

## The Impact of Microplastic Pollution in Soils on The Uptake of Plant Nutrient Elements

### Topraklardaki Mikroplastik Kirliliğinin Bitki Besin Elementlerinin Alımı Üzerindeki Etkisi

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#### Abstract

Microplastics are small plastic particles, ranging from 1 µm to 5 mm in size, composed of various types and proportions of polymers and additives. They have become an increasing environmental concern due to the pollution they cause in today's world. The plants grown by producers in soils contaminated with microplastics may be negatively affected depending on the amount of microplastics present in the soil. In this study, which emphasizes this issue, the utilization of plant nutrients from the soil by wheat plants grown in soils contaminated with different proportions of microplastics was investigated. The wheat plant (*Triticum aestivum* L.), which holds significant importance in both domestic and global agriculture and is produced on a large scale by producers in the Thrace region, was chosen for the study. The NKÜ Lider variety was preferred due to its high yield, popularity among Thrace farmers, and resistance to drought and cold. The soils used in the study were obtained from production areas at Tekirdağ Namık Kemal University campus, transferred to pots, and prepared as growing environments with 10 g microplastics / kg soil, 50 g microplastics / kg soil, and 100 g microplastics / kg soil, with three replications. Additionally, wheat plants were grown in a microplastic-free control environment with three replications for comparison. In the study, plant growth characteristics, such as plant height, moisture, and organic matter, were observed, while the levels of plant nutrients (N, P, K, Ca, Mg, Fe, Cu, Zn, and Na) in plant samples taken for analysis were also examined. As a result of the study, the effect of different levels of microplastic contamination in the soil on the nutrient uptake of the wheat (*Triticum aestivum* L.) plants was revealed.

**Keywords:** Microplastic, Plant nutrient element, Soil pollution, Wheat

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## Öz

Mikroplastikler; partikül boyutu 1 µm'den 5 mm'ye kadar olan, farklı çeşit ve oranlarda polimer ve katkı maddelerinden oluşan ve günümüz dünyasında yarattıkları çevre kirliliği ile gün geçtikte daha fazla gündeme gelen küçük parçacıklardır. Topraklarda bulunan mikroplastik miktarına bağlı olarak kirlenmiş topraklarda üreticiler tarafından yetiştirilen bitkiler bu durumdan olumsuz olarak etkilenebilmektedir. Bu husus ön planda tutularak yapılan çalışmada çeşitli oranlarda mikroplastik ile kirlenmiş topraklarda yetişen buğday bitkisinin toprakta bulunan bitki besin elementlerinden faydalanma durumları araştırılmıştır. Bitki olarak ülkemizde ve dünyada kültür tarımında önemli yer tutan ve Trakya bölgesinde üreticiler tarafından büyük ölçekli tarım topraklarında üretimi yapılan buğday bitkisi (*Triticum aestivum* L.) tercih edilmiş olup, verim özelliğinin yüksek olması, Trakya Bölgesi yetiştiricilerinin tercih ettiği bir çeşit olması, kuraklık ve soğuğa dayanım özelliğinden dolayı da NKÜ Lider çeşidi tercih edilmiştir. Araştırmada saksılara doldurulan topraklar, Tekirdağ Namık Kemal Üniversitesi yerleşkesinde bulunan üretim alanlarından temin edilerek saksı ortamlarına aktarılmış ve 3 tekerrürlü olmak üzere 10 g mikroplastik / kg toprak, 50 g mikroplastik / kg toprak ve 100 g mikroplastik / kg toprak içerecek şekilde bitki yetiştirme ortamları hazırlanmıştır. Ayrıca 3 tekerrürlü mikroplastik içermeyen kontrol yetiştirme ortamında da buğday bitkileri yetiştirilerek karşılaştırma yapılmıştır. Çalışmada bitki büyüme özellikleri olarak bitki boyu büyümesi, nem ve organik madde miktarına bakılırken, bitki besin elementi alım özellikleri açısından da N, P, K, Ca, Mg, Fe, Cu, Zn ve Na bitki besin elementlerinin analiz için alınan bitki örneklerinde bulunan düzeyleri incelenmiştir. Yapılan çalışma sonucunda toprakta bulunan farklı mikroplastik kirlenme düzeylerinin, yetiştirilen buğday (*Triticum aestivum* L.) bitkisi örneklerindeki bitki besin elementi alımına etkisi ortaya konulmuştur.

