718	0.203	ns
Error	15.159	16	0.947			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 35. Grain yield (g·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Grain yield (g·pot^{-1})								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	4.94	0.0865	d	7.22	0.1701	c	8.80	0.0755	bc
0:OMF	4.98	0.1503	d	7.58	0.0869	c	8.51	0.3329	c
25:MF	7.96	0.1193	c	8.88	0.2843	b	10.3	0.7463	bc
25:OMF	8.31	0.3580	c	9.19	0.1079	b	10.1	0.5965	bc
50:MF	8.74	0.4183	c	9.64	0.3885	ab	10.1	0.0866	bc
50:OMF	10.0	0.4670	b	10.2	0.2575	a	10.4	0.4783	b
100:MF	9.86	0.4943	b	9.55	0.3657	ab	10.4	1.10	b
100:OMF	11.2	0.2621	a	10.4	0.4382	a	12.4	0.2466	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 36. Results of three-way ANOVA analysis for shoot P concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.114	2	0.057	149.435	0.000	***
FERTYPE	0.001	1	0.001	3.329	0.074	ns
RATE	0.005	3	0.002	4.633	0.006	**
SOIL P*FERTYPE	0.000	2	0.000	0.284	0.754	ns
SOIL P*RATE	0.005	6	0.001	2.275	0.052	ns
FERTYPE*RATE	0.002	3	0.001	1.856	0.150	ns
SOIL P*FERTYPE*RATE	0.003	6	0.000	1.211	0.317	ns
Error	0.018	48	0.000			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: P rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 37. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot phosphorus concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.007	3	0.002	27.327	0.000	***
FERTYPE	0.000	1	0.000	1.059	0.319	ns
RATE*FERTYPE	0.000	3	0.000	1.327	0.300	ns
Error	0.001	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 38. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot phosphorus concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.003	3	0.001	3.604	0.037	*
FERTYPE	0.001	1	0.001	1.633	0.219	ns
RATE*FERTYPE	0.001	3	0.000	1.575	0.234	ns
Error	0.005	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 39. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot phosphorus concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.000	3	0.000	0.172	0.914	ns
FERTYPE	0.001	1	0.001	1.189	0.292	ns
RATE*FERTYPE	0.003	3	0.001	1.376	0.286	ns
Error	0.012	16	0.001			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 40. Shoot Phosphorus concentration (%) of wheat plants, harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Shoot phosphorus concentration (%)									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	0.1060	0.0040	e	0.1697	0.0155		0.2233	0.0059	
0:OMF	0.1043	0.0015	e	0.1480	0.0137		0.2400	0.0012	
25:MF	0.1267	0.0032	cd	0.1677	0.0075		0.2437	0.0287	
25:OMF	0.1150	0.0055	de	0.1710	0.0121		0.2023	0.0048	
50:MF	0.1417	0.0085	abc	0.1923	0.0043		0.2407	0.0245	
50:OMF	0.1323	0.0049	bc	0.1650	0.0020		0.2143	0.0009	
100:MF	0.1463	0.0061	ab	0.1863	0.0099		0.2203	0.0137	
100:OMF	0.1537	0.0055	a	0.1953	0.0085		0.2223	0.0187	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 41. Results of three-way ANOVA analysis for P uptake (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil).

Shoot phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	404.125	2	202.063	235.613	0.000	***
FERTYPE	0.611	1	0.611	0.712	0.403	ns
RATE	146.196	3	48.732	56.823	0.000	***
SOIL P*FERTYPE	5.373	2	2.687	3.133	0.053	ns
SOIL P*RATE	53.879	6	8.980	10.471	0.000	***
FERTYPE*RATE	19.278	3	6.426	7.493	0.000	***
SOIL P*FERTYPE*RATE	6.468	6	1.078	1.257	0.295	ns
Error	41.165	48	0.858			

The sources include FERTYPE: Fertilizer types, RATE: phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant

Appendix 42. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot phosphorus content (mg·[2 plants]$^{-1}$) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	131.976	3	43.992	53.419	0.000	***
FERTYPE	1.794	1	1.794	2.178	0.159	ns
RATE*FERTYPE	2.503	3	0.834	1.013	0.413	ns
Error	13.176	16	0.824			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 43. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot phosphorus content (mg·[2 plants]$^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	60.915	3	20.305	24.182	0.000	***
FERTYPE	0.664	1	0.664	0.791	0.387	ns
RATE*FERTYPE	13.782	3	4.594	5.471	0.009	**
Error	13.435	16	0.840			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 44. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot phosphorus content (mg·[2 plants]$^{-1}$) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	7.183	3	2.394	2.632	0.086	ns
FERTYPE	3.526	1	3.526	3.876	0.067	ns
RATE*FERTYPE	9.460	3	3.153	3.467	0.041	*
Error	14.554	16	0.910			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 45. Shoot Phosphorus content of wheat plants (mg·[2 plants]$^{-1}$), harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Shoot phosphorus content (mg·[2 plants]$^{-1}$)								
RATE&TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	2.22	0.3973	d	6.66	0.3986	de	11.2	0.3692	bc
0:OMF	2.19	0.2201	d	6.21	0.6046	e	11.3	0.9698	bc
25:MF	5.20	0.4929	c	8.20	0.5931	cd	11.3	0.3060	bc
25:OMF	5.29	0.2364	c	7.59	0.4407	de	10.1	0.1732	c
50:MF	6.28	0.6016	bc	10.5	0.2367	ab	13.4	0.9438	a
50:OMF	6.79	0.4267	bc	8.25	0.5264	cd	10.8	0.1732	bc
100:MF	7.88	0.6860	b	9.69	0.6126	bc	11.5	0.0203	bc
100:OMF	9.49	0.8225	a	11.7	0.6784	a	12.1	0.5514	ab

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 46. Results of three-way ANOVA analysis for straw P concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0	2	0	24.523	0.000	***
FERTYPE	0	1	0	2.090	0.155	ns
RATE	0	3	0	8.129	0.000	***
SOIL P*FERTYPE	0	2	0	1.297	0.283	ns
SOIL P*RATE	0	6	0	5.426	0.000	***
FERTYPE*RATE	0	3	0	1.316	0.280	ns
SOIL P*FERTYPE*RATE	0	6	0	1.658	0.152	ns
Error	0	48	0			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 47. Results of three-way ANOVA analysis for grain P concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.038	2	0.019	51.478	0.000	***
FERTYPE	0.000	1	0.000	0.335	0.565	ns
RATE	0.005	3	0.002	4.626	0.006	**
SOIL P*FERTYPE	0.000	2	0.000	0.366	0.695	ns
SOIL P*RATE	0.010	6	0.002	4.477	0.001	**
FERTYPE*RATE	0.002	3	0.001	1.813	0.157	ns
SOIL P*FERTYPE*RATE	0.003	6	0.001	1.419	0.227	ns
Error	0.018	48	0.000			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 48. Results of three-way ANOVA analysis for straw P content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	9.973	2	4.987	62.067	0.000	***
FERTYPE	0.247	1	0.247	3.070	0.086	ns
RATE	10.290	3	3.430	42.694	0.000	***
SOIL P*FERTYPE	0.233	2	0.116	1.450	0.245	ns
SOIL P*RATE	3.014	6	0.502	6.253	0.000	***
FERTYPE*RATE	0.486	3	0.162	2.015	0.124	ns
SOIL P*FERTYPE*RATE	0.675	6	0.113	1.400	0.234	ns
Error	3.856	48	0.080			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 49. Results of three-way ANOVA analysis for grain P content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	1202.772	2	601.386	163.004	0.000	***
FERTYPE	26.152	1	26.152	7.088	0.011	*
RATE	1193.698	3	397.899	107.850	0.000	***
SOIL P*FERTYPE	2.379	2	1.189	0.322	0.726	ns
SOIL P*RATE	167.789	6	27.965	7.580	0.000	***
FERTYPE*RATE	62.930	3	20.977	5.686	0.002	**
SOIL P*FERTYPE*RATE	26.785	6	4.464	1.210	0.318	ns
Error	177.091	48	3.689			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 50. Results of three-way ANOVA analysis for total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Total phosphorus uptake (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	1430.951	2	715.476	190.744	0.000	***
FERTYPE	31.469	1	31.469	8.390	0.006	**
RATE	1424.602	3	474.867	126.598	0.000	***
SOIL P*FERTYPE	3.515	2	1.757	0.468	0.629	ns
SOIL P*RATE	171.954	6	28.659	7.640	0.000	***
FERTYPE*RATE	73.006	3	24.335	6.488	0.001	**
SOIL P*FERTYPE*RATE	26.880	6	4.480	1.194	0.325	ns
Error	180.047	48	3.751			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 51. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw phosphorus concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0	3	0	2.967	0.063	ns
FERTYPE	0	1	0	0.033	0.857	ns
RATE*FERTYPE	0	3	0	2.256	0.121	ns
Error	0	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 52. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw phosphorus concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0	3	0	1.318	0.303	ns
FERTYPE	0	1	0	0.188	0.670	ns
RATE*FERTYPE	0	3	0	0.565	0.646	ns
Error	0	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 53. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw phosphorus concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0	3	0	19.492	0.000	***
FERTYPE	0	1	0	5.625	0.031	*
RATE*FERTYPE	0	3	0	3.092	0.057	ns
Error	0	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 54. Straw phosphorus concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Straw phosphorus concentration %									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	0.0137	0.0009		0.0117	0.0003		0.0140	0.0017	b
0:OMF	0.0120	0.0006		0.0117	0.0020		0.0137	0.0003	b
25:MF	0.0117	0.0003		0.0133	0.0003		0.0137	0.0003	b
25:OMF	0.0113	0.0007		0.0140	0.0010		0.0137	0.0003	b
50:MF	0.0127	0.0007		0.0137	0.0003		0.0170	0.0006	a
50:OMF	0.0140	0.0006		0.0117	0.0018		0.0130	0.0006	b
100:MF	0.0123	0.0003		0.0133	0.0003		0.0190	0.0000	a
100:OMF	0.0133	0.0009		0.0133	0.0009		0.0183	0.0007	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 55. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain phosphorus concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.005	3	0.002	6.656	0.004	**
FERTYPE	0.000	1	0.000	0.588	0.454	ns
RATE*FERTYPE	0.001	3	0.000	1.950	0.162	ns
Error	0.004	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 56. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain phosphorus concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.009	3	0.003	6.755	0.004	**
FERTYPE	0.000	1	0.000	0.109	0.745	ns
RATE*FERTYPE	0.004	3	0.001	2.680	0.082	ns
Error	0.007	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 57. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain phosphorus concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.001	3	0	0.735	0.546	ns
FERTYPE	0.000	1	0	0.479	0.499	ns
RATE*FERTYPE	0.000	3	0	0.060	0.980	ns
Error	0.006	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 58. Grain phosphorus concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Grain phosphorus concentration %									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	0.2070	0.0061	c	0.2650	0.0052	bc	0.2927	0.0052	
0:OMF	0.2290	0.0044	bc	0.2717	0.0125	abc	0.2890	0.0092	
25:MF	0.2567	0.0052	ab	0.2373	0.0285	c	0.3010	0.0162	
25:OMF	0.2393	0.0050	ab	0.2330	0.0046	c	0.3000	0.0200	
50:MF	0.2633	0.0046	a	0.2813	0.0064	ab	0.3113	0.0037	
50:OMF	0.2493	0.0154	ab	0.2520	0.0069	bc	0.3023	0.0052	
100:MF	0.2530	0.0119	ab	0.2700	0.0074	abc	0.2990	0.0057	
100:OMF	0.2423	0.0130	ab	0.3083	0.0035	a	0.2900	0.0150	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 59. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus content (mg·[pot]$^{-1}$) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw phosphorus content (mg·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	6.349	3	2.116	37.419	0.000	***
FERTYPE	0.326	1	0.326	5.759	0.029	*
RATE*FERTYPE	0.531	3	0.177	3.132	0.055	ns
Error	0.905	16	0.057			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 60. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus content (mg·[pot]$^{-1}$) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw phosphorus content (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1.547	3	0.516	5.216	0.011	*
FERTYPE	0.145	1	0.145	1.471	0.243	ns
RATE*FERTYPE	0.129	3	0.043	0.436	0.730	ns
Error	1.582	16	0.099			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 61. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw phosphorus content (mg·[pot]$^{-1}$) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw phosphorus content (mg.pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	5.409	3	1.803	21.056	0.000	***
FERTYPE	0.008	1	0.008	0.099	0.758	ns
RATE*FERTYPE	0.500	3	0.167	1.947	0.163	ns
Error	1.370	16	0.086			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 62. Straw phosphorus content (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Straw phosphorus content (mg·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	1.27	0.1011	cd	1.75	0.0710		2.28	0.3516	d
0:OMF	1.13	0.0828	d	1.81	0.2902		2.33	0.0785	d
25:MF	1.66	0.1293	c	2.29	0.0220		2.50	0.0719	d
25:OMF	1.69	0.1081	c	2.54	0.2011		2.64	0.0667	cd
50:MF	2.18	0.1307	b	2.26	0.1012		3.07	0.1490	bc
50:OMF	2.62	0.1788	a	2.23	0.2793		2.54	0.1609	d
100:MF	2.12	0.0724	b	2.20	0.1400		3.48	0.1056	ab
100:OMF	2.72	0.2260	a	2.55	0.1600		3.67	0.1722	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 63. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain phosphorus content (mg.pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	807.255	3	269.085	177.034	0.000	***
FERTYPE	8.042	1	8.042	5.291	0.035	*
RATE*FERTYPE	6.444	3	2.148	1.413	0.276	ns
Error	24.319	16	1.520			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 64. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain phosphorus content (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	330.547	3	110.182	27.564	0.000	***
FERTYPE	16.784	1	16.784	4.199	0.057	ns
RATE*FERTYPE	49.373	3	16.458	4.117	0.024	*
Error	63.957	16	3.997			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 65. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain phosphorus content (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	223.685	3	74.562	13.432	0.000	***
FERTYPE	3.705	1	3.705	0.667	0.426	ns
RATE*FERTYPE	33.898	3	11.299	2.036	0.149	ns
Error	88.814	16	5.551			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 66. Grain phosphorus content (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Grain phosphorus content (mg·pot^{-1})								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	10.2	0.1871	d	19.1	0.8228	c	25.8	0.6424	c
0:OMF	11.4	0.5063	d	20.6	0.8122	c	24.6	1.15	c
25:MF	20.4	0.6222	c	20.9	1.92	c	30.8	0.8278	b
25:OMF	19.9	1.04	c	21.4	0.6192	c	30.2	0.9817	b
50:MF	23.0	1.15	b	27.2	1.73	b	31.4	0.1938	b
50:OMF	24.8	0.3171	b	25.6	0.4781	b	31.5	1.25	b
100:MF	24.8	0.3044	b	25.8	0.9586	b	31.0	2.77	b
100:OMF	27.0	0.8836	a	32.1	1.05	a	35.8	1.46	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 67. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Total phosphorus uptake (mg·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	950.847	3	316.949	200.620	0.000	***
FERTYPE	11.607	1	11.607	7.347	0.015	*
RATE*FERTYPE	9.472	3	3.157	1.998	0.155	ns
Error	25.278	16	1.580			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 68. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Total phosphorus uptake (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	357.359	3	119.120	28.981	0.000	***
FERTYPE	20.002	1	20.002	4.866	0.042	*
RATE*FERTYPE	53.639	3	17.880	4.350	0.020	*
Error	65.764	16	4.110			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 69. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Total phosphorus uptake (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	288.349	3	96.116	17.278	0.000	***
FERTYPE	3.375	1	3.375	0.607	0.447	ns
RATE*FERTYPE	36.776	3	12.259	2.204	0.127	ns
Error	89.006	16	5.563			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively

