Turkish Journal of Agriculture - Food Science and Technology, 13(4): 941-945, 2025
DOI: https://doi.org/10.24925/turjaf.v13i4.941-945.7371

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Optimizing Biochar Applications for Improved Growth and Nutritional Quality of Basil Plants Using Rice and Corn Biochars

Güzella Yılmaz Vural[1,a,*], **Halil Erdem**[2,b], **Kenan Yıldız**[1,c]

[1]Tokat Gaziosmanpasa University, Faculty of Agriculture, Department of Horticulture, 60240, Tokat, Türkiye.
[2]Tokat Gaziosmanpasa University University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, 60240, Tokat, Türkiye
[*]Corresponding author

ARTICLE INFO

Research Article

Received : 29.11.2024
Accepted : 28.01.2025

Keywords:
Biochar
Edible flower
Heavy metal
Nutrient element
Phenolics

ABSTRACT

The study aimed to determine the effects of biochar obtained from rice husk and corn harvest residues on the growth, nutritional content and some biochemical properties of basil plants. Both biochars were applied by mixing them into potting soil at 2% and 5% rates. To determine the effect of applications on plant development, the height and weight of plants and leaf weights, and number of side branches were recorded. Additionally, chlorophyll content (SPAD), phenol content, antioxidant content and P, Mg, Ca, K, S, Fe, Zn, Mn, Cu and B concentrations in the leaves were determined. Compared to the control, significant increases were detected in the leaf weights, height and weights of the plants grown in all pots containing biochar. The highest plants were obtained from 5% rice biochar (RB5) treatment. The highest leaf weight and the highest number of side branches were also observed. in the RB5 treatment. Leaf K contents in RB5 and maize harvest residue biochar (CB) treatments were higher compared to the control. Leaf B, Fe and Mn contents were lower in certain biochar treatments than the control. Biochar applications did not cause a significant change in the antioxidant and chlorophyll content of basil plants. The total phenolic content significantly increased only in RB5 treatment. The effect of biochar application varied depending on the application rate and the properties of the biomass from which the biochar was obtained. Therefore, it is not possible to draw a general conclusion about the effects of biochar applications on plant growth. Contradictory results can be obtained depending on the type of plants and biochars and the characteristics of the growth medium.

[a] *guzella.yilmaz@gop.edu.tr* *https://orcid.org/0000-0002-9284-9698*
[c] *kenanyildiz@gop.edu.tr* *https://orcid.org/0000-0003-3455-5146*
[b] *halil.erdem@gop.edu.tr* *https://orcid.org/0000-0002-3296-1549*

Introduction

Biochar is a stable carbon-rich substance produced by heating organic wastes at high temperatures in relatively oxygen-free environments (Karhu et al., 2011). Biochar may positively contribute mitigating the problems caused by climate change (Lehmann et al., 2006), reducing plant uptake of heavy metals (Erdem et al., 2017), and minimizing the effects of soil borne pathogens (Eo et al., 2018). Many studies reported that biochar added to the growing environment increases soil quality and promotes plant growth (Luo and Gu, 2016; Günal and Erdem, 2021; Lehmann et al., 2003). However, the effect of biochar applications on plant growth varies depending on the plant type, the conditions of the growing environment, the feedstock of biochar, pyrolysis temperature, and the dose of biochar (Ma et al., 2019; Głodowska et al., 2017; Nobile et al., 2020; Acir and Erdem, 2020). Biochar application increases cation exchange capacity, specific surface area, and water-holding capacity of soils, thus the improvement in soil properties positively affects plant growth (Karhu et al., 2011). Negatively charged functional groups, large surface area, and high porosity of biochar increase the retention of water and nutrients in biochar-amended soils (Conte et al., 2013). In addition, the biochar applications increase total nutrient content such as C, K, N, Ca, M, P and enzyme activity of soils (Wang et al., 2014).