**Anahtar Kelimeler:** Mikroplastik, Bitki besin elementi, Toprak kirliliği, Buğday

## 1. Introduction

Plastics are materials produced from polymers, composed of repeating chains of monomers. Although plant-based materials such as corn and sugarcane have recently been used to produce plastics, the majority of plastic production is still based on petroleum and natural gas (Tsiropoulos et al., 2015).

It is estimated that 4% of the crude oil produced globally is used as raw material for plastic production (Yıldıztekin et al., 2017). Due to the differences in raw materials, each plastic has a unique structure, and this allows for the production of a wide variety of plastic materials. The most commonly used types of plastics today include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and polyamide (PA) (Waring et al., 2018).

Plastics, which are one of the major causes of pollution in our time, lead to irreversible environmental issues concerning air, water, and soil quality. Oceans and seas are among the most affected areas by plastic pollution. Plastics that enter the oceans and seas through various pathways create large plastic waste islands (Yurtsever, 2018).

It is estimated that the amount of plastic waste exposed to terrestrial environments is 4 to 23 times greater than that in the oceans (Horton et al., 2017). It is known that a large majority of plastic waste in terrestrial environments originates from polyethylene packaging materials (Barnes et al., 2009). The plastic consumption which was 1.7 million tons in the 1950s has now exceeded 300 million tons and continues to rise rapidly (Fonseca et al., 2017).

The benefits of environmental cleaning that can be realized range from increasing soil organic matter to reducing soil problems and will ultimately increase soil quality and productivity within the scope of sustainable agriculture (Barlas et al., 2018).

Due to their durability and the fact that they do not naturally decompose, it is predicted that plastics will continue to exert their polluting effects for many years if their usage persists. Although plastic materials are highly durable, they break down over time into smaller particles due to various factors. The reasons for this breakdown are generally biological, thermal, mechanical, thermo-oxidative, and due to sunlight (Chubarenko et al., 2020). Plastics that break down into smaller monomeric particles through these various factors lead to the formation of microplastics and nanoplastics.

Microplastics are defined as small plastic particles with a size range of 1  $\mu\text{m}$  to 5 mm, consisting of different types and proportions of polymers and additives (Fonseca et al., 2017). Microplastics can be divided into two groups based on their sources: primary and secondary. Primary microplastics refer to industrially sourced microbeads that contaminate the environment during production and transport. Secondary microplastics are the main pollutants causing pollution in oceans, air, and soil, resulting from the breakdown of plastic materials used by humans (Andrady, 2017).

Since wheat cultivation areas in our country have reached their limits, it is very important to increase the yield per unit area (Mut et al., 2024). In wheat cultivation, quality should be considered along with yield. The quality of wheat varies depending on the variety, climate factors, soil characteristics and cultivation technique.

Recently, the presence of microplastics in terrestrial and marine environments has become a subject of research interest (Welle and Franz, 2018). Numerous studies have shown that microplastics can be found in receiving waters, sediments, oceans, and even in human breast milk (Park et al., 2020).

In this study, the contents of certain plant nutrient elements (N, P, K, Ca, Mg, Fe, Zn, Cu, Na) in plants grown in soils containing different concentrations of microplastics were examined to investigate the effect of microplastic levels on nutrient element uptake by plants. The effect of microplastics causing soil pollution on nutrient element uptake was investigated using the wheat plant (*Triticum aestivum* L.) under pot experiments.

## 2. Materials and Methods

In this experiment, transparent nylon (polyhexamethylene adipamide) was used as microplastic. For this purpose, 10 kg of nylon was procured, and nylon samples were rinsed with pure water and dried at room temperature. After drying, the samples were cut into small pieces with scissors and then further reduced to the microplastic size limit using a shredder. Homogeneity and size control were conducted under a light microscope

on three 20-gram samples taken from different points of the microplastic pile. The prepared microplastic particles were transferred into airtight bags, each containing 100 grams. This study was established as a randomized block design with three replications.