Appendix 70. Total phosphorus uptake (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Total phosphorus uptake (mg·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	11.5	0.2259	d	20.9	0.8617	c	28.0	0.2898	c
0:OMF	12.5	0.5892	d	22.4	0.7118	c	26.9	1.17	c
25:MF	22.1	0.6035	c	23.2	1.91	c	33.3	0.7553	b
25:OMF	21.6	1.15	c	24.0	0.7979	c	32.8	0.9854	b
50:MF	25.2	1.03	b	29.4	1.69	b	34.5	0.3427	b
50:OMF	27.5	0.2018	b	27.9	0.2240	b	34.1	1.39	b
100:MF	27.0	0.2710	b	28.0	1.07	b	34.5	2.66	b
100:OMF	29.7	0.9781	a	34.6	1.18	a	39.5	1.64	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 71. Results of three-way ANOVA for shoot N concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.149	2	0.075	4.868	0.012	*
FERTYPE	0.401	1	0.401	26.185	0.000	***
RATE	0.097	3	0.032	2.102	0.112	ns
SOIL P*FERTYPE	0.002	2	0.001	0.065	0.937	ns
SOIL P*RATE	0.147	6	0.024	1.597	0.168	ns
FERTYPE*RATE	0.114	3	0.038	2.476	0.073	ns
SOIL P*FERTYPE*RATE	0.094	6	0.016	1.027	0.419	ns
Error	0.736	48	0.015			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 72. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot nitrogen concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.172	3	0.057	2.907	0.067	ns
FERTYPE	0.150	1	0.150	7.625	0.014	*
RATE*FERTYPE	0.008	3	0.003	0.134	0.938	ns
Error	0.315	16	0.020			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 73. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot nitrogen concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.016	3	0.005	0.375	0.772	ns
FERTYPE	0.145	1	0.145	10.112	0.006	**
RATE*FERTYPE	0.077	3	0.026	1.799	0.188	ns
Error	0.229	16	0.014			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 74. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot nitrogen concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.056	3	0.019	1.549	0.241	ns
FERTYPE	0.109	1	0.109	9.058	0.008	**
RATE*FERTYPE	0.123	3	0.041	3.428	0.043	*
Error	0.192	16	0.012			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 75. Shoot Nitrogen concentration (%) of wheat plants, harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Shoot nitrogen concentration %								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	2.26	0.1172		2.31	0.0905		2.43	0.1177	a
0:OMF	2.40	0.0329		2.34	0.0346		2.32	0.0913	abc
25:MF	2.22	0.1146		2.16	0.0303		2.19	0.0519	bc
25:OMF	2.34	0.0684		2.45	0.0151		2.35	0.0061	ab
50:MF	2.05	0.0833		2.35	0.1514		2.13	0.0296	c
50:OMF	2.20	0.0355		2.40	0.0403		2.37	0.0747	ab
100:MF	2.05	0.0196		2.21	0.0254		2.17	0.0199	bc
100:OMF	2.26	0.1064		2.45	0.0491		2.42	0.0132	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 76. Results of three-way ANOVA for shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil).

Shoot nitrogen content (mg·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	7992.737	2	3996.368	25.776	0.000	***
FERTYPE	1570.054	1	1570.054	10.126	0.003	**
RATE	14990.960	3	4996.987	32.229	0.000	***
SOIL P*FERTYPE	974.216	2	487.108	3.142	0.052	ns
SOIL P*RATE	8703.297	6	1450.549	9.356	0.000	***
FERTYPE*RATE	1622.662	3	540.887	3.489	0.023	*
SOIL P*FERTYPE*RATE	689.628	6	114.938	0.741	0.619	ns
Error	7442.128	48	155.044			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 77. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot nitrogen content (mg·[2 plants]$^{-1}$) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	18840.594	3	6280.198	37.253	0.000	***
FERTYPE	2062.575	1	2062.575	12.235	0.003	**
RATE*FERTYPE	520.747	3	173.582	1.030	0.406	ns
Error	2697.283	16	168.580			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 78. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot nitrogen content (mg·[2 plants]$^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	4601.009	3	1533.670	8.232	0.002	**
FERTYPE	479.989	1	479.989	2.576	0.128	ns
RATE*FERTYPE	1230.089	3	410.030	2.201	0.128	ns
Error	2980.738	16	186.296			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 79. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot nitrogen content (mg·[2 plants]$^{-1}$) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	252.653	3	84.218	0.764	0.531	ns
FERTYPE	1.707	1	1.707	0.015	0.903	ns
RATE*FERTYPE	561.453	3	187.151	1.697	0.208	ns
Error	1764.107	16	110.257			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 80. Shoot Nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants, harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Shoot nitrogen content (mg·[2 plants]$^{-1}$)								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	46.1	4.94	c	91.2	3.91	d	122	8.69	
0:OMF	50.5	4.69	c	100	14.1	cd	109	9.14	
25:MF	90.5	5.84	b	106	5.01	bcd	111	3.00	
25:OMF	108	7.09	b	109	5.23	bcd	115	5.86	
50:MF	90.7	6.86	b	128	8.14	ab	120	4.00	
50:OMF	113	5.00	b	120	7.81	bc	117	0.8819	
100:MF	110	7.09	b	115	9.77	bcd	115	7.75	
100:OMF	140	14.0	a	147	2.60	a	128	3.84	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 81. Results of three-way ANOVA for straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.039	2	0.020	1.176	0.317	ns
FERTYPE	0.045	1	0.045	2.668	0.109	ns
RATE	0.276	3	0.092	5.510	0.002	**
SOIL P*FERTYPE	0.003	2	0.001	0.076	0.927	ns
SOIL P*RATE	0.089	6	0.015	0.891	0.509	ns
FERTYPE*RATE	0.016	3	0.005	0.310	0.818	ns
SOIL P*FERTYPE*RATE	0.030	6	0.005	0.303	0.932	ns
Error	0.801	48	0.017			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 82. Results of three-way ANOVA for grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.355	2	0.177	2.607	0.084	ns
FERTYPE	0.001	1	0.001	0.017	0.896	ns
RATE	0.671	3	0.224	3.289	0.028	*
SOIL P*FERTYPE	0.012	2	0.006	0.088	0.916	ns
SOIL P*RATE	0.096	6	0.016	0.235	0.963	ns
FERTYPE*RATE	0.022	3	0.007	0.108	0.955	ns
SOIL P*FERTYPE*RATE	0.249	6	0.041	0.610	0.721	ns
Error	3.265	48	0.068			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 83. Results of three-way ANOVA for straw nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw nitrogen content (mg.pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	1060.001	2	530.000	1.022	0.368	ns
FERTYPE	370.646	1	370.646	0.714	0.402	ns
RATE	157.463	3	52.488	0.101	0.959	ns
SOIL P*FERTYPE	79.315	2	39.658	0.076	0.927	ns
SOIL P*RATE	3607.621	6	601.270	1.159	0.344	ns
FERTYPE*RATE	389.472	3	129.824	0.250	0.861	ns
SOIL P*FERTYPE*RATE	1074.806	6	179.134	0.345	0.909	ns
Error	24903.497	48	518.823			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 84. Results of three-way ANOVA for grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain nitrogen content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	16367.194	2	8183.597	13.960	0.000	***
FERTYPE	4050.000	1	4050.000	6.909	0.011	*
RATE	61931.667	3	20643.889	35.215	0.000	***
SOIL P*FERTYPE	766.583	2	383.292	0.654	0.525	ns
SOIL P*RATE	17498.583	6	2916.431	4.975	0.000	***
FERTYPE*RATE	4096.111	3	1365.370	2.329	0.086	ns
SOIL P*FERTYPE*RATE	3229.639	6	538.273	0.918	0.490	ns
Error	28138.667	48	586.222			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 85. Results of three-way ANOVA for total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg·P kg^{-1} soil).

Total nitrogen uptake (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	25336.111	2	12668.056	13.764	0.000	***
FERTYPE	1974.014	1	1974.014	2.145	0.150	ns
RATE	55659.042	3	18553.014	20.159	0.000	***
SOIL P*FERTYPE	1195.111	2	597.556	0.649	0.527	ns
SOIL P*RATE	30590.333	6	5098.389	5.540	0.000	***
FERTYPE*RATE	2687.486	3	895.829	0.973	0.413	ns
SOIL P*FERTYPE*RATE	4959.556	6	826.593	0.898	0.504	ns
Error	44176.667	48	920.347			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 86. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw nitrogen concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.173	3	0.058	2.814	0.073	ns
FERTYPE	0.009	1	0.009	0.440	0.516	ns
RATE*FERTYPE	0.001	3	0.000	0.020	0.996	ns
Error	0.327	16	0.020			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 87. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw nitrogen concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.143	3	0.048	2.650	0.084	ns
FERTYPE	0.026	1	0.026	1.464	0.244	ns
RATE*FERTYPE	0.009	3	0.003	0.160	0.922	ns
Error	0.288	16	0.018			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 88. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw nitrogen concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.049	3	0.016	1.414	0.275	ns
FERTYPE	0.012	1	0.012	1.008	0.330	ns
RATE*FERTYPE	0.036	3	0.012	1.032	0.405	ns
Error	0.186	16	0.012			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 89. Straw nitrogen concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Straw nitrogen concentration %								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	0.5600	0.0667		0.5007	0.1011		0.4797	0.0425	
0:OMF	0.5073	0.0487		0.4983	0.0200		0.4263	0.0392	
25:MF	0.4817	0.1162		0.4003	0.0413		0.2867	0.0522	
25:OMF	0.4587	0.1039		0.3140	0.0225		0.3700	0.0824	
50:MF	0.4150	0.0539		0.3317	0.0603		0.4350	0.0512	
50:OMF	0.3613	0.0877		0.2560	0.1062		0.3140	0.0626	
100:MF	0.3213	0.0638		0.3870	0.0025		0.4093	0.0829	
100:OMF	0.2957	0.0936		0.2863	0.1422		0.3237	0.0684	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 90. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain nitrogen concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.304	3	0.101	2.067	0.145	ns
FERTYPE	0.005	1	0.005	0.097	0.760	ns
RATE*FERTYPE	0.079	3	0.026	0.539	0.663	ns
Error	0.784	16	0.049			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 91. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain nitrogen concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.195	3	0.065	0.585	0.634	ns
FERTYPE	0.003	1	0.003	0.026	0.874	ns
RATE*FERTYPE	0.124	3	0.041	0.372	0.774	ns
Error	1.783	16	0.111			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 92. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain nitrogen concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.268	3	0.089	2.046	0.148	ns
FERTYPE	0.006	1	0.006	0.127	0.727	ns
RATE*FERTYPE	0.067	3	0.022	0.514	0.678	ns
Error	0.698	16	0.044			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 93. Grain nitrogen concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Grain nitrogen concentration (%)									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	3.06	0.0364		2.90	0.2999		2.76	0.0580	
0:OMF	2.93	0.3166		2.86	0.1728		2.89	0.2633	
25:MF	2.83	0.1333		2.86	0.0539		2.68	0.1054	
25:OMF	2.97	0.0479		2.62	0.1592		2.62	0.1127	
50:MF	2.73	0.0313		2.56	0.3187		2.77	0.0540	
50:OMF	2.87	0.0749		2.72	0.1108		2.61	0.0402	
100:MF	2.71	0.0291		2.67	0.0329		2.54	0.0871	
100:OMF	2.67	0.0397		2.71	0.1850		2.52	0.0876	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 94. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw nitrogen content (mg·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1576.011	3	525.337	1.006	0.416	ns
FERTYPE	22.932	1	22.932	0.044	0.837	ns
RATE*FERTYPE	75.931	3	25.310	0.048	0.985	ns
Error	8352.138	16	522.009			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 95. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw nitrogen content (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1620.756	3	540.252	0.975	0.429	ns
FERTYPE	302.176	1	302.176	0.545	0.471	ns
RATE*FERTYPE	182.033	3	60.678	0.110	0.953	ns
Error	8864.553	16	554.035			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 96. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw nitrogen content (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	568.317	3	189.439	0.394	0.759	ns
FERTYPE	124.853	1	124.853	0.260	0.617	ns
RATE*FERTYPE	1206.313	3	402.104	0.837	0.493	ns
Error	7686.806	16	480.425			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 97. Straw nitrogen content (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Straw nitrogen content (mg·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	50.7	6.25		73.0	14.8		77.7	10.4	
0:OMF	46.2	3.39		75.1	2.46		70.9	5.84	
25:MF	68.3	19.3		67.3	7.42		51.6	9.59	
25:OMF	66.7	15.4		55.3	2.45		70.2	16.2	
50:MF	70.3	10.4		55.5	11.2		79.0	10.9	
50:OMF	64.8	14.3		47.1	18.5		59.2	10.8	
100:MF	54.1	10.8		63.6	2.61		75.3	18.0	
100:OMF	57.8	17.4		53.5	26.8		65.0	15.0	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 98. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain nitrogen content (mg·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	62488.125	3	20829.375	53.023	0.000	***
FERTYPE	3384.375	1	3384.375	8.615	0.010	*
RATE*FERTYPE	2124.125	3	708.042	1.802	0.187	ns
Error	6285.333	16	392.833			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 99. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain nitrogen content (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	11116.667	3	3705.556	4.350	0.020	*
FERTYPE	1040.167	1	1040.167	1.221	0.285	ns
RATE*FERTYPE	1791.167	3	597.056	0.701	0.565	ns
Error	13629.333	16	851.833			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 100. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain nitrogen content (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	5825.458	3	1941.819	3.778	0.032	*
FERTYPE	392.042	1	392.042	0.763	0.395	ns
RATE*FERTYPE	3410.458	3	1136.819	2.212	0.126	ns
Error	8224.000	16	514.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 101. Grain nitrogen content (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Grain nitrogen content (mg·pot^{-1})								
RATE&TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	151	3.61	d	209	18.6		243	6.93	b
0:OMF	147	18.9	d	217	14.7		246	22.9	b
25:MF	225	13.5	c	254	7.02		276	10.3	ab
25:OMF	246	9.74	bc	241	13.7		264	10.3	b
50:MF	239	13.6	bc	246	26.7		279	5.86	ab
50:OMF	287	7.22	a	277	8.09		272	9.77	ab
100:MF	267	11.5	ab	255	7.69		263	19.7	b
100:OMF	298	5.61	a	282	25.3		311	8.33	a