Basil (*Ocimum basilicum* L.), belongs to the Labiate family. The fresh leaves of basil plants are usually consumed. Essential oils obtained from the basil plant are frequently used in medicine to treat stomach disorders, as a urinary tract antiseptic, analgesic, diuretic, carminative and sedative (Asımgil, 1996; Baytop, 1999). Basil also has antimicrobial and antifungal properties (Skaltsa and Loukis, 1985). In addition to medicine and cosmetics uses, medicinal aromatic plants have functional uses. The medicinal aromatic plants have advantages in the fields of medicine and pharmacy, and also make important contributions to landscaping (Pouya and Demir, 2017). The use of medicinal aromatic plants in landscape design is important to increase plant diversity (Karagöz et al., 2010). High resistance of medicinal aromatic plants to different conditions and form, size and color characteristics increase the importance in landscape designs. In addition, the local medicinal aromatic plants can be more adaptable to new environments compared to other plants to low water requirements. Therefore, the use of medicinal aromatic plants such as basil in landscape designs reduces the costs for design and maintenance (Bayramoğlu, 2016).

This study investigated the impact of different biochar types and application rates on basil (*Ocimum basilicum* L.) growth, nutritional content and some biochemical properties.

Materials and Methods

Plant Materials

The study was conducted in an unheated greenhouse. Biochars produced from rice husk and corn harvest residues were used in the study. Biochars were obtained by slow pyrolysis of rice husk and maize harvest residues at 500ºC for 6 hours in an anoxic environment (Ronsse et al., 2013). Rice husk and corn residue biochars had the following properties; carbon/nitrogen ratio 138/1 and 110/1, pH 10.2 and 9.21, specific surface area 212 and 398 m^2 g^{-1}, total P concentration 0.05 and 3.69 g kg^{-1}, K concentration 38 .9 and 34.3 g kg^{-1} (Günal et al., 2019). Basil seedlings obtained from seeds planted in a soil (1): peat (1) mixture were used as plant material in the research.

Experimental Details

The pots used in the study had a volume of 2 liters. Each pot was prepared with a 1/1 soil/peat mixture with a dry weight of 1800 g. 90 mg kg^{-1} N, 80 mg kg^{-1} P and 100 mg kg^{-1} K, 2 mg kg^{-1} Fe, and 1 mg kg^{-1} Zn were fertilized per pot (kaçar*).* Three different doses of rice husk (RB) and maize harvest residue (CB) biochar (0, 2, and 5%) were homogeneously mixed with soil and peat along with basic fertilizers.

The experiment was planned according to the randomized plot design with 6 replications. One plant was planted in each pot. Plants were checked every day and watered with distilled water when they needed. Plant height, number of side branches and SPAD measurements were made when plant growth stopped (before flowering). Total plant (stem+leaf) and total leaf weights of the plants were determined before the harvest.

Leaf Analysis

Mineral analysis

Leaf samples washed with pure water were dried in an oven at 70°C for 48 hours and ground in an agate mill. The ground plant samples were burned in a H_2O_2-HNO_3 acid mixture using a microwave device (Mars Xpress). P, K, Ca, Mg, S, Fe, Zn, Mn, Cu and B concentrations in the burned samples were determined using the ICP-OES device (Varian Vista Pro) (Kaçar and İnal, 2008).

Chlorophyll level

Chlorophyll level was determined by using a chlorophyll meter (SPAD-Minolta SPAD-502, Osaka, Japan). The SPAD measurements on basil leaves were carried out in three replications, and the measurement in each replicate was repeated for 3 different leaves in each treatment.

Total phenol (TP) and total antioxidant (TEAC) analyses

Phenolic content in plant samples was determined using Folin-Ciocalteu (Singleton and Rossi, 1965). Homogenized plant samples were extracted in a solution consisting of water, acetone and acetic acid (70:29.5:0.5) for one day. After the plant samples were extracted, they were kept in distilled water for 8 minutes and 7% sodium carbonate was added to the Folin-Ciocalteu mixture. The color of the solution changed to a bluish color after two hours of incubation, and the absorbance of the samples at a wavelength of 750 nm was measured in a spectrophotometer. The results were calculated as µg gallic acid equivalent (GAE) g-1 fresh weight (FW) in gallic acid.