The soils used in the experiment were collected from the Tekirdağ Namık Kemal University campus and blended to achieve homogeneity. Twelve pots, each filled with 20 kg of soil, first group included three pots identified as the control group, and the soils in these pots were not contaminated with microplastics. In the second group, three pots were treated with 10 grams of microplastic per kilogram of soil (MP 10). The third group consisted of three pots treated with 50 grams of microplastic per kilogram of soil (MP 50). The fourth group included three pots treated with 100 grams of microplastic per kilogram of soil (MP 100).

After the soil and microplastic contents of the pots were prepared, equal amounts (100 each) of wheat seeds were sown in each pot. The NKÜ Lider variety, known for its robust yield potential and resistance to cold and drought, was used. Upon sowing, 5 grams of fertilizer known as 15-15-15 and 50 grams of vermicompost were applied to each pot.

The experiment was conducted in the garden of the Faculty of Agriculture at Tekirdağ Namık Kemal University, where all pots were exposed to the same environmental conditions. During the experimental period, due to favorable weather conditions and sufficient rainfall, no watering was performed. The seeds were sown on December 17, 2023, and the growing plants were harvested for analysis on February 22, 2024. The total number of days for plant growth in the experiment was 68 days. The experimental design was planned and executed with three replications for each application.

### ***2.1. Devices and Chemicals Used for Analyses***

A precise scale (Precisa XB 220 A) with a sensitivity of 0.0001 g was used to weigh microplastics. A two-part Kjeldahl Nitrogen Determination device was used for nitrogen determination. The combustion unit was the Gerhardt device, and the distillation unit was the Gerhardt Vapodest. A Cem Mars 6 Microwave device was used for preparing plant samples for elemental analysis. The elemental analyses were carried out using a Perkin Elmer Nexion 350X model ICP-MS device. An Nabetherm L3 model ash furnace was used for organic matter analysis. For moisture analyses, an Elektro-Mag M5040P device was used. A SOİF BK 5000 Trinocular Light Microscope was used for the control of microplastic particles. All chemicals used in the analytical stage were chosen with instrumental purity in mind. The ultra-pure water required for analyses was obtained from a Milipore Direct-Q device.

### ***2.2. Chemical and Physical Analyses Conducted***

Upon completion of the 68-day experiment, the plant samples were harvested and transferred to the laboratory. For each group, 20 plants were randomly selected and separated on measuring plant height (above-ground biomass length). The above-ground biomass samples of the plants were then homogenized using scissors and a grinder and were prepared for the analysis phase in glass containers.

For nitrogen determination: The macro Kjeldahl method was used (Kacar and İnal, 2008; Sağlam, 2012). For this purpose, 1-gram samples were weighed, burned with sulfuric acid in the combustion unit for 4 hours, then the dissolved sample was distilled in the distillation device, and the nitrogen gas was captured in boric acid. Subsequently, this solution was titrated with 0.1 N HCl solution to determine the nitrogen content in the samples. For phosphorus, potassium, calcium, iron, magnesium, copper, zinc, and sodium analyses: The prepared samples were digested using 5 ml nitric acid and 2 ml hydrogen peroxide in the microwave device and analyzed with ICP-MS (Zarcinas et al., 1987).

Organic matter analysis: According to TS 9103, 5 grams of plant samples were weighed in porcelain crucibles and burned at 650°C for 4 hours in the ash furnace to determine gravimetrically (TSE, 1991).

Moisture analysis: The TS EN ISO 712 (2012) method was used, in which the samples were exposed to 130°C for 2 hours, and the moisture content was determined gravimetrically (Kacar and İnal, 2008).

Plant height: After harvesting the plants, the vertical distance between the soil surface and the highest point of the plant was measured.

Statistical Analysis: In this study a randomized block design was used with three replications. The data from the experiments were analyzed with means compared through Duncan's Multiple Range Test at a confidence level of less than 5%. (Düzgüneş et al., 1987).