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 102. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Total nitrogen uptake (mg·pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	76328.125	3	25442.708	37.226	0.000	***
FERTYPE	2882.042	1	2882.042	4.217	0.057	ns
RATE*FERTYPE	2310.458	3	770.153	1.127	0.368	ns
Error	10935.333	16	683.458			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 103. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Total nitrogen uptake (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	4965.125	3	1655.042	1.071	0.389	ns
FERTYPE	210.042	1	210.042	0.136	0.717	ns
RATE*FERTYPE	2049.458	3	683.153	0.442	0.726	ns
Error	24726.000	16	1545.375			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 104. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Total nitrogen uptake (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	4956.125	3	1652.042	3.104	0.056	ns
FERTYPE	77.042	1	77.042	0.145	0.709	ns
RATE*FERTYPE	3287.125	3	1095.708	2.059	0.146	ns
Error	8515.333	16	532.208			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 105. Total nitrogen uptake (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Total nitrogen uptake (mg·pot^{-1})								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	202	4.70	c	282	31.9		321	3.93	
0:OMF	193	16.6	c	292	15.6		317	17.0	
25:MF	293	19.4	b	321	13.3		327	16.2	
25:OMF	313	25.0	ab	296	12.1		334	9.21	
50:MF	309	5.57	ab	302	24.6		358	16.7	
50:OMF	351	10.2	a	324	10.7		331	7.67	
100:MF	321	14.4	ab	319	8.14		338	8.96	
100:OMF	356	13.4	a	335	41.8		376	18.7	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 106. Results of three-way ANOVA for shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.235	2	0.118	4.564	0.015	*
FERTYPE	0.033	1	0.033	1.276	0.264	ns
RATE	0.184	3	0.061	2.386	0.081	ns
SOIL P*FERTYPE	0.018	2	0.009	0.348	0.708	ns
SOIL P*RATE	0.220	6	0.037	1.421	0.226	ns
FERTYPE*RATE	0.037	3	0.012	0.482	0.696	ns
SOIL P*FERTYPE*RATE	0.143	6	0.024	0.923	0.487	ns
Error	1.237	48	0.026			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 107. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot potassium concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.273	3	0.091	1.613	0.226	ns
FERTYPE	0.032	1	0.032	0.561	0.465	ns
RATE*FERTYPE	0.091	3	0.030	0.535	0.665	ns
Error	0.904	16	0.056			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 108. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot potassium concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.034	3	0.011	2.079	0.143	ns
FERTYPE	0.019	1	0.019	3.531	0.079	ns
RATE*FERTYPE	0.044	3	0.015	2.723	0.079	ns
Error	0.087	16	0.005			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 109. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot potassium concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.097	3	0.032	2.100	0.141	ns
FERTYPE	0.000	1	0.000	0.000	0.986	ns
RATE*FERTYPE	0.045	3	0.015	0.975	0.429	ns
Error	0.246	16	0.015			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 110. Shoot Potassium concentration (%) of wheat plants, harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Shoot potassium concentration (%)								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	4.18	0.1351		3.90	0.0796		3.97	0.0938	
0:OMF	4.02	0.0245		3.98	0.0079		4.04	0.1164	
25:MF	4.16	0.0791		4.02	0.0182		3.88	0.0141	
25:OMF	3.99	0.0292		3.93	0.0231		3.78	0.0238	
50:MF	4.05	0.0637		4.06	0.0526		3.90	0.0454	
50:OMF	4.18	0.3404		3.91	0.0550		3.83	0.0697	
100:MF	3.90	0.0404		3.93	0.0358		3.84	0.1031	
100:OMF	3.81	0.0562		3.85	0.0111		3.95	0.0202	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 111. Results of three-way ANOVA for shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg $P \cdot kg^{-1}$ soil).

Shoot potassium content (mg·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	11129.193	2	5564.597	13.133	0.000	***
FERTYPE	75.891	1	75.891	0.179	0.674	ns
RATE	47260.830	3	15753.610	37.180	0.000	***
SOIL P*FERTYPE	2549.246	2	1274.623	3.008	0.059	ns
SOIL P*RATE	28419.735	6	4736.622	11.179	0.000	***
FERTYPE*RATE	1968.967	3	656.322	1.549	0.214	ns
SOIL P*FERTYPE*RATE	3286.084	6	547.681	1.293	0.279	ns
Error	20338.031	48	423.709			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 112. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at MODERATE-P fertility level.

Shoot potassium content (mg·[2 plants]$^{-1}$) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	63673.773	3	21224.591	42.791	0.000	***
FERTYPE	1960.595	1	1960.595	3.953	0.064	ns
RATE*FERTYPE	1233.426	3	411.142	0.829	0.497	ns
Error	7936.031	16	496.002			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 113. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at HIGH-P fertility level.

Shoot potassium content (mg·[2 plants]$^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	11039.667	3	3679.889	7.993	0.002	**
FERTYPE	13.500	1	13.500	0.029	0.866	ns
RATE*FERTYPE	2972.167	3	990.722	2.152	0.134	ns
Error	7366.667	16	460.417			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 114. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting) at VERY HIGH-P fertility level.

Shoot potassium content (mg·[2 plants]$^{-1}$) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	967.125	3	322.375	1.024	0.408	ns
FERTYPE	651.042	1	651.042	2.069	0.170	ns
RATE*FERTYPE	1049.458	3	349.819	1.112	0.374	ns
Error	5035.333	16	314.708			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 115. Shoot Potassium content (mg·[2 plants]$^{-1}$) of wheat plants, harvested at the end of the tillering stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Shoot potassium content (mg·[2 plants]$^{-1}$)								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	86.6	14.0	d	154	7.21	c	199	11.3	
0:OMF	84.3	6.93	d	171	25.0	bc	190	19.1	
25:MF	171	14.1	c	196	7.23	ab	196	7.54	
25:OMF	184	6.89	bc	175	8.37	bc	186	10.1	
50:MF	178	6.39	bc	221	2.85	a	219	9.21	
50:OMF	214	17.1	ab	195	8.14	ab	190	1.45	
100:MF	209	14.6	abc	206	18.3	ab	202	8.02	
100:OMF	235	16.9	a	230	4.36	a	210	5.93	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 116. Results of three-way ANOVA for straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	1.075	2	0.538	17.087	0.000	***
FERTYPE	0.813	1	0.813	25.844	0.000	***
RATE	1.810	3	0.603	19.172	0.000	***
SOIL P*FERTYPE	0.013	2	0.007	0.209	0.812	ns
SOIL P*RATE	0.474	6	0.079	2.510	0.034	*
FERTYPE*RATE	0.123	3	0.041	1.306	0.283	ns
SOIL P*FERTYPE*RATE	0.440	6	0.073	2.333	0.047	*
Error	1.510	48	0.031			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 117. Results of three-way ANOVA for grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	0.024	2	0.012	2.381	0.103	ns
FERTYPE	0.007	1	0.007	1.472	0.231	ns
RATE	0.149	3	0.050	10.015	0.000	***
SOIL P*FERTYPE	0.007	2	0.003	0.688	0.507	ns
SOIL P*RATE	0.044	6	0.007	1.472	0.208	ns
FERTYPE*RATE	0.004	3	0.001	0.293	0.830	ns
SOIL P*FERTYPE*RATE	0.056	6	0.009	1.903	0.100	ns
Error	0.237	48	0.005			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 118. Results of three-way ANOVA for straw potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw potassium content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	33187.028	2	16593.514	10.011	0.000	***
FERTYPE	43.556	1	43.556	0.026	0.872	ns
RATE	78982.722	3	26327.574	15.883	0.000	***
SOIL P*FERTYPE	707.194	2	353.597	0.213	0.809	ns
SOIL P*RATE	134233.194	6	22372.199	13.497	0.000	***
FERTYPE*RATE	14528.556	3	4842.852	2.922	0.043	*
SOIL P*FERTYPE*RATE	13173.028	6	2195.505	1.325	0.265	ns
Error	79562.667	48	1657.556			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 119. Results of three-way ANOVA for grain potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain potassium content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	770.186	2	385.093	7.539	0.001	**
FERTYPE	25.395	1	25.395	0.497	0.484	ns
RATE	1390.169	3	463.390	9.071	0.000	***
SOIL P*FERTYPE	29.808	2	14.904	0.292	0.748	ns
SOIL P*RATE	739.337	6	123.223	2.412	0.041	*
FERTYPE*RATE	70.630	3	23.543	0.461	0.711	ns
SOIL P*FERTYPE*RATE	655.655	6	109.276	2.139	0.066	ns
Error	2451.973	48	51.083			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 120. Results of three-way ANOVA for total potassium uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (103 days after planting), as affected by various soil Olsen P levels (MODERATE-P, HIGH-P and VERY HIGH-P), fertilizer types (OMF and MF), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Total potassium uptake (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
SOIL P	44236.111	2	22118.056	13.240	0.000	***
FERTYPE	128.000	1	128.000	0.077	0.783	ns
RATE	98813.000	3	32937.667	19.716	0.000	***
SOIL P*FERTYPE	886.333	2	443.167	0.265	0.768	ns
SOIL P*RATE	150569.000	6	25094.833	15.021	0.000	***
FERTYPE*RATE	16266.778	3	5422.259	3.246	0.030	*
SOIL P*FERTYPE*RATE	13043.222	6	2173.870	1.301	0.275	ns
Error	80188.667	48	1670.597			

The sources include SOIL P: Olsen P levels, FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 121. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw potassium concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.701	3	0.234	11.127	0.000	***
FERTYPE	0.374	1	0.374	17.799	0.001	**
RATE*FERTYPE	0.058	3	0.019	0.917	0.455	ns
Error	0.336	16	0.021			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 122. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw potassium concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.216	3	0.072	3.192	0.052	ns
FERTYPE	0.208	1	0.208	9.216	0.008	**
RATE*FERTYPE	0.031	3	0.010	0.461	0.713	ns
Error	0.361	16	0.023			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 123. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw potassium concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1.366	3	0.455	8.958	0.001	**
FERTYPE	0.245	1	0.245	4.811	0.043	*
RATE*FERTYPE	0.475	3	0.158	3.112	0.056	ns
Error	0.814	16	0.051			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 124. Straw potassium concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Straw potassium concentration (%)									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	3.43	0.0662	a	2.98	0.0539	a	3.46	0.3139	a
0:OMF	3.15	0.0418	bc	2.89	0.0091	a	2.77	0.0593	b
25:MF	3.21	0.0913	ab	2.93	0.0392	a	2.71	0.0097	b
25:OMF	2.85	0.0227	d	2.77	0.0104	ab	2.66	0.0289	b
50:MF	3.03	0.0603	bcd	3.03	0.1741	a	2.63	0.1178	b
50:OMF	2.76	0.0481	d	2.81	0.0526	ab	2.59	0.0692	b
100:MF	2.91	0.1328	cd	2.84	0.0969	a	2.49	0.0522	b
100:OMF	2.82	0.1321	d	2.55	0.1142	b	2.45	0.1061	b

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 125. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain potassium concentration (%) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.118	3	0.039	5.816	0.007	**
FERTYPE	0.013	1	0.013	1.861	0.191	ns
RATE*FERTYPE	0.030	3	0.010	1.472	0.260	ns
Error	0.108	16	0.007			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 126. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain potassium concentration (%) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.067	3	0.022	4.050	0.026	*
FERTYPE	0.000	1	0.000	0.001	0.970	ns
RATE*FERTYPE	0.018	3	0.006	1.069	0.390	ns
Error	0.088	16	0.006			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 127. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain potassium concentration (%) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	0.007	3	0.002	0.918	0.454	ns
FERTYPE	0.001	1	0.001	0.580	0.457	ns
RATE*FERTYPE	0.013	3	0.004	1.733	0.200	ns
Error	0.041	16	0.003			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 128. Grain potassium concentration (%) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