The homogenized plant samples were mixed with 7 nm ABTS (2,2'-Azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) and 2.45 mM potassium bisulfate to determine the total antioxidant capacity (TEAC) (Saracoglu, 2018). Then, the solution was simplified to 0.700±0.01 absorbance at 734 nm wavelength using 20 mM sodium acetate (pH 4.5) buffer. Finally, 2.97 mL of prepared copper was mixed with 30 µL of extract and 10 min later, the absorbance at 734 wavelength was determined using a spectrophotometer. The absorbance values were calculated using Trolox (10–100 µmolL-1) standard curve line and presented as µmol Trolox equivalent (TE) g^{-1} fw.

Statistical Analysis

Statistical analyses were conducted using the SAS software. Data were subjected to analysis of variance (ANOVA), followed by Duncan's multiple range test to determine significant differences between treatment means.

Results

An increase in the height of the plants grown in all pots containing biochar was observed compared to the height of the plants grown in the control pots. The increase in plant height was greater in RB5 and CB2 treatments compared to the RB2 and CB5. The mean plant height was 10.8 cm in the control, while it was 17.53 and 18.27 cm in CB2 and RB5 treatments, respectively. The effect of maize biochar on the number of lateral branches was not significant, while both doses of rice biochar caused an increase in the number of lateral branches. The stimulating effect of biochar applications on plant growth is evident in total herb weight and total leaf weight. The total herb and total leaf weights in all biochar applications were higher than the control. The highest weights were recorded in the RB5 treatment (Table 1).

Biochar applications caused significant changes in leaf K, B, Fe and Mn contents, while the amount of other nutrients did not change significantly (Table 2). Leaf K content significantly increased in RB5 and CB2 treatments compared to the control. The K content increased from 3.9 in the control treatment to 4.1 in both RB5 and CB2 treatments. The biochar applications, except CB5, caused significant decrease in leaf B, Fe and Mn contents.

Chlorophyll contents measured in SPAD did not change significantly with biochar applications. The total phenol content of basil plants to biochar applications varied depending on the type and dose of biochars.

Table1. The effects of different biochar doses on some plant growth parameters in basil plants

Doses	Plant height (cm)	Number of lateral branches (branch/plant)	Upper part weight (g/plant)	Leaf weight (g/plant)
Control	10.8 c	8.6 b	4.3 d	2.9 d
RB2	15.89 b	16.1 a	13.5 bc	8.2 bc
RB5	18.27 a	19.4 a	20.7 a	12.2 a
CB2	17.53 a	9.8 b	16.0 b	9.8 b
CB5	15.34 b	10.2 b	11.2 c	7.3 c

The difference between the means shown with different letters in the same column are statistically significant ($p<0.05$).

Table 2. The effects of biochar doses on nutrient contents of basil leaves

Doses	K (%)	Mg (%)	P ^{ns} (%)	S (%)	Ca (%)	B (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
Control	3.60 b	0.81	0.52	0.26	3.62	29.5 a	42.0	727.1 a	61.0 a	30.4
RB2	3.90 ab	0.55	0.43	0.20	2.92	24.2 b	42.6	339.0 b	49.9 b	31.3
RB5	4.11 a	0.55	0.47	0.21	2.89	24.8 b	39.1	289.3 b	47.6 b	32.1
CB2	4.11 a	0.56	0.46	0.21	3.01	24.4 b	39.7	297.4 b	51.1 b	32.9
CB5	3.97 ab	0.63	0.48	0.20	3.03	27.5 a	43.1	695.8 a	66.0 a	32.9

The difference between the means shown with different letters in the same column are statistically significant ($p<0.05$); ns is not statistically significant.

Table 3. Effects of biochar doses on the biochemical properties of basil leaves

Doses	TP (µg GAE g^{-1} fw)	TEAC (µmol TE g^{-1} fw)^{ns}	SPAD^{ns}
Control	3607.0 b	35.05	23.9
RB2	3884.1 ab	39.33	21.7
RB5	5473.6 a	44.95	21.8
CB2	3921.6 ab	35.48	21.3
CB5	4048.6 ab	34.29	21.2

The difference between the means shown with different letters in the same column are statistically significant ($p<0.05$); ns is not statistically significant.