### 3. Results and Discussion

The data obtained at the end of the experiment are presented in Table 1. Samples labeled as “Blank” represent the control group, which consists of the average values obtained from three different pots without microplastic contamination. Samples coded as MP10 indicate the average results obtained from plants grown in soil contaminated with 10 grams of microplastic per kilogram, with three replications. Samples coded as MP50 represent the average results from plants grown in soil contaminated with 50 grams of microplastic per kilogram, while samples coded as MP100 reflect the average results obtained from plants grown in soil contaminated with 100 grams of microplastic per kilogram. The average values for all experimental groups are summarized in Table 1.

The current level of research on the effects of microplastics on plants remains limited and needs to be expanded. Research conducted has determined that microplastics have significant effects on various plants, including wheat, perennial ryegrass (*Lolium perenne*), arugula (*Lepidium sativum*), and green onion (*Allium fistulosum*).

In a study conducted by Bosker et al. (2019) on arugula (*Lepidium sativum*), it was found that microplastics decreased germination rates and reduced root growth. Although microplastics cannot be directly absorbed by plant roots, they can negatively affect the survival and growth processes of target plants through various mechanisms such as blocking sunlight, damaging root tissues, clogging cell wall pores, and altering the physicochemical properties of the soil. (Rozman et al., 2021). Our study supports existing literature by demonstrating that increased microplastic exposure inhibits root growth.

In a study by De Souza Machado et al. (2019) on green onion (*Allium fistulosum*), it was reported that the type of microplastic particles caused significant changes in factors such as plant water content, leaf nitrogen content, C/N ratio, and root characteristics; our findings support these results.

In a 2021 study by Lian et al. (2021), it was found that nano plastics applied through leaves significantly reduced the dry weight, size, and leaf area of lettuce (*Lactuca sativa* L.). The data obtained in our study support these findings.

**Table 1. Statistical analysis results of the experiment**

Parameters	Blank	MP 10	MP 50	MP 100	Mean Square
Plant Height (cm)	27.20 b	28.40 a	23.90 c	24.10 c	14.917**
Organic Matter (%)	97.09 d	97.69 b	97.31 c	98.12 a	0.616**
Moisture (%)	83.96 d	85.48 c	85.76 b	87.42 a	6.031**
N (%)	0.60	0.61	0.60	0.62	0.000
P (mg/kg)	1438 a	1370 b	1202 c	1101 d	70939.222**
K (mg/kg)	6622 a	6145 b	5701 c	5226 d	1074056.306**
Mg (mg/kg)	304.60 ab	257.10 c	312.30 a	296.10 b	1800.890**
Ca (mg/kg)	1365 a	1218 ab	1116 b	934.30 c	98579.934**
Fe (mg/kg)	186.50 a	107.70 b	103.70 b	54.26 c	8970.082**
Cu (mg/kg)	1.52 ab	1.53 a	1.50 b	1.20 c	0.076**
Zn (mg/kg)	5.34 b	5.51 b	9.17 a	2.89 c	20.074**
Na (mg/kg)	63.56 c	55.03 d	70.96 b	85.46 a	499.374**

\*According to the Duncan Multiple Range Test, means with the same letter for every factor and interactions are not statistically different at 0.01 and 0.05

#### 3.1. Plant Height Results

In this study, when the size of the above-ground parts of the plants was examined, it was observed that the results ranged from 23.1 cm to 28.5 cm. Among the treatments, the MP 50 group had the shortest plants, with an average height of 23.9 cm. while the MP 10 group had the longest plants at 28.4 cm. When comparing the treatment

groups statistically, a significant difference was found at the 0.05 level ( $p < 0.05$ ) although the MP10 treatment gave higher plant height compared to the other treatments.

### **3.2. The Result of Plant Organic Matter**

Upon examining the organic matter results of the above-ground parts of the plants, it was found that the control group had the lowest organic matter content at 97.09% (ranging from 97.05% to 97.13%). The MP 100 group had the highest organic matter content at 98.12% (ranging from 97.99% to 98.31%).