	Grain potassium concentration %								
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	0.6667	0.0218	a	0.6370	0.0090		0.5547	0.0243	
0:OMF	0.6533	0.0093	ab	0.6347	0.0159		0.5193	0.0389	
25:MF	0.4867	0.0058	cd	0.5697	0.0167		0.4727	0.0193	
25:OMF	0.4587	0.0683	cd	0.4847	0.0208		0.5210	0.0249	
50:MF	0.5067	0.0176	bcd	0.5057	0.0131		0.5353	0.0489	
50:OMF	0.5287	0.0496	abcd	0.5650	0.1089		0.4567	0.0059	
100:MF	0.6047	0.0998	abc	0.4780	0.0142		0.4990	0.0106	
100:OMF	0.4407	0.0075	d	0.5107	0.0383		0.5020	0.0337	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 129. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium content ($mg \cdot [pot]^{-1}$) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Straw potassium content ($mg \cdot pot^{-1}$) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	187732.458	3	62577.486	60.106	0.000	***
FERTYPE	40.042	1	40.042	0.038	0.847	ns
RATE*FERTYPE	9645.458	3	3215.153	3.088	0.057	ns
Error	16658.000	16	1041.125			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 130. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium content ($mg \cdot [pot]^{-1}$) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Straw potassium content ($mg \cdot pot^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	20280.333	3	6760.111	6.890	0.003	**
FERTYPE	450.667	1	450.667	0.459	0.508	ns
RATE*FERTYPE	635.667	3	211.889	0.216	0.884	ns
Error	15699.333	16	981.208			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 131. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on straw potassium content (mg·[pot]$^{-1}$) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Straw potassium content (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	5203.125	3	1734.375	0.588	0.632	ns
FERTYPE	260.042	1	260.042	0.088	0.770	ns
RATE*FERTYPE	17420.458	3	5806.819	1.968	0.159	ns
Error	47205.333	16	2950.333			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 132. Straw potassium content (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Straw potassium content (mg·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	310	3.06	e	433	10.9	b	559	76.4	
0:OMF	289	12.5	e	436	4.10	b	461	10.4	
25:MF	444	33.4	cd	492	17.9	ab	488	15.4	
25:OMF	413	0.6667	d	490	14.7	ab	503	10.0	
50:MF	511	13.2	ab	501	17.9	a	476	24.3	
50:OMF	502	9.45	abc	526	10.4	a	493	9.56	
100:MF	489	19.5	bc	467	32.0	ab	450	6.35	
100:OMF	559	29.2	a	476	22.0	ab	490	29.3	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 133. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Grain potassium content (mg.pot^{-1}) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	1670.324	3	556.775	9.101	0.001	**
FERTYPE	0.385	1	0.385	0.006	0.938	ns
RATE*FERTYPE	268.982	3	89.661	1.466	0.261	ns
Error	978.868	16	61.179			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 134. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Grain potassium content (mg·pot^{-1}) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	126.573	3	42.191	0.958	0.436	ns
FERTYPE	49.450	1	49.450	1.123	0.305	ns
RATE*FERTYPE	191.645	3	63.882	1.451	0.265	ns
Error	704.580	16	44.036			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 135. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on grain potassium content ($mg \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Grain potassium content ($mg \cdot pot^{-1}$) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	332.610	3	110.870	2.308	0.115	ns
FERTYPE	5.368	1	5.368	0.112	0.743	ns
RATE*FERTYPE	265.658	3	88.553	1.844	0.180	ns
Error	768.525	16	48.033			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 136. Grain potassium content ($mg \cdot pot^{-1}$) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus application as either OMF or MF. Mean values are the average of three independent replicates.

Grain potassium content ($mg \cdot pot^{-1}$)									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	32.9	0.4997	d	46.0	1.73		48.8	2.48	
0:OMF	32.5	0.8160	d	48.1	0.7944		44.3	4.45	
25:MF	38.7	0.9604	cd	50.6	2.23		48.4	1.63	
25:OMF	38.6	7.36	cd	44.5	2.09		53.1	5.68	
50:MF	44.1	0.9074	bcd	48.8	2.81		53.9	4.48	
50:OMF	53.4	7.08	ab	57.0	9.61		47.6	1.63	
100:MF	58.9	7.36	a	45.6	0.4444		52.0	5.82	
100:OMF	49.2	1.40	abc	52.8	1.98		62.0	3.26	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 137. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total potassium uptake ($mg \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage at MODERATE-P fertility level.

Total potassium uptake ($mg \cdot pot^{-1}$) at MODERATE-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	223660.500	3	74553.500	63.837	0.000	***
FERTYPE	28.167	1	28.167	0.024	0.879	ns
RATE*FERTYPE	7763.167	3	2587.722	2.216	0.126	ns
Error	18686.000	16	1167.875			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 138. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total potassium uptake ($mg \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage at HIGH-P fertility level.

Total potassium uptake ($mg \cdot pot^{-1}$) at HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	22693.333	3	7564.444	7.346	0.003	**
FERTYPE	793.500	1	793.500	0.771	0.393	ns
RATE*FERTYPE	1333.833	3	444.611	0.432	0.733	ns
Error	16474.667	16	1029.667			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 139. Analysis of variance investigating the impact of phosphorus rates and fertilizer types on total potassium uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage at VERY HIGH-P fertility level.

Total potassium uptake (mg·pot^{-1}) at VERY HIGH-P						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
RATE	3028.167	3	1009.389	0.359	0.784	ns
FERTYPE	192.667	1	192.667	0.068	0.797	ns
RATE*FERTYPE	20213.000	3	6737.667	2.394	0.106	ns
Error	45028.000	16	2814.250			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 140. Total potassium uptake (mg·pot^{-1}) of wheat plants, harvested at the end of the ripening stage, grown in soils with varying bioavailable P levels (MODERATE-P, HIGH-P and VERY HIGH-P), as affected by the increasing rates of phosphorus applications as either OMF or MF. Mean values are the average of three independent replicates.

Total potassium content (mg·pot^{-1})									
RATE:TYPES	MODERATE-P			HIGH-P			VERY HIGH-P		
	mean	SE	groups	mean	SE	groups	mean	SE	groups
0:MF	343	2.65	c	479	9.85	d	608	74.5	
0:OMF	321	13.4	c	484	4.73	cd	505	12.2	
25:MF	483	32.7	b	543	19.0	abc	537	13.7	
25:OMF	451	7.21	b	535	13.4	abcd	556	11.2	
50:MF	555	12.8	a	550	18.5	ab	530	20.3	
50:OMF	556	13.4	a	583	16.7	a	541	10.8	
100:MF	548	24.0	a	513	31.8	bcd	502	2.31	
100:OMF	609	29.7	a	529	21.4	abcd	552	31.0	

The sources include SOIL P: Olsen P levels (MODERATE-P: Moderate fertility; HIGH-P: High fertility; VERY HIGH-P: Very high fertility), FERTYPE: Fertilizer types (OMF and MF), and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 141. Results of three-way ANOVA for shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P kg^{-1} soil).

Shoot dry weight (g·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.377	1	1.377	2.705	0.110	ns
FERTFORM	0.207	1	0.207	0.406	0.529	ns
RATE	38.475	3	12.825	25.193	0.000	***
FERTYPE*FERTFORM	0.325	1	0.325	0.639	0.430	ns
FERTYPE*RATE	3.784	3	1.261	2.478	0.079	ns
FERTFORM*RATE	0.246	3	0.082	0.161	0.922	ns
FERTYPE*FERTFORM*RATE	2.947	3	0.982	1.930	0.145	ns
Error	16.290	32	0.509			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 142. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot dry weight (g·[2 plants]$^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.182	1	0.182	0.255	0.620	ns
RATE	19.254	3	6.418	8.991	0.001	**
FERTYPE*RATE	2.178	3	0.726	1.017	0.411	ns
Error	11.421	16	0.714			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 143. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage

Shoot dry weight (g·[2 plants]$^{-1}$) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.520	1	1.520	4.995	0.040	*
RATE	19.466	3	6.489	21.323	0.000	***
FERTYPE*RATE	4.554	3	1.518	4.988	0.012	*
Error	4.869	16	0.304			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 144. Shoot dry weight (g·[2 plants]$^{-1}$) of wheat plants at the end of the tillering stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Shoot dry weight (g·[2 plants]$^{-1}$)						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	3.56	0.0300	bc	3.13	0.3553	bc
0:OMF	2.52	0.0851	c	2.53	0.2390	c
25:MF	4.49	0.3231	ab	5.42	0.2099	a
25:OMF	4.33	0.8764	ab	3.63	0.3603	b
50:MF	5.50	0.6231	a	4.89	0.3147	a
50:OMF	5.35	0.4116	a	5.53	0.4052	a
100:MF	4.64	0.3449	ab	4.89	0.2608	a
100:OMF	5.30	0.5886	a	4.63	0.3507	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 145. Results of three-way ANOVA for plant height (cm) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Plant height (cm)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	157.470	1	157.470	26.370	0.000	***
FERTFORM	34.578	1	34.578	5.791	0.022	*
RATE	1001.400	3	333.800	55.899	0.000	***
FERTYPE*FERTFORM	13.547	1	13.547	2.269	0.142	ns
FERTYPE*RATE	330.925	3	110.308	18.472	0.000	***
FERTFORM*RATE	23.871	3	7.957	1.333	0.281	ns
FERTYPE*FERTFORM*RATE	12.611	3	4.204	0.704	0.557	ns
Error	191.088	32	5.971			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 146. Results of three-way ANOVA for spike length (cm) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Spike length (cm)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	5.307	1	5.307	21.451	0.000	***
FERTFORM	0.626	1	0.626	2.529	0.122	ns
RATE	34.449	3	11.483	46.418	0.000	***
FERTYPE*FERTFORM	0.203	1	0.203	0.820	0.372	ns
FERTYPE*RATE	2.311	3	0.770	3.113	0.040	*
FERTFORM*RATE	0.070	3	0.023	0.095	0.963	ns
FERTYPE*FERTFORM*RATE	0.024	3	0.008	0.032	0.992	ns
Error	7.916	32	0.247			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 147. Results of three-way ANOVA for spike count (number of spikes per pot) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg·P kg^{-1} soil).

Spike count (number of spikes per pot)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.187	1	0.187	0.148	0.703	ns
FERTFORM	0.521	1	0.521	0.410	0.527	ns
RATE	82.229	3	27.410	21.568	0.000	***
FERTYPE*FERTFORM	1.688	1	1.688	1.328	0.258	ns
FERTYPE*RATE	4.729	3	1.576	1.240	0.311	ns
FERTFORM*RATE	11.063	3	3.688	2.902	0.050	ns
FERTYPE*FERTFORM*RATE	1.229	3	0.410	0.322	0.809	ns
Error	40.667	32	1.271			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 148. Results of three-way ANOVA for biological yields (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Biological yield (g·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	423.952	1	423.952	116.582	0.000	***
FERTFORM	46.185	1	46.185	12.700	0.001	**
RATE	2636.885	3	878.962	241.705	0.000	***
FERTYPE*FERTFORM	0.982	1	0.982	0.270	0.607	ns
FERTYPE*RATE	207.707	3	69.236	19.039	0.000	***
FERTFORM*RATE	19.806	3	6.602	1.815	0.164	ns
FERTYPE*FERTFORM*RATE	19.339	3	6.446	1.773	0.172	ns
Error	116.368	32	3.637			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 149. Results of three-way ANOVA for straw yields (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw yield (g·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	63.239	1	63.239	31.368	0.000	***
FERTFORM	16.003	1	16.003	7.938	0.008	**
RATE	633.758	3	211.253	104.787	0.000	***
FERTYPE*FERTFORM	0.009	1	0.009	0.004	0.948	ns
FERTYPE*RATE	49.627	3	16.542	8.205	0.000	***
FERTFORM*RATE	8.915	3	2.972	1.474	0.240	ns
FERTYPE*FERTFORM*RATE	9.827	3	3.276	1.625	0.203	ns
Error	64.513	32	2.016			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 150. Results of three-way ANOVA for grain yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain yield (g·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	159.714	1	159.714	225.789	0.000	***
FERTFORM	7.816	1	7.816	11.049	0.002	**
RATE	692.914	3	230.971	326.526	0.000	***
FERTYPE*FERTFORM	1.174	1	1.174	1.659	0.207	ns
FERTYPE*RATE	61.752	3	20.584	29.100	0.000	***
FERTFORM*RATE	3.065	3	1.022	1.444	0.248	ns
FERTYPE*FERTFORM*RATE	1.903	3	0.634	0.897	0.454	ns
Error	22.635	32	0.707			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 151. Results of three-way ANOVA for SPAD reading measured on the wheat flag leaves at the boot stage, as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

SPAD reading						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	617.528	1	617.528	229.736	0.000	***
FERTFORM	4.421	1	4.421	1.645	0.209	ns
RATE	899.363	3	299.788	111.529	0.000	***
FERTYPE*FERTFORM	0.487	1	0.487	0.181	0.673	ns
FERTYPE*RATE	394.626	3	131.542	48.937	0.000	***
FERTFORM*RATE	8.181	3	2.727	1.015	0.399	ns
FERTYPE*FERTFORM*RATE	6.609	3	2.203	0.820	0.493	ns
Error	86.016	32	2.688			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 152. Results of three-way ANOVA for harvest index of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Harvest index (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	171.981	1	171.981	76.798	0.000	***
FERTFORM	2.728	1	2.728	1.218	0.278	ns
RATE	672.508	3	224.169	100.103	0.000	***
FERTYPE*FERTFORM	5.353	1	5.353	2.390	0.132	ns
FERTYPE*RATE	57.187	3	19.062	8.512	0.000	***
FERTFORM*RATE	5.762	3	1.921	0.858	0.473	ns
FERTYPE*FERTFORM*RATE	3.154	3	1.051	0.470	0.706	ns
Error	71.661	32	2.239			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 153. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on plant height (cm) of wheat plants harvested at the end of the ripening stage.