Both doses of corn residue biochar did not cause a significant change in total phenol content compared to the control. Low dose of rice husk biochar was not significant, while high dose rice husk biochar (RB5) significantly increased the total phenol content (Table 3). The antioxidant capacity of plants varied from 35.05 µmol TE g^{-1} fw (kontrol) to 44.95 µmol TE g^{-1} fw (RB5), but the differences between treatments were not significant.

Discussion

Similar to the results reported in previous studies on basil (Jabborova et al., 2021) and other plants (Dispenza et al., 2016), in this study it was observed that biochar application increased plant growth. This situation may be due to in part the amendment effect of biochar on the potting soil. Kim et al. (2017) stated that biochar application reduces the particle density and total pore space of the growth medium, while increases the bulk weight and available water content, resulting in better plant growth in biochar added soil.

Although there are many studies reporting that biochar applications improve plant growth, it is noteworthy that a generalization cannot be made on this subject and the results obtained may vary depending on the plant species and biochar source (Zhang et al., 2020). Supporting this view, the effects of the applications in this study also differed depending on the dose and type of biochar. High dose of rice biochar (RB5) and low dose of corn biochar (CB2) were more effective on plant height (Table 1). The variation in plant growth with biochar applications depending on the application ratio and nature of biomass has been reported in previous studies (Jeffrey et al., 2011; Zhang et al., 2012).

The number of lateral branches is a very important feature in terms of form and appearance especially in plants grown for ornamental purposes. Research results revealed that the number of lateral branches of basil plants can be significantly increased with RB application.

Some studies reported that biochar positively affects plant development by improving nutrient uptake, soil nutrient availability and biological activities (Literatür). In this study, it was determined that biochar caused changes in some nutrient contents of the plant. Significant increases in leaf K content and decreases in in leaf B, Fe and Mn contents resulting from biochar application were detected. Similar to our findings, Dispenza et al. (2016) reported that biochar increased leaf K content of Euphorbia × lomi plants while decreased Fe, Mn and Mg contents. The results have been attributed to the better ion balance in plant organs due to the positive effects of biochar on plant growth.

Some of previous studies stated that biochar application increases photosynthesis rate and chlorophyll content (He et al., 2020; Ding et al., 2020; Jabborova et al., 2021). As a result of this study, there was no significant change in chlorophyll values; It reveals that the effect of biochar applications may vary depending on the source, biochar dose and plant type grown.

Phenolic substances are the main antioxidants that increase the nutritional value of plants, as well as are the main mechanism developed by plants against oxidative stress. Quartacci et al (2017) reported that biochar, which increases nutrient and water uptake, can also affect the phenolic content of plants by changing the conditions of the growing medium. In their studies with lettuce, these researchers determined that biochar application increased total phenol content phenolic acids and anthocyanins content. Similarly, Jabborova et al (2021) reported that biochar improved the physiological properties of basil plant by increasing its total sugar and flavonoid contents. In this study, although total phenol content was higher in all biochar applications than in the control, only the increase in the RB5 treatment was found to be significant. The effects of the treatments on antioxidant capacity were similar to the changes in total phenol. The antioxidant capacity in RB5 application, which increased the total phenol content, was slightly higher than the control, but the difference was not statistically significant. Other biochar applications did not cause a significant change in antioxidant capacity.

Conclusion

This study reveals the significant potential of biochar applications in improving the growth and biochemical properties of basil plants. Specifically, the application of 5% rice biochar (RB5) significantly improved plant height, weight, and phenolic content, suggesting that carefully optimized biochar treatments can enhance both agronomic and nutritional aspects of basil cultivation. However, the effects of biochar were dependent on the biochar type, application rate, and the plant's growing medium, indicating the necessity for context-specific adjustments. Moreover, while biochar positively influenced potassium uptake, it resulted in reduced concentrations of other essential nutrients such as B, Fe, and Mn, emphasizing the need for balanced nutrient management. This study underscores the complex interplay between biochar properties, plant type, and soil conditions, offering insights for sustainable agriculture practices. Further research is recommended to investigate long-term effects and to refine biochar application strategies for diverse crops and growing environments.

Declarations

Ethical Approval Certificate

There is no content in the study that requires ethics committee approval.