Statistical evaluations showed significant differences in organic matter content between all groups ( $p < 0.05$ ). It was observed that the organic matter content increased in plants grown in soils contaminated with microplastics. As microplastic pollution increased, the plants' water consumption also rose, leading to an increase in organic matter content. Plastic particles have a very high content of carbon (Rillig, 2018), and most of this carbon will be relatively inert, since the material does not readily decompose.

### **3.3. Moisture Analysis Results**

When examining the moisture results of the plants, it was found that the control group had the lowest moisture content at 83.96% (ranging from 83.88% to 84.08%). The MP 100 group had the highest moisture content at 87.42% (ranging from 87.36% to 87.48%).

Statistical evaluations revealed significant differences in moisture content among all groups ( $p < 0.05$ ). It was determined that as microplastic pollution increased, the water consumption of the plants also increased. Microplastic can change soil biophysical properties, including soil aggregation, bulk density and water holding capacity (Wan et al., 2019).

### **3.4. Nitrogen (N) Content of Plant Samples**

When examining the nitrogen (N) results of the above-ground parts of the plants grown in the research, it was found that the results ranged from 0.60% to 0.64%. The average results also fell within this range.

Statistical evaluations showed no significant difference in nitrogen content among the plant groups ( $p > 0.05$ ). The data obtained indicate that despite the increase in microplastic pollution, the plants continued to uptake the nitrogen necessary for their growth.

### **3.5. Phosphorus (P) Content of Plant Samples**

The phosphorus (P) content of plant samples varied between 1071.6 mg/kg and 1467.2 mg/kg. The highest phosphorus uptake was observed in the control group, while the lowest phosphorus uptake was in the MP 100 group.

Regarding average results, phosphorus contents ranged from 1102.37 mg/kg to 1438.73 mg/kg. A significant difference was found among all groups ( $p < 0.05$ ). Phosphorus uptake can tolerate a certain level of microplastic concentration, but it decreases as pollution levels rise. Phosphorus is considered one of the most limiting nutrients regulating key ecological processes in terrestrial ecosystems (Hu et al., 2023). However, there is still no complete understanding of how microplastics affect the phosphorus cycle.

### **3.6. Potassium (K) Content of Plant Samples**

Potassium (K) contents ranged from 5193.5 mg/kg to 6768.6 mg/kg. The highest potassium uptake was found in the control group, while the lowest uptake was recorded in the MP 100 group.

When examining average results, potassium contents ranged from 5226.57 mg/kg to 6623.20 mg/kg. Statistical analyses indicate that a significant difference was found among all groups ( $p < 0.05$ ). At the same time microplastic pollution increased, potassium uptake decreased.

### **3.7. Magnesium (Mg) Content of Plant Samples**

Magnesium (Mg) contents varied between 250.9 mg/kg and 317.6 mg/kg. Average results were between 257.17 mg/kg and 312.30 mg/kg.

The highest magnesium uptake was observed in the MP 50 group, while the lowest uptake was found in the MP 10 group. Statistical analyses showed significant differences between the control and MP 50 groups and the

other groups ( $p < 0.05$ ). Microplastic pollution affected magnesium uptake up to a certain level, after which the effect stabilized.

### 3.8. Calcium (Ca) Content of Plant Samples

The calcium (Ca) contents of the plant samples varied between 915.6 mg/kg and 1388.9 mg/kg. The average results ranged from 934.37 mg/kg to 1366.20 mg/kg.

The highest calcium uptake was in the control group, while the lowest calcium uptake was found in the MP 100 group. Statistical evaluations indicated that a significant difference was found among all groups ( $p < 0.05$ ). As the level of microplastic pollution increased, calcium uptake significantly decreased.

### 3.9. Iron (Fe) Content of Plant Samples

Iron (Fe) contents varied between 51.8 mg/kg and 190.4 mg/kg. Average results ranged from 54.27 mg/kg to 186.5 mg/kg.

The highest iron uptake was observed in the control group, while the lowest iron uptake was found in the MP 100 group. When comparing the treatment groups statistically, there is a significant difference was found among all groups ( $p < 0.05$ ). With the increase in microplastic pollution, iron uptake decreased, stabilizing after reaching a certain level before decreasing again at high levels.