Harvest plant height (cm) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	39.322	1	39.322	11.548	0.004	**
RATE	429.984	3	143.328	42.093	0.000	***
FERTYPE*RATE	217.017	3	72.339	21.245	0.000	***
Error	54.481	16	3.405			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 154. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on plant height (cm) of wheat plants harvested at the end of the ripening stage.

Plant height (cm) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	131.695	1	131.695	15.425	0.001	**
RATE	595.287	3	198.429	23.241	0.000	***
FERTYPE*RATE	126.519	3	42.173	4.939	0.013	*
Error	136.607	16	8.538			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 155. Plant height (cm) of wheat plants following the application of Increasing Rates of Phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

Plant height (cm)						
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	73.2	0.7902	c	71.0	1.32	d
0:OMF	67.5	0.6005	d	70.2	1.18	d
25:MF	73.3	1.48	c	77.5	2.58	c
25:OMF	83.7	0.2888	a	87.4	1.12	a
50:MF	76.8	1.19	b	76.8	1.72	c
50:OMF	82.3	1.34	a	85.3	1.99	ab
100:MF	81.4	1.55	a	81.9	2.09	bc
100:OMF	81.4	0.4662	a	83.0	0.6288	ab

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 156. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on spike length (cm) of wheat plants harvested at the end of the ripening stage.

Spike length (cm) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.717	1	1.717	7.857	0.013	*
RATE	18.205	3	6.068	27.761	0.000	***
FERTYPE*RATE	1.132	3	0.377	1.727	0.202	ns
Error	3.497	16	0.219			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 157. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on spike length (cm) of wheat plants harvested at the end of the ripening stage.

Spike length (cm) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	3.792	1	3.792	13.731	0.002	**
RATE	16.315	3	5.438	19.691	0.000	***
FERTYPE*RATE	1.202	3	0.401	1.451	0.265	ns
Error	4.419	16	0.276			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 158. Spike length (cm) of wheat plants following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

Spike length (cm)						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	9.69	0.1968	c	9.87	0.6005	d
0:OMF	9.56	0.4041	c	9.94	0.0757	d
25:MF	10.7	0.4336	b	10.9	0.2510	c
25:OMF	11.7	0.1434	a	12.2	0.3014	ab
50:MF	11.3	0.2105	ab	11.4	0.0306	bc
50:OMF	12.2	0.1114	a	12.4	0.2885	a
100:MF	11.5	0.1794	ab	11.5	0.2254	abc
100:OMF	12.0	0.2887	a	12.3	0.2853	ab

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 159. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on spike count (number of $spikes \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage.

Spike count (number of $spikes \cdot pot^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.375	1	0.375	0.220	0.646	ns
RATE	24.458	3	8.153	4.772	0.015	*
FERTYPE*RATE	3.792	3	1.264	0.740	0.544	ns
Error	27.333	16	1.708			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 160. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on spike count (number of spikes·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Spike count (number of spikes·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.500	1	1.500	1.800	0.198	ns
RATE	68.833	3	22.944	27.533	0.000	***
FERTYPE*RATE	2.167	3	0.722	0.867	0.479	ns
Error	13.333	16	0.833			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 161. Spike count (number of spikes·pot^{-1}) of wheat plants following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Spike count (number of spikes·pot^{-1}) GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	8.33	0.6667		6.00	0.0000	c
0:OMF	7.00	0.5774		5.67	0.3333	c
25:MF	8.00	1.15		8.00	0.5774	b
25:OMF	8.33	0.8819		9.33	0.3333	ab
50:MF	8.67	0.3333		9.33	0.3333	ab
50:OMF	9.33	0.3333		9.67	0.8819	ab
100:MF	10.7	0.6667		10.0	0.5774	a
100:OMF	10.0	1.00		10.7	0.6667	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 162. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on biological yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Biological yield (g·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	232.867	1	232.867	68.043	0	***
RATE	1169.047	3	389.682	113.863	0	***
FERTYPE*RATE	109.569	3	36.523	10.672	0	***
Error	54.758	16	3.422			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 163. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on biological yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Biological yield (g·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	192.066	1	192.066	49.879	0.000	***
RATE	1487.644	3	495.881	128.779	0.000	***
FERTYPE*RATE	117.478	3	39.159	10.170	0.001	**
Error	61.610	16	3.851			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 164. Biological yield (g·pot^{-1}) of wheat plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Biological yield (g·pot^{-1})						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	25.9	0.5022	d	25.4	0.4071	d
0:OMF	26.1	0.6350	d	26.6	0.4788	d
25:MF	32.5	0.8626	c	34.2	1.79	c
25:OMF	42.7	0.8298	b	46.8	0.4972	a
50:MF	34.6	1.49	c	40.0	1.24	b
50:OMF	45.0	0.5877	ab	46.2	0.9713	a
100:MF	43.0	0.3555	b	45.4	1.72	a
100:OMF	47.2	2.09	a	48.0	0.9991	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 165. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw yield (g·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	30.888	1	30.888	16.114	0.001	**
RATE	254.771	3	84.924	44.304	0.000	***
FERTYPE*RATE	20.346	3	6.782	3.538	0.039	*
Error	30.670	16	1.917			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 166. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw yield (g·pot^{-1}) – POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	32.359	1	32.359	15.299	0.001	**
RATE	387.902	3	129.301	61.130	0.000	***
FERTYPE*RATE	39.108	3	13.036	6.163	0.005	**
Error	33.843	16	2.115			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 167. Straw yield (g·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Straw yield (g·pot^{-1})						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	18.7	0.5406	c	18.0	0.3499	d
0:OMF	18.8	0.6990	c	18.8	0.6111	d
25:MF	22.7	0.8426	b	23.1	1.21	c
25:OMF	26.8	0.6428	a	29.8	0.7242	a
50:MF	23.2	0.4609	b	26.3	1.03	b
50:OMF	27.3	0.3345	a	28.1	0.5229	ab
100:MF	27.1	0.3480	a	28.8	1.30	ab
100:OMF	28.0	1.66	a	28.9	0.3442	ab

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 168. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain yield (g·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	94.134	1	94.134	146.344	0	***
RATE	336.242	3	112.081	174.244	0	***
FERTYPE*RATE	36.967	3	12.322	19.156	0	***
Error	10.292	16	0.643			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 169. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain yield (g·pot^{-1}) of wheat plants harvested at the end of the ripening stage

Grain yield (g·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	66.753	1	66.753	86.527	0	***
RATE	359.736	3	119.912	155.432	0	***
FERTYPE*RATE	26.688	3	8.896	11.531	0	***
Error	12.344	16	0.771			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 170. Grain yield (g·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Grain yield (g·pot^{-1})						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	7.15	0.0950	f	7.33	0.1633	e
0:OMF	7.31	0.1284	f	7.73	0.1424	e
25:MF	9.79	0.0704	e	11.1	0.5906	d
25:OMF	15.8	0.3587	c	17.1	0.6170	b
50:MF	11.4	1.04	d	13.7	0.3910	c
50:OMF	17.7	0.3135	b	18.1	0.7048	ab
100:MF	15.8	0.3961	c	16.6	0.4268	b
100:OMF	19.2	0.4704	a	19.0	0.6701	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 171. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on SPAD reading measurement on the wheat flag leaves at the boot stage.

SPAD Reading measurement- GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	291.671	1	291.671	85.327	0	***
RATE	531.185	3	177.062	51.798	0	***
FERTYPE*RATE	179.415	3	59.805	17.496	0	***
Error	54.693	16	3.418			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 172. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on SPAD reading measurement on the wheat flag leaves at the boot stage.

SPAD Reading measurement - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	326.344	1	326.344	166.699	0	***
RATE	376.359	3	125.453	64.082	0	***
FERTYPE*RATE	221.821	3	73.940	37.769	0	***
Error	31.323	16	1.958			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 173. SPAD reading measurement on the wheat flag leaves at the boot stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

SPAD Reading measurement						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	33.2	0.9956	c	35.4	0.9688	c
0:OMF	34.2	1.34	bc	35.4	0.8152	c
25:MF	32.6	0.4778	c	34.1	1.01	c
25:OMF	46.5	0.8211	a	47.4	0.4147	ab
50:MF	37.1	1.79	b	35.5	0.8834	c
50:OMF	47.8	0.5699	a	49.1	0.5215	a
100:MF	45.5	1.00	a	45.1	1.08	b
100:OMF	47.8	0.9320	a	47.8	0.4539	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 174. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on harvest index (%) of wheat plants harvested at the end of the ripening stage.

Harvest index (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	119.008	1	119.008	48.214	0.000	***
RATE	389.167	3	129.722	52.555	0.000	***
FERTYPE*RATE	40.953	3	13.651	5.530	0.008	**
Error	39.493	16	2.468			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 175. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on harvest index (%) of wheat plants harvested at the end of the ripening stage.

Harvest index (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	58.325	1	58.325	29.011	0.000	***
RATE	289.103	3	96.368	47.933	0.000	***
FERTYPE*RATE	19.389	3	6.463	3.215	0.051	ns
Error	32.167	16	2.010			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 176. Harvest index (%) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

Harvest index (%)						
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	27.7	0.7295	d	28.9	0.5559	d
0:OMF	28.1	0.9747	d	29.1	1.02	d
25:MF	30.1	0.7768	cd	32.4	0.3224	c
25:OMF	37.1	0.6263	b	36.5	1.31	b
50:MF	32.8	1.56	c	34.2	0.8734	bc
50:OMF	39.3	0.3239	ab	39.2	0.9268	a
100:MF	36.9	0.7844	b	36.6	0.5029	b
100:OMF	40.7	0.9671	a	39.7	0.5761	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 177. Results of three-way ANOVA for shoot P concentrations (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.008	1	0.008	20.135	0.000	***
FERTFORM	0.018	1	0.018	44.775	0.000	***
RATE	0.108	3	0.036	88.882	0.000	***
FERTYPE*FERTFORM	0.002	1	0.002	5.277	0.028	*
FERTYPE*RATE	0.001	3	0.000	0.723	0.546	ns
FERTFORM*RATE	0.009	3	0.003	7.091	0.001	**
FERTYPE*FERTFORM*RATE	0.001	3	0.000	0.771	0.519	ns
Error	0.013	32	0.000			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 178. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot phosphorus concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot phosphorus concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.009	1	0.009	31.892	0.000	***
RATE	0.030	3	0.010	33.528	0.000	***
FERTYPE*RATE	0.002	3	0.001	1.940	0.164	ns
Error	0.005	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 179. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot phosphorus concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot phosphorus concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.001	1	0.001	1.876	0.190	ns
RATE	0.088	3	0.029	56.148	0.000	***
FERTYPE*RATE	0.000	3	0.000	0.073	0.974	ns
Error	0.008	16	0.001			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 180. Shoot phosphorus concentration (%) of wheat plants at the end of the tillering stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Shoot phosphorus concentration (%) GRANULAR mean	SE	groups	POWDERED mean	SE	groups
0:MF	0.0827	0.0054	f	0.0827	0.0067	c
0:OMF	0.1003	0.0094	ef	0.0910	0.0035	c
25:MF	0.1080	0.0015	def	0.1513	0.0109	b
25:OMF	0.1377	0.0117	cd	0.1713	0.0068	b
50:MF	0.1307	0.0162	cde	0.2130	0.0132	a
50:OMF	0.1803	0.0080	b	0.2243	0.0274	a
100:MF	0.1547	0.0110	bc	0.2383	0.0023	a
100:OMF	0.2157	0.0089	a	0.2497	0.0153	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 181. Results of three-way ANOVA for shoot P content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot phosphorus content (mg·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	8.024	1	8.024	4.750	0.037	*
FERTFORM	34.237	1	34.237	20.267	0.000	***
RATE	476.560	3	158.853	94.033	0.000	***
FERTYPE*FERTFORM	10.839	1	10.839	6.416	0.016	*
FERTYPE*RATE	19.179	3	6.393	3.784	0.020	*
FERTFORM*RATE	16.667	3	5.556	3.289	0.033	*
FERTYPE*FERTFORM*RATE	10.341	3	3.447	2.041	0.128	ns
Error	54.059	32	1.689			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 182. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot phosphorus content (mg·[2 plants]$^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	18.757	1	18.757	8.850	0.009	**
RATE	163.157	3	54.386	25.660	0.000	***
FERTYPE*RATE	18.358	3	6.119	2.887	0.068	ns
Error	33.911	16	2.119			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 183. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot phosphorus content (mg·[2 plants]$^{-1}$) – POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.106	1	0.106	0.084	0.776	ns
RATE	330.070	3	110.023	87.376	0.000	***
FERTYPE*RATE	11.162	3	3.721	2.955	0.064	ns
Error	20.147	16	1.259			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 184. Shoot phosphorus content (mg·[2 plants]$^{-1}$) of wheat plants at the end of the tillering stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Shoot phosphorus content (mg·[2 plants]$^{-1}$) GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	2.94	0.1681	d	2.60	0.4354	d
0:OMF	2.51	0.1639	d	2.31	0.2884	d
25:MF	4.85	0.3810	cd	8.18	0.5638	b
25:OMF	5.76	0.7883	c	6.21	0.6260	c
50:MF	7.34	1.61	bc	10.4	0.6595	a
50:OMF	9.62	0.7230	ab	12.2	0.8984	a
100:MF	7.11	0.1666	bc	11.7	0.5161	a
100:OMF	11.4	1.30	a	11.5	0.9311	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 185. Results of three-way ANOVA for straw (shoots + husk) P concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0	1	0	71.843	0.000	***
FERTFORM	0	1	0	20.212	0.000	***
RATE	0	3	0	18.330	0.000	***
FERTYPE*FERTFORM	0	1	0	0.030	0.865	ns
FERTYPE*RATE	0	3	0	8.307	0.000	***
FERTFORM*RATE	0	3	0	5.011	0.006	**
FERTYPE*FERTFORM*RATE	0	3	0	1.755	0.176	ns
Error	0	32	0			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 186. Results of three-way ANOVA for grain P concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain phosphorus concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	0.010	1	0.010	49.129	0.000	***
FERTFORM	0.001	1	0.001	6.732	0.014	*
RATE	0.011	3	0.004	17.707	0.000	***
FERTYPE*FERTFORM	0.003	1	0.003	14.656	0.001	**
FERTYPE*RATE	0.008	3	0.003	12.872	0.000	***
FERTFORM*RATE	0.004	3	0.001	5.907	0.003	**
FERTYPE*FERTFORM*RATE	0.002	3	0.001	2.640	0.066	ns
Error	0.006	32	0.000			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 187. Results of three-way ANOVA for straw (shoots + husk) P content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	13.097	1	13.097	25.166	0.000	***
FERTFORM	4.854	1	4.854	9.327	0.005	**
RATE	14.742	3	4.914	9.442	0.000	***
FERTYPE*FERTFORM	0.008	1	0.008	0.015	0.903	ns
FERTYPE*RATE	3.263	3	1.088	2.090	0.121	ns
FERTFORM*RATE	4.417	3	1.472	2.829	0.054	ns
FERTYPE*FERTFORM*RATE	3.969	3	1.323	2.542	0.074	ns
Error	16.654	32	0.520			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 188. Results of three-way ANOVA for grain P content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	215.844	1	215.844	42.895	0.000	***
FERTFORM	219.481	1	219.481	43.618	0.000	***
RATE	4160.292	3	1386.764	275.597	0.000	***
FERTYPE*FERTFORM	36.268	1	36.268	7.208	0.011	*
FERTYPE*RATE	71.374	3	23.791	4.728	0.008	**
FERTFORM*RATE	95.694	3	31.898	6.339	0.002	**
FERTYPE*FERTFORM*RATE	16.924	3	5.641	1.121	0.355	ns
Error	161.019	32	5.032			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 189. Results of three-way ANOVA for total P uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Total phosphorus content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	122.603	1	122.603	23.394	0.000	***
FERTFORM	159.055	1	159.055	30.350	0.000	***
RATE	4637.303	3	1545.768	294.952	0.000	***
FERTYPE*FERTFORM	35.204	1	35.204	6.717	0.014	*
FERTYPE*RATE	58.212	3	19.404	3.703	0.022	*
FERTFORM*RATE	70.000	3	23.333	4.452	0.010	*
FERTYPE*FERTFORM*RATE	22.379	3	7.460	1.423	0.254	ns
Error	167.704	32	5.241			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 190. Results of three-way ANOVA for phosphorus harvest index (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Phosphorus Harvest Index (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	193.899	1	193.899	54.892	0.000	***
FERTFORM	93.177	1	93.177	26.378	0.000	***
RATE	657.730	3	219.243	62.067	0.000	***
FERTYPE*FERTFORM	3.105	1	3.105	0.879	0.356	ns
FERTYPE*RATE	42.923	3	14.308	4.050	0.015	*
FERTFORM*RATE	51.633	3	17.211	4.872	0.007	**
FERTYPE*FERTFORM*RATE	15.562	3	5.187	1.469	0.242	ns
Error	113.036	32	3.532			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 191. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw phosphorus concentration (%)- GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0	1	0	31.200	0.000	***
RATE	0	3	0	4.014	0.026	*
FERTYPE*RATE	0	3	0	2.318	0.114	ns
Error	0	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 192. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw phosphorus concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0	1	0	43.018	0.000	***
RATE	0	3	0	23.119	0.000	***
FERTYPE*RATE	0	3	0	9.088	0.001	**
Error	0	16	0			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 193. Straw phosphorus concentration (%) of wheat plants at the end of the ripening stage following application of Increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Straw phosphorus concentration (%)						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	0.0323	0.0012	a	0.0323	0.0009	a
0:OMF	0.0300	0.0015	a	0.0297	0.0019	a
25:MF	0.0310	0.0006	a	0.0303	0.0012	a
25:OMF	0.0200	0.0010	b	0.0177	0.0007	c
50:MF	0.0310	0.0012	a	0.0247	0.0023	b
50:OMF	0.0247	0.0024	b	0.0153	0.0015	c
100:MF	0.0310	0.0025	a	0.0240	0.0006	b
100:OMF	0.0247	0.0018	b	0.0237	0.0007	b