Author Contribution Statement

G.Y.V: Planning and implementation of the study, Biochar production, Writing.

H.E.: İmplementation of the study, Biochar production.

K.Y.: Writing Review, and Editing.

Fund Statement

Not applicable.

Conflict of Interest

The authors declare that they have no competing interests.

References

Acir, Y., Erdem, H. (2020). The effect of biochar applications on cadmium (Cd) uptake of bread wheat. Academic Journal of Agriculture 9(2): 327-336. ISSN: 2147-6403 e-ISSN: 2618-5881 DOI: http://dx.doi.org/10.29278/azd.813360 (in Turkish).

Asımgil, A. (1996). Medicinal Herbs, Timaş Publications, 352 pp, Istanbul. (in Turkish).

Bayramoğlu, E. (2016). Sustainable Landscape Arrangement Approach: Evaluation of KTU Kanuni Campus in terms of Xeriscape, Journal of Artvin Coruh University, Faculty of Forestry,17(2), 119-127. (in Turkish).

Baytop, T. (1999). Treatment with Herbs in Turkey (Past and Present), 2nd Edition Nobel Medicine Bookstores Ltd. Sti. pp 3-8, Istanbul (in Turkish).

Conte, P., Marsala, V., De Pasquale, C., Bubici, S., Valagussa, M., Pozzi, A., Alonzo, G. (2013). Nature of water-biochar interface interactions, GCB Bioenergy 5:116–121.

Ding, Z., Zhou, Z., Lin, X., Zhao, F., Wang, B., Lin, F., Ge, Y., Eissaet, M.A. (2020). Biochar impacts on NH3-volatilisation kinetics and growth of sweet basil *(Ocimum basilicum L.)* under saline conditions. Ind. Crop. Prod. 157, 112903.

Dispenza, V., De Pasquale, C., Fascella, G., Mammano, M.M., Alonzo, G. (2016). Use of biochar as peat substitute for growing substrates of *Euphorbia* × *lomi* potted plants. Spanish Journal of Agricultural Research 14(4), 1-11.

Eo, J., Park, K.C., Kim, M.H., Kwon, S.I., Song, Y.J. (2018). Effects of rice husk and rice husk biochar on root rot disease of ginseng (Panax ginseng) and on soil organisms, Biological Agriculture & Horticulture, 34(1), 27-39.

Erdem, H., Kınay, A., Gunal, E., Yaban, H., Tutus, Y. (2017). The effects of biochar application on cadmium uptake of tobacco. Carpathian Journal of Earth and Environmental Sciences, 12(2), 447-456

Głodowska, M., Schwinghamer, T., Husk, B., Smith, D. (2017). Biochar based inoculants improve soybean growth and nodulation. Agric. Sci. 8, 1048–1064. https://doi.org/10.4236/as.2017.89076.

Günal, H., Bayram, Ö., Günal, E., Erdem, H. (2019). Characterization of soil amendment potential of 18 different biochar types produced by slow pyrolysis. Eurasian J. Soil Sci., 8 (4) :329-339.

Günal, E., Erdem, H. (2021). Effects of Three Different Biochars Enriched with Dairy Effluent on Wheat Growth. Levantine Journal of Applied Sciences, 1:1-15. https://doi.org/10.56917/ljoas.1

He, Y., Yao, Y., Ji, Y., Deng, J., Zhou, G., Liu, R., Shao, J., Zhou, L., Li, N., Zhou, X., Bai, SH. (2020). Biochar amendment boosts photosynthesis and biomass in C3 but not C4 plants: a global synthesis. GCB Bioenergy 12, 605–617. https://doi.org/10.1111/ gcbb.12720.

Jabborova, D., Ma, H., Bellingrath-Kimura, S.D., Wirth, S. (2021). Impacts of biochar on basil (Ocimum basilicum) growth, root morphological traits, plant biochemical and physiological properties and soil enzymatic activities.

Jeffrey, S., Verheijen, F.G.A., Van der Velde, M., Bastos, A.C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agric Ecosyst Environ 144:175–187.