### 3.10. Copper (Cu) Content of Plant Samples

Copper (Cu) contents ranged from 1.17 mg/kg to 1.55 mg/kg. Average results varied between 1.20 mg/kg and 1.53 mg/kg. Zong et al. (2021) Effects of polystyrene microplastic on uptake and toxicity of copper and cadmium in hydroponic wheat seedlings (*Triticum aestivum* L.)

The highest copper uptake was observed in the control group, while the lowest uptake was noted in the MP 100 group. When comparing the treatment groups statistically, a significant difference was found at the 0.05 level.

### 3.11. Zinc (Zn) Content of Plant Samples

Zinc (Zn) contents varied between 2.78 mg/kg and 9.33 mg/kg. Average results were between 2.89 mg/kg and 9.17 mg/kg.

The highest zinc uptake was found in the MP 50 group, while the lowest uptake was in the MP 100 group. Statistical analyses indicate that a significant difference was found among all groups ( $p < 0.05$ ). Zinc uptake initially increased, then rapidly decreased.

### 3.12. Sodium (Na) Content of Plant Samples

Sodium (Na) contents ranged from 54.2 mg/kg to 88.8 mg/kg. Average results varied between 55.3 mg/kg and 85.47 mg/kg.

The highest sodium uptake was recorded in the MP 100 group, while the lowest uptake was found in the MP 10 group. When comparing the treatment groups statistically, a significant difference was found at the 0.05 level.

## 4. Conclusions

In this study, the effect of different levels of microplastic pollution in soils on the uptake of vital plant nutrient elements by wheat (*Triticum aestivum* L.) was examined, highlighting the importance of the issue.

Among the investigated nutrient elements, only nitrogen (N) was found to be unaffected by microplastic pollution up to the study's limit level. A distinct impact was observed for all other nutrient elements.

Phosphorus (P): A microplastic pollution level of 10 g per kg could be tolerated, but at higher pollution levels, phosphorus uptake decreased.

Potassium (K): Potassium uptake decreased as microplastic pollution increased.

Magnesium (Mg): A microplastic pollution level of 10 g per kg reduced magnesium uptake, while higher levels showed no significant effects.

Calcium (Ca): Calcium uptake decreased as microplastic pollution increased.

Iron (Fe): With increasing microplastic levels, iron uptake initially decreased and then stabilized before decreasing again at high levels.

Copper (Cu): A level of 50 g of microplastics per kg could be tolerated, but at higher levels, copper uptake decreased.

Zinc (Zn): A microplastic level of 10 g per kg was tolerated, but as pollution increased, uptake initially increased and then decreased rapidly.

Sodium (Na): Sodium uptake decreased at a level of 10 g of microplastics per kg, but at higher levels, there was a rapid increase.

In examining plant heights, it was noted that the control and MP 10 groups had similar lengths, while plants at higher microplastic levels showed reduced heights. In contrast, organic matter and moisture content increased proportionally with microplastic pollution. In previous studies, there is insufficient data regarding the availability of plant nutrients in soil and plants related to microplastics

In conclusion, the findings show that microplastics have a statistically significant effect on many nutrient element uptakes and that it would be harmful for plants. Considering microplastics plays a crucial role in plant growth, Future studies will help us better understand the negative or positive effects of microplastics in the soil on plants and will be necessary to eliminate any potential adverse effects. However, more research should be conducted in the future to address this issue and uncover important aspects. Measures should be taken to limit plastic usage, raise awareness among users regarding microplastic pollution, and implement recycling practices to mitigate microplastic pollution.

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#### **Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

#### **Conflicts of Interest**

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

#### **Authorship Contribution Statement**

Concept: Kocabaş, A., Bellitürk, K.; Design: Kocabaş, A., Bellitürk, K.; Data Collection or Processing: Kocabaş, A., Bellitürk, K., Solmaz, Y., Könte E.; Statistical Analyses: Solmaz, Y.; Literature Search: Kocabaş, A., Bellitürk, K., Solmaz, Y., Könte E.; Writing, Review and Editing: Kocabaş, A., Bellitürk, K., Solmaz, Y., Könte E.

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