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 194. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain phosphorus concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	0.012	1	0.012	96.620	0	***
RATE	0.006	3	0.002	16.960	0	***
FERTYPE*RATE	0.008	3	0.003	20.819	0	***
Error	0.002	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 195. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain phosphorus concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain phosphorus concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	0.001	1	0.001	3.634	0.075	ns
RATE	0.008	3	0.003	9.557	0.001	**
FERTYPE*RATE	0.002	3	0.001	2.053	0.147	ns
Error	0.004	16	0.000			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 196. Grain phosphorus concentration (%) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

	Grain phosphorus concentration (%)					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:TSP	0.2533	0.0098	a	0.2433	0.0027	abc
0:OMF	0.2503	0.0028	a	0.2357	0.0073	bc
25:TSP	0.2580	0.0058	a	0.2313	0.0104	bc
25:OMF	0.1640	0.0036	d	0.1950	0.0047	d
50:TSP	0.2455	0.0101	a	0.2437	0.0134	abc
50:OMF	0.1847	0.0050	c	0.2253	0.0032	c
100:TSP	0.2410	0.0030	a	0.2593	0.0168	ab
100:OMF	0.2217	0.0062	b	0.2697	0.0090	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 197. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw phosphorus content ($mg \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage.

Straw phosphorus content ($mg \cdot pot^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	6.231	1	6.231	10.183	0.006	**
RATE	11.615	3	3.872	6.328	0.005	**
FERTYPE*RATE	2.085	3	0.695	1.136	0.364	ns
Error	9.789	16	0.612			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 198. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw phosphorus content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	6.875	1	6.875	16.023	0.001	**
RATE	7.544	3	2.515	5.861	0.007	**
FERTYPE*RATE	5.147	3	1.716	3.999	0.027	*
Error	6.865	16	0.429			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 199. Straw phosphorus content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

	Straw phosphorus content (mg·pot^{-1})					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	6.06	0.3456	bcd	5.82	0.0520	abc
0:OMF	5.63	0.4120	cd	5.57	0.1811	bc
25:MF	7.04	0.1949	abc	7.01	0.4669	a
25:OMF	5.35	0.1934	d	5.27	0.3238	cd
50:MF	7.19	0.1570	ab	6.50	0.6751	ab
50:OMF	6.76	0.7335	bcd	4.29	0.3295	d
100:MF	8.40	0.6874	a	6.92	0.3897	a
100:OMF	6.88	0.4815	bc	6.85	0.2638	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 200. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain phosphorus content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	37.579	1	37.579	6.808	0.019	*
RATE	1551.396	3	517.132	93.688	0.000	***
FERTYPE*RATE	25.069	3	8.356	1.514	0.249	ns
Error	88.315	16	5.520			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 201. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain phosphorus content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain phosphorus content (mg·pot^{-1}) - POWDERED final harvest						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	214.533	1	214.533	47.212	0.000	***
RATE	2704.589	3	901.530	198.400	0.000	***
FERTYPE*RATE	63.228	3	21.076	4.638	0.016	*
Error	72.704	16	4.544			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 202. Grain phosphorus content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Grain phosphorus content (mg·pot^{-1}) GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:TSP	18.1	0.5066	e	17.8	0.5144	e
0:OMF	18.3	0.2259	e	18.2	0.6678	e
25:TSP	25.3	0.6785	d	25.7	2.08	d
25:OMF	26.0	1.10	d	33.3	0.5815	c
50:TSP	27.9	2.52	d	33.2	1.55	c
50:OMF	32.6	0.4608	c	40.8	1.03	b
100:TSP	38.2	1.37	b	42.9	1.79	b
100:OMF	42.6	2.07	a	51.3	0.3313	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 203. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total phosphorus content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	13.206	1	13.206	2.218	0.156	ns
RATE	1825.913	3	608.638	102.226	0.000	***
FERTYPE*RATE	27.567	3	9.189	1.543	0.242	ns
Error	95.261	16	5.954			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 204. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on total phosphorus uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total phosphorus content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	144.601	1	144.601	31.937	0.000	***
RATE	2881.390	3	960.463	212.133	0.000	***
FERTYPE*RATE	53.024	3	17.675	3.904	0.029	*
Error	72.442	16	4.528			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 205. Total phosphorus uptake (mg·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Total phosphorus content (mg·pot^{-1}) GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:TSP	24.2	0.7274	d	23.7	0.5461	f
0:OMF	23.9	0.5895	d	23.8	0.8325	f
25:TSP	32.3	0.8734	c	32.7	2.40	e
25:OMF	31.4	1.21	c	38.5	0.2664	d
50:TSP	35.1	2.41	c	39.7	1.13	d
50:OMF	39.4	1.04	b	45.1	0.8218	c
100:TSP	46.6	0.8992	a	49.8	1.74	b
100:OMF	49.4	2.25	a	58.1	0.5060	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 206. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on phosphorus harvest index (%) of wheat plants harvested at the end of the ripening stage.

Phosphorus Harvest Index (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	73.966	1	73.966	17.572	0.001	**
RATE	211.861	3	70.620	16.777	0.000	***
FERTYPE*RATE	8.411	3	2.804	0.666	0.585	ns
Error	67.350	16	4.209			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 207. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on phosphorus harvest index (%) of wheat plants harvested at the end of the ripening stage.

Phosphorus harvest index (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	123.038	1	123.038	43.090	0.000	***
RATE	497.502	3	165.834	58.078	0.000	***
FERTYPE*RATE	50.074	3	16.691	5.846	0.007	**
Error	45.686	16	2.855			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 208. Phosphorus harvest index (%) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Phosphorus harvest index (%)					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:TSP	74.9	0.9424	e	75.4	0.4539	e
0:OMF	76.5	1.20	de	76.6	0.3015	de
25:TSP	78.2	0.0179	cde	78.5	1.10	d
25:OMF	82.9	0.5891	ab	86.3	0.9342	bc
50:TSP	79.3	1.67	bcd	83.6	1.91	c
50:OMF	82.9	1.49	ab	90.5	0.8158	a
100:TSP	81.9	1.67	bc	86.1	0.8972	bc
100:OMF	86.1	0.8645	a	88.2	0.3726	ab

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 209. Results of three-way ANOVA for shoot N concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P kg^{-1} soil).

Shoot nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.825	1	1.825	144.567	0.000	***
FERTFORM	0.000	1	0.000	0.029	0.865	ns
RATE	0.755	3	0.252	19.950	0.000	***
FERTYPE*FERTFORM	0.041	1	0.041	3.267	0.080	ns
FERTYPE*RATE	0.121	3	0.040	3.185	0.037	*
FERTFORM*RATE	0.028	3	0.009	0.749	0.531	ns
FERTYPE*FERTFORM*RATE	0.087	3	0.029	2.297	0.096	ns
Error	0.404	32	0.013			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 210. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot nitrogen concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot nitrogen concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1.207	1	1.207	131.560	0.000	***
RATE	0.373	3	0.124	13.537	0.000	***
FERTYPE*RATE	0.156	3	0.052	5.678	0.008	**
Error	0.147	16	0.009			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 211. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot nitrogen concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot nitrogen concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.659	1	0.659	40.994	0.000	***
RATE	0.411	3	0.137	8.529	0.001	**
FERTYPE*RATE	0.051	3	0.017	1.064	0.392	ns
Error	0.257	16	0.016			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 212. Shoot nitrogen concentration (%) of wheat plants at the end of the tillering stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Shoot nitrogen concentration (%)						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	1.56	0.0344	b	1.75	0.0751	ab
0:OMF	2.06	0.1291	a	1.96	0.0650	a
25:MF	1.38	0.0182	c	1.31	0.0422	c
25:OMF	1.66	0.0314	b	1.72	0.1155	b
50:MF	1.35	0.0101	c	1.43	0.0543	c
50:OMF	1.68	0.0619	b	1.71	0.0681	b
100:MF	1.34	0.0141	c	1.40	0.0233	c
100:OMF	2.03	0.0344	a	1.83	0.0987	ab