Kacar, B., İnal, A. (2008). Plant Analysis, Nobel Publishing Distribution Ltd. Publications, Publication No: 1241; Sciences: 63, (I. Edition) Ankara (in Turkish)

Karagöz, A., Zencirci, N., Tan, A., Taşkın, T., Köksel, H., Sürek, M., Toker, C., Özbek, K. (2010). Conservation and Use of Plant Genetic Resources, Turkish Chamber of Agricultural Engineers VII. Technical Congress, 11-15. (in Turkish)

Karhu, K., Mattila, T., Bergstrom, I., Regina, K. (2011). Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – results from a short-term pilot field study. Agric. Ecosyst. Environ. 140, 309–313. https://doi.org/10.1016/j. agee.2010.12.005

Kim, H.S., Kim, K.R., Yang, J.E., Ok, Y.S., Kim, W.I., Kunhikrishnan, A., Kim, K.H. (2017). Amelioration of horticultural hrowing media properties through rice hull biochar incorporation. Waste Biomass Valor 8:483–492

Lehmann, J., da Silva, Jr., JP, Steiner, C., Nehls, T., Zech, W., Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments, Plant and Soil 249: 343–357

Lehmann, J., Gaunt, J., Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems-a review. Mitig. Adapt. Strateg. Glob. Chang. 11, 403–427

Luo, L., Gu, J.D. (2016). Alteration of extracellular enzyme activity and microbial abundance by biochar addition: Implication for carbon sequestration in subtropical mangrove sediment. Journal of Environmental Management 182: 29-36

Ma, H., Egamberdieva, D., Wirth, S., Bellingrath-Kimura, S.D. (2019). Effect of biochar and irrigation on soybean-rhizobium symbiotic performance and soil enzymatic activity in field rhizosphere. Agronomy 9, 626

Nobile, C., Denier, J., Houben, D. (2020). Linking biochar properties to biomass of basil, lettuce and pansy cultivated in growing media. Sci. Hortic. 261, 109001 https://doi.org/10.1016/j.scienta.2019.109001.

Pouya, S., Demir, S. (2017). The use of medicinal and aromatic plants in landscape architecture, The Journal of International Social Research 10:4 www.sosyalarastirmalar.com ISSN:1307-9581 http://dx.doi.org/10.17719/jisr.20175434680 (in Turkish).

Quartacci, M.F., Sgherri, C., Frisenda, S. (2017). Biochar amendment affects phenolic composition and antioxidant capacity restoring the nutraceutical value of lettuce grown in a copper-contaminated soil. *S*ci. Hortic., 215 (2017), pp. 9-14.

Ronsse, F., Van Hecke, S., Dickinson, D., Prins, W. (2013). Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions. Gcb Bioenergy, 5(2), 104-115.

Saracoglu, O. (2018). Phytochemical accumulation of anthocyanin rich mulberry (*Morus laevigata*) during ripening. Journal of Food Measurement and Characterization, 12(3), 2158-2163.

Sharafzadeh, S., & Alizadeh, O. (2011). Nutrient supply and fertilization of basil. Advances in Environmental Biology, 5(5), 956-960.

Singleton, V., Rossi, JL. (1965). Colorimetry of Total Phenolics with Phosphomolybdic-Phosphotungstic Acid Reagents. Amer. J. Enol. Vitic. 16:144-158.

Skaltsa, H., Loukis, A. (1985). Analysis of the Essential Oil of Grek Sweet Basil. Laboratory of Pharmacognosy- University of Athens PH. D Thesis.

Wang, Y., Yin, R., Liu, R. (2014). Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil. J. Anal. Appl. Pyrolysis 110, 375–381. https://doi.org/10.1016/j.jaap.2014.10.006

Zhang, A.F., Bian, R.J., Pan, G.X., Cui, L.Q., Hussain, Q., Li, L.Q., Zweng, J., Zheng, X., Han, X., Yu, X. (2012). Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Research 127: 153-160.

Zhang, K., Wang, Y., Mao, J., Chen, B., 2020. Effects of biochar nanoparticles on seed germination and seedling growth. Environ. Pollut. 256, 113409 https://doi.org/10.1016/j.envpol.2019.113409.