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 213. Results of three-way ANOVA for shoot N content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot nitrogen content (mg·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1550.499	1	1550.499	15.393	0.000	***
FERTFORM	84.755	1	84.755	0.841	0.366	ns
RATE	6744.022	3	2248.007	22.317	0.000	***
FERTYPE*FERTFORM	302.960	1	302.960	3.008	0.092	ns
FERTYPE*RATE	2407.115	3	802.372	7.966	0.000	***
FERTFORM*RATE	140.910	3	46.970	0.466	0.708	ns
FERTYPE*FERTFORM*RATE	694.965	3	231.655	2.300	0.096	ns
Error	3223.379	32	100.731			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 214. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot nitrogen content (mg·[2 plants]$^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1612.106	1	1612.106	10.149	0.006	**
RATE	3738.722	3	1246.241	7.845	0.002	**
FERTYPE*RATE	1938.244	3	646.081	4.067	0.025	*
Error	2541.571	16	158.848			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 215. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot nitrogen content (mg·[2 plants]$^{-1}$) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	241.354	1	241.354	5.664	0.030	*
RATE	3146.210	3	1048.737	24.611	0.000	***
FERTYPE*RATE	1163.837	3	387.946	9.104	0.001	**
Error	681.808	16	42.613			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 216. Shoot nitrogen content (mg·[2 plants]$^{-1}$) of wheat plants at the end of the tillering stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Shoot nitrogen content (mg·[2 plants]$^{-1}$)					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	55.8	1.65	c	54.4	4.03	cd
0:OMF	51.8	2.87	c	49.3	3.77	d
25:MF	61.6	3.62	c	70.8	0.7751	b
25:OMF	71.4	13.4	bc	61.5	2.41	bc
50:MF	74.6	8.80	bc	69.9	6.86	b
50:OMF	89.2	4.55	ab	94.0	3.14	a
100:MF	62.2	4.09	c	68.5	2.66	b
100:OMF	107	10.3	a	84.1	3.58	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 217. Results of three-way ANOVA for straw N concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.332	1	0.332	121.323	0.000	***
FERTFORM	0.017	1	0.017	6.063	0.019	*
RATE	2.180	3	0.727	265.460	0.000	***
FERTYPE*FERTFORM	0.001	1	0.001	0.470	0.498	ns
FERTYPE*RATE	0.112	3	0.037	13.676	0.000	***
FERTFORM*RATE	0.019	3	0.006	2.302	0.096	ns
FERTYPE*FERTFORM*RATE	0.051	3	0.017	6.199	0.002	**
Error	0.088	32	0.003			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 218. Results of three-way ANOVA for grain N concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain nitrogen concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.023	1	0.023	3.011	0.092	ns
FERTFORM	0.000	1	0.000	0.000	0.986	ns
RATE	1.574	3	0.525	67.439	0.000	***
FERTYPE*FERTFORM	0.001	1	0.001	0.122	0.729	ns
FERTYPE*RATE	0.196	3	0.065	8.396	0.000	***
FERTFORM*RATE	0.010	3	0.003	0.408	0.748	ns
FERTYPE*FERTFORM*RATE	0.046	3	0.015	1.954	0.141	ns
Error	0.249	32	0.008			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 219. Results of three-way ANOVA for straw N content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw nitrogen content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	13432.253	1	13432.253	99.111	0.000	***
FERTFORM	451.305	1	451.305	3.330	0.077	ns
RATE	39775.144	3	13258.381	97.828	0.000	***
FERTYPE*FERTFORM	24.782	1	24.782	0.183	0.672	ns
FERTYPE*RATE	4542.165	3	1514.055	11.172	0.000	***
FERTFORM*RATE	754.420	3	251.473	1.856	0.157	ns
FERTYPE*FERTFORM*RATE	1289.885	3	429.962	3.173	0.037	*
Error	4336.867	32	135.527			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 220. Results of three-way ANOVA for grain N content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain nitrogen content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	36866.551	1	36866.551	130.275	0.000	***
FERTFORM	2577.979	1	2577.979	9.110	0.005	**
RATE	126748.617	3	42249.539	149.297	0.000	***
FERTYPE*FERTFORM	117.189	1	117.189	0.414	0.524	ns
FERTYPE*RATE	11381.181	3	3793.727	13.406	0.000	***
FERTFORM*RATE	777.548	3	259.183	0.916	0.444	ns
FERTYPE*FERTFORM*RATE	879.690	3	293.230	1.036	0.390	ns
Error	9055.674	32	282.990			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 221. Results of three-way ANOVA for total N uptake ($mg\cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg $P\cdot kg^{-1}$ soil).

Total nitrogen uptake ($mg\cdot pot^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	5792.587	1	5792.587	13.137	0.001	**
FERTFORM	872.013	1	872.013	1.978	0.169	ns
RATE	31629.625	3	10543.208	23.911	0.000	***
FERTYPE*FERTFORM	249.752	1	249.752	0.566	0.457	ns
FERTYPE*RATE	2341.208	3	780.403	1.770	0.173	ns
FERTFORM*RATE	956.501	3	318.834	0.723	0.546	ns
FERTYPE*FERTFORM*RATE	1598.417	3	532.806	1.208	0.323	ns
Error	14109.803	32	440.931			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant ($P < 0.01$), significant ($P < 0.05$) and not significant respectively.

Appendix 222. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw nitrogen concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.146	1	0.146	43.473	0	***
RATE	1.010	3	0.337	100.223	0	***
FERTYPE*RATE	0.133	3	0.044	13.170	0	***
Error	0.054	16	0.003			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 223. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw nitrogen concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.187	1	0.187	88.558	0.000	***
RATE	1.189	3	0.396	187.316	0.000	***
FERTYPE*RATE	0.031	3	0.010	4.807	0.014	*
Error	0.034	16	0.002			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 224. Straw nitrogen concentration (%) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

Straw nitrogen concentration (%)						
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	0.7887	0.0765	a	0.8925	0.0384	a
0:OMF	0.8645	0.0020	a	0.7420	0.0350	b
25:MF	0.5403	0.0210	b	0.5320	0.0316	c
25:OMF	0.2427	0.0247	d	0.2333	0.0123	e
50:MF	0.5188	0.0235	b	0.3463	0.0205	d
50:OMF	0.2450	0.0121	d	0.2077	0.0142	e
100:MF	0.3687	0.0292	c	0.3383	0.0287	d
100:OMF	0.2403	0.0223	d	0.2193	0.0187	e

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P\cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 225. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain nitrogen concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.017	1	0.017	2.873	0.109	ns
RATE	0.680	3	0.227	38.550	0.000	***
FERTYPE*RATE	0.170	3	0.057	9.630	0.001	**
Error	0.094	16	0.006			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 226. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain nitrogen concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain nitrogen concentration (%) – POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.007	1	0.007	0.772	0.393	ns
RATE	0.903	3	0.301	31.111	0.000	***
FERTYPE*RATE	0.072	3	0.024	2.467	0.100	ns
Error	0.155	16	0.010			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 227. Grain nitrogen concentration (%) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

	Grain nitrogen concentration (%)					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	2.02	0.0084	b	2.16	0.0538	a
0:OMF	2.22	0.0102	a	2.17	0.0592	a
25:MF	1.87	0.0534	c	1.76	0.0424	bc
25:OMF	1.73	0.0142	cde	1.79	0.0472	b
50:MF	1.85	0.0970	cd	1.82	0.0337	b
50:OMF	1.58	0.0142	f	1.59	0.0613	c
100:MF	1.71	0.0182	def	1.67	0.0627	bc
100:OMF	1.70	0.0502	ef	1.71	0.0810	bc

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 228. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw nitrogen content ($mg \cdot pot^{-1}$) of wheat plants harvested at the end of the ripening stage.

Straw nitrogen content ($mg \cdot pot^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	6151.561	1	6151.561	39.011	0	***
RATE	18886.873	3	6295.624	39.924	0	***
FERTYPE*RATE	5026.207	3	1675.402	10.625	0	***
Error	2523.033	16	157.690			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 229. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw nitrogen content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	7305.475	1	7305.475	64.442	0.000	***
RATE	21642.690	3	7214.230	63.637	0.000	***
FERTYPE*RATE	805.842	3	268.614	2.369	0.109	ns
Error	1813.834	16	113.365			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 230. Straw nitrogen content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Straw nitrogen content (mg·pot^{-1})						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	147	11.0	a	161	4.02	a
0:OMF	162	6.37	a	140	11.3	b
25:MF	122	0.8387	b	123	6.19	b
25:OMF	65.1	7.20	c	69.6	5.30	d
50:MF	121	7.69	b	91.0	4.53	c
50:OMF	66.9	2.50	c	58.3	4.17	d
100:MF	99.8	6.89	b	96.9	4.94	c
100:OMF	67.7	9.64	c	63.5	5.37	d

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 231. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain nitrogen content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	20570.416	1	20570.416	105.653	0.000	***
RATE	64365.157	3	21455.052	110.196	0.000	***
FERTYPE*RATE	4463.459	3	1487.820	7.642	0.002	**
Error	3115.178	16	194.699			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 232 Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain nitrogen content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain nitrogen content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	16413.324	1	16413.324	44.207	0.000	***
RATE	63161.008	3	21053.669	56.705	0.000	***
FERTYPE*RATE	7797.412	3	2599.137	7.000	0.003	**
Error	5940.496	16	371.281			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 233. Grain nitrogen content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

	Grain nitrogen content (mg·pot^{-1})					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	145	1.43	e	158	2.20	e
0:OMF	162	2.12	de	168	5.99	de
25:MF	183	4.95	d	195	13.1	d
25:OMF	275	7.08	b	305	3.15	ab
50:MF	209	17.0	c	248	10.3	c
50:OMF	280	7.20	b	288	3.30	b
100:MF	271	9.67	b	277	5.42	bc
100:OMF	325	1.92	a	327	24.9	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 234. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total nitrogen uptake (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	4223.962	1	4223.962	11.147	0.004	**
RATE	18396.417	3	6132.139	16.182	0.000	***
FERTYPE*RATE	329.950	3	109.983	0.290	0.832	ns
Error	6063.060	16	378.941			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 235. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on total nitrogen uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total nitrogen uptake (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1818.376	1	1818.376	3.616	0.075	ns
RATE	14189.708	3	4729.903	9.405	0.001	**
FERTYPE*RATE	3609.674	3	1203.225	2.392	0.107	ns
Error	8046.743	16	502.921			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant ($P < 0.001$), very significant, ($P < 0.01$) significant ($P < 0.05$) and not significant respectively.

Appendix 236. Total nitrogen uptake (mg·pot^{-1}) of wheat plants at the end of the ripening stage following the application of increasing rates of phosphorus as either OMF or MF in granular or powdered form. Mean values are the average of three independent replicates.

	Total nitrogen uptake (mg·pot^{-1})					
RATE&TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	291	12.2	e	319	2.33	c
0:OMF	324	5.56	cde	308	10.6	c
25:MF	305	4.94	de	318	16.1	c
25:OMF	340	7.05	bcd	374	3.86	ab
50:MF	330	23.7	cd	339	5.82	bc
50:OMF	347	5.04	bc	347	5.80	bc
100:MF	371	10.5	ab	374	5.10	ab
100:OMF	393	7.80	a	390	29.3	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 237. Results of three-way ANOVA for shoot K concentration (%) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.757	1	0.757	15.345	0.000	***
FERTFORM	0.035	1	0.035	0.712	0.405	ns
RATE	1.819	3	0.606	12.286	0.000	***
FERTYPE*FERTFORM	0.067	1	0.067	1.348	0.254	ns
FERTYPE*RATE	0.219	3	0.073	1.481	0.238	ns
FERTFORM*RATE	0.073	3	0.024	0.493	0.690	ns
FERTYPE*FERTFORM*RATE	0.537	3	0.179	3.624	0.023	*
Error	1.579	32	0.049			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 238. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot potassium concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.636	1	0.636	7.558	0.014	*
RATE	0.975	3	0.325	3.860	0.030	*
FERTYPE*RATE	0.524	3	0.175	2.076	0.144	ns
Error	1.347	16	0.084			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 239. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot potassium concentration (%) of wheat plants harvested at the end of the tillering stage.

Shoot potassium concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.187	1	0.187	12.929	0.002	**
RATE	0.917	3	0.306	21.083	0.000	***
FERTYPE*RATE	0.231	3	0.077	5.319	0.010	*
Error	0.232	16	0.014			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 240. Shoot potassium concentration (%) of wheat plants at the end of the tillering stage following the application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Shoot potassium concentration (%)						
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	3.19	0.0940	b	3.42	0.0668	a
0:OMF	3.94	0.0943	a	3.61	0.0676	a
25:MF	2.89	0.1751	b	3.11	0.0306	bc
25:OMF	3.28	0.0353	b	3.20	0.0880	b
50:MF	2.95	0.0786	b	3.00	0.0147	bc
50:OMF	3.20	0.1501	b	2.95	0.0668	c
100:MF	3.37	0.3788	b	2.95	0.1149	c
100:OMF	3.29	0.0522	b	3.44	0.0555	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 241. Results of three-way ANOVA for shoot K content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage (45 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Shoot potassium content (mg·[2 plants]$^{-1}$)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	48.570	1	48.570	0.096	0.759	ns
FERTFORM	496.728	1	496.728	0.979	0.330	ns
RATE	25719.176	3	8573.059	16.893	0.000	***
FERTYPE*FERTFORM	723.386	1	723.386	1.425	0.241	ns
FERTYPE*RATE	3175.652	3	1058.551	2.086	0.122	ns
FERTFORM*RATE	708.640	3	236.213	0.465	0.708	ns
FERTYPE*FERTFORM*RATE	2476.687	3	825.562	1.627	0.203	ns
Error	16239.807	32	507.494			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 242. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot potassium content (mg·[2 plants]$^{-1}$) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	198.535	1	198.535	0.270	0.610	ns
RATE	14412.457	3	4804.152	6.538	0.004	**
FERTYPE*RATE	901.081	3	300.360	0.409	0.749	ns
Error	11756.783	16	734.799			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 243. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants harvested at the end of the tillering stage.

Shoot potassium content (mg·[2 plants]$^{-1}$) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	573.422	1	573.422	2.047	0.172	ns
RATE	12015.360	3	4005.120	14.294	0.000	***
FERTYPE*RATE	4751.257	3	1583.752	5.652	0.008	**
Error	4483.024	16	280.189			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 244. Shoot potassium content (mg·[2 plants]$^{-1}$) of wheat plants at the end of the tillering stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

Shoot potassium content (mg·[2 plants]$^{-1}$)						
RATE&TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	114	4.19	bc	107	11.6	b
0:OMF	99.1	2.60	c	91.0	6.91	b
25:MF	130	13.3	abc	169	6.25	a
25:OMF	141	27.4	abc	115	8.63	b
50:MF	162	17.2	ab	146	9.95	a
50:OMF	170	9.71	a	162	8.11	a
100:MF	156	18.2	ab	145	11.8	a
100:OMF	174	16.8	a	159	12.2	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 245 Results of three-way ANOVA for straw K concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.005	1	0.005	0.125	0.726	ns
FERTFORM	0.496	1	0.496	11.312	0.002	**
RATE	2.637	3	0.879	20.031	0.000	***
FERTYPE*FERTFORM	0.510	1	0.510	11.619	0.002	**
FERTYPE*RATE	1.206	3	0.402	9.163	0.000	***
FERTFORM*RATE	0.438	3	0.146	3.327	0.032	*
FERTYPE*FERTFORM*RATE	0.652	3	0.217	4.949	0.006	**
Error	1.404	32	0.044			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 246. Results of three-way ANOVA for grain K concentration (%) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain potassium concentration (%)						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.001	1	0.001	1.110	0.300	ns
FERTFORM	0.004	1	0.004	5.780	0.022	*
RATE	0.019	3	0.006	8.425	0.000	***
FERTYPE*FERTFORM	0.000	1	0.000	0.364	0.550	ns
FERTYPE*RATE	0.007	3	0.002	3.208	0.036	*
FERTFORM*RATE	0.002	3	0.001	0.706	0.556	ns
FERTYPE*FERTFORM*RATE	0.006	3	0.002	2.494	0.078	ns
Error	0.024	32	0.001			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, and RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 247. Results of three-way ANOVA for straw K content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Straw potassium content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	36046.68	1	36046.685	14.440	0.001	**
FERTFORM	13897.76	1	13897.763	5.567	0.025	*
RATE	126933.04	3	42311.014	16.949	0.000	***
FERTYPE*FERTFORM	32016.68	1	32016.680	12.825	0.001	**
FERTYPE*RATE	191773.70	3	63924.565	25.607	0.000	***
FERTFORM*RATE	19003.16	3	6334.385	2.537	0.074	ns
FERTYPE*FERTFORM*RATE	27127.56	3	9042.519	3.622	0.023	*
Error	79883.18	32	2496.350			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 248. Results of three-way ANOVA for grain K content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Grain potassium content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	3689.757	1	3689.757	145.544	0.000	***
FERTFORM	473.202	1	473.202	18.666	0.000	***
RATE	18653.547	3	6217.849	245.265	0.000	***
FERTYPE*FERTFORM	0.155	1	0.155	0.006	0.938	ns
FERTYPE*RATE	1385.695	3	461.898	18.220	0.000	***
FERTFORM*RATE	105.491	3	35.164	1.387	0.265	ns
FERTYPE*FERTFORM*RATE	68.052	3	22.684	0.895	0.454	ns
Error	811.250	32	25.352			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 249. Results of three-way ANOVA for total K uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage (128 days after planting), as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Total potassium content (mg·pot^{-1})						
Source	Type III Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	62801.872	1	62801.872	22.902	0.000	***
FERTFORM	9242.047	1	9242.047	3.370	0.076	ns
RATE	206054.997	3	68684.999	25.048	0.000	***
FERTYPE*FERTFORM	32157.681	1	32157.681	11.727	0.002	**
FERTYPE*RATE	219341.990	3	73113.997	26.663	0.000	***
FERTFORM*RATE	17917.354	3	5972.451	2.178	0.110	ns
FERTYPE*FERTFORM*RATE	29293.794	3	9764.598	3.561	0.025	*
Error	87749.961	32	2742.186			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 250. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw potassium concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.311	1	0.311	5.553	0.032	*
RATE	0.693	3	0.231	4.128	0.024	*
FERTYPE*RATE	1.753	3	0.584	10.446	0.000	***
Error	0.895	16	0.056			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 251. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on straw potassium concentration (%) of wheat plants harvested at the end of the ripening stage.

Straw potassium concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.205	1	0.205	6.433	0.022	*
RATE	2.383	3	0.794	24.948	0.000	***
FERTYPE*RATE	0.105	3	0.035	1.100	0.378	ns
Error	0.509	16	0.032			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 252. Straw potassium concentration (%) of wheat plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Straw potassium concentration (%)					
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	2.53	0.1851	b	2.74	0.0386	a
0:OMF	2.59	0.1183	b	2.55	0.1569	ab
25:MF	1.97	0.0877	c	2.19	0.1161	c
25:OMF	3.08	0.1709	a	2.09	0.0587	c
50:MF	2.37	0.1378	bc	2.29	0.0761	bc
50:OMF	2.47	0.0677	b	2.24	0.1653	bc
100:MF	2.31	0.1320	bc	1.97	0.0627	c
100:OMF	1.95	0.1517	c	1.57	0.0694	d

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 253. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain potassium concentration (%) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.000	1	0.000	0.097	0.760	ns
RATE	0.012	3	0.004	5.094	0.012	*
FERTYPE*RATE	0.012	3	0.004	4.942	0.013	*
Error	0.012	16	0.001			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 254. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain potassium concentration (%) of wheat plants harvested at the end of the ripening stage.

Grain potassium concentration (%) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	0.001	1	0.001	1.439	0.248	ns
RATE	0.008	3	0.003	3.987	0.027	*
FERTYPE*RATE	0.001	3	0.000	0.561	0.648	ns
Error	0.011	16	0.001			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 255. Grain potassium concentration (%) of wheat plants at the end of the ripening stage following application of Increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Grain potassium concentration (%)					
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	0.4127	0.0111	cd	0.4293	0.0146	
0:OMF	0.4373	0.0240	bcd	0.4538	0.0081	
25:MF	0.4050	0.0136	d	0.4700	0.0239	
25:OMF	0.4702	0.0136	ab	0.4805	0.0058	
50:MF	0.4905	0.0097	a	0.4817	0.0134	
50:OMF	0.4505	0.0153	abcd	0.4727	0.0259	
100:MF	0.4963	0.0254	a	0.4802	0.0095	
100:OMF	0.4607	0.0059	abc	0.5063	0.0084	

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P \cdot kg^{-1}$ soil). SE represents Standard Error.

Appendix 256. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on straw potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw potassium content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	68003.66	1	68003.659	22.834	0.000	***
RATE	87808.98	3	29269.659	9.828	0.001	**
FERTYPE*RATE	178649.04	3	59549.681	19.995	0.000	***
Error	47650.61	16	2978.163			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 257. Analysis of variance investigating the impact of Phosphorus Rates and Fertilizer Types applied in the powdered form on straw potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Straw potassium content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	59.706	1	59.706	0.030	0.865	ns
RATE	58127.222	3	19375.741	9.618	0.001	**
FERTYPE*RATE	40252.209	3	13417.403	6.660	0.004	**
Error	32232.573	16	2014.536			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 258. Straw potassium content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following application of Increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Straw potassium content (mg·pot^{-1})					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	471	22.1	d	495	6.99	bc
0:OMF	485	16.2	d	480	23.5	c
25:MF	449	34.2	d	504	25.4	bc
25:OMF	825	45.4	a	621	11.9	a
50:MF	551	42.6	cd	603	35.0	a
50:OMF	674	20.9	b	627	34.0	a
100:MF	627	40.0	bc	566	31.2	ab
100:OMF	539	10.7	cd	454	25.2	c

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 259. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on grain potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain potassium content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1868.863	1	1868.863	78.887	0	***
RATE	8859.067	3	2953.022	124.650	0	***
FERTYPE*RATE	933.336	3	311.112	13.132	0	***
Error	379.048	16	23.690			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 260. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on grain potassium content (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Grain potassium content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	1821.049	1	1821.049	67.415	0.000	***
RATE	9899.971	3	3299.990	122.165	0.000	***
FERTYPE*RATE	520.411	3	173.470	6.422	0.005	**
Error	432.202	16	27.013			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 261. Grain potassium content (mg·pot^{-1}) of wheat plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Grain potassium content (mg·pot^{-1})					
RATE:TYPES	GRANULAR			POWDERED		
	mean	SE	groups	mean	SE	groups
0:MF	29.5	0.9519	e	31.4	0.5034	e
0:OMF	32.0	1.56	de	35.1	1.19	e
25:MF	39.6	1.33	d	52.4	5.40	d
25:OMF	74.4	0.8404	b	82.2	3.93	b
50:MF	56.0	5.74	c	65.9	3.66	c
50:OMF	79.6	2.10	b	85.4	1.95	b
100:MF	78.6	3.94	b	79.6	2.26	b
100:OMF	88.4	2.11	a	96.3	1.86	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 262. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on total potassium uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total potassium content (mg·pot^{-1}) - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	92419.32	1	92419.320	28.978	0	***
RATE	134214.45	3	44738.150	14.028	0	***
FERTYPE*RATE	202529.89	3	67509.963	21.168	0	***
Error	51028.05	16	3189.253			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 263. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on total potassium uptake (mg·pot^{-1}) of wheat plants harvested at the end of the ripening stage.

Total potassium content (mg·pot^{-1}) - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig,	stars
FERTYPE	2540.233	1	2540.233	1.107	0.308	ns
RATE	89757.900	3	29919.300	13.036	0.000	***
FERTYPE*RATE	46105.897	3	15368.632	6.696	0.004	**
Error	36721.909	16	2295.119			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 264. Total potassium uptake (mg·pot^{-1}) of Wheat Plants at the end of the ripening stage following application of increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

RATE:TYPES	Total potassium content (mg·pot^{-1}) GRANULAR mean	SE	groups	POWDERED mean	SE	groups
0:MF	501	22.8	e	527	6.51	b
0:OMF	517	15.8	de	515	24.3	b
25:MF	489	35.3	e	557	30.2	b
25:OMF	899	45.4	a	703	8.77	a
50:MF	607	47.8	cd	669	38.1	a
50:OMF	754	22.9	b	712	35.8	a
100:MF	705	39.4	bc	646	32.2	a
100:OMF	628	8.63	c	551	27.0	b

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 265. Results of three-way ANOVA for soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 45 days, as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P·kg^{-1} soil).

Olsen P at Tillering stage						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	42.578	1	42.578	5.938	0.021	*
FERTFORM	11.361	1	11.361	1.584	0.217	ns
RATE	9186.958	3	3062.319	427.058	0.000	***
FERTYPE*FERTFORM	57.396	1	57.396	8.004	0.008	**
FERTYPE*RATE	24.500	3	8.167	1.139	0.348	ns
FERTFORM*RATE	12.027	3	4.009	0.559	0.646	ns
FERTYPE*FERTFORM*RATE	23.008	3	7.669	1.070	0.376	ns
Error	229.464	32	7.171			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 266. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 45 days.

Olsen P at Tillering stage - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	99,422	1	99,422	13,672	0,002	**
RATE	4492,970	3	1497,657	205,952	0,000	***
FERTYPE*RATE	44,596	3	14,865	2,044	0,148	ns
Error	116,350	16	7,272			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 267. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 45 days.

Olsen P at Tillering stage - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	0.552	1	0.552	0.078	0.783	ns
RATE	4706.015	3	1568.672	221.890	0.000	***
FERTYPE*RATE	2.912	3	0.971	0.137	0.936	ns
Error	113.114	16	7.070			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 268. Soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 45 days following application of Increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean values are the average of three independent replicates.

	Olsen P at Tillering stage					
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	5.55	0.4471	e	5.45	0.6255	d
0:OMF	5.85	0.6255	e	5.72	0.4310	d
25:MF	11.7	0.2471	d	13.6	1.63	c
25:OMF	19.5	2.99	c	13.6	0.8103	c
50:MF	21.1	2.23	c	21.4	2.40	b
50:OMF	24.2	1.09	c	19.9	1.86	b
100:MF	40.5	1.20	b	43.2	1.69	a
100:OMF	45.6	1.48	a	43.2	1.69	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg P·kg^{-1} soil). SE represents Standard Error.

Appendix 269. Results of three-way ANOVA for soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 128 days, as affected by various fertilizer types (OMF and MF), fertilizer forms (granular and powdered), and P rates (0, 25, 50, and 100 mg P kg^{-1} soil).

Olsen P at Ripening stage						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	135.180	1	135.180	15.760	0.000	***
FERTFORM	6.227	1	6.227	0.726	0.401	ns
RATE	7959.517	3	2653.172	309.312	0.000	***
FERTYPE*FERTFORM	2.306	1	2.306	0.269	0.608	ns
FERTYPE*RATE	229.452	3	76.484	8.917	0.000	***
FERTFORM*RATE	11.437	3	3.812	0.444	0.723	ns
FERTYPE*FERTFORM*RATE	47.670	3	15.890	1.852	0.158	ns
Error	274.485	32	8.578			

The sources include FERTYPE: Fertilizer types, FERTFORM: Fertilizer forms, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant (P < 0.01), significant (P < 0.05) and not significant respectively.

Appendix 270. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the granular form on soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 128 days.

Olsen P at Ripening stage - GRANULAR						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	86.397	1	86.397	9.442	0.007	**
RATE	3704.449	3	1234.816	134.945	0.000	***
FERTYPE*RATE	57.198	3	19.066	2.084	0.143	ns
Error	146.408	16	9.151			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 271. Analysis of variance investigating the impact of phosphorus rates and fertilizer types applied in the powdered form on soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 128 days.

Olsen P at Ripening stage - POWDERED						
Source	Type II Sum of Squares	df	Mean Square	F	Sig.	stars
FERTYPE	51.088	1	51.088	6.382	0.022	*
RATE	4266.505	3	1422.168	177.665	0.000	***
FERTYPE*RATE	219.924	3	73.308	9.158	0.001	**
Error	128.077	16	8.005			

The sources include FERTYPE: Fertilizer types, RATE: Phosphorus rates. ***, **, * and ns represent highly significant (P < 0.001), very significant, (P < 0.01) significant (P < 0.05) and not significant respectively.

Appendix 272. Soil *$NaHCO_3$*-Extractable P levels (Olsen-P) of the experimental soil incubated for 128 days following application of Increasing rates of phosphorus as either OMF or MF, in granular or powdered form. Mean Values are the average of three independent replicates.

	Olsen P at Ripening stage					
RATE:TYPES		GRANULAR			POWDERED	
	mean	SE	groups	mean	SE	groups
0:MF	1.46	0.4053	f	0.5813	0.2636	e
0:OMF	1.46	0.0411	f	1.36	0.0480	e
25:MF	7.72	0.0613	e	11.5	0.7263	cd
25:OMF	11.5	0.9844	de	9.41	0.5388	d
50:MF	14.2	1.05	cd	16.0	2.35	c
50:OMF	17.0	0.4944	c	15.8	1.77	c
100:MF	30.9	3.58	b	30.7	2.69	b
100:OMF	39.4	3.02	a	43.9	2.14	a

The sources include FERTYPE: Fertilizer types; FERTFORM: Fertilizer forms (GRANULAR: Granular fertilizer form; POWDERED: Powdered fertilizer form); and RATE : Phosphorus rates (0, 25, 50 and 100 mg $P{\cdot}kg^{-1}$ soil). SE represents Standard Error.