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Residues, An Alternative for Reducing Water Contamination, Leaching, and Greenhouse Gas Emission

Residu, Alternatif Mengurangi Pencemaran Air, Pencucian, dan Emisi Gas Rumah Kaca

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ABSTRAK

Studi ini menyelidiki kemanjuran residu anggur dalam mengurangi kontaminasi air. Temuan kami menunjukkan penurunan signifikan dalam pencucian nitrat setelah penggunaan residu anggur. Ukuran partikel residu yang lebih kecil mencatat pengurangan pencucian nitrat yang lebih besar dibandingkan dengan ukuran partikel yang lebih besar. Memanfaatkan cabang limbah anggur untuk produksi biochar menawarkan solusi berkelanjutan, meningkatkan retensi air, kandungan bahan organik, dan mengurangi pencucian nutrisi. Biochar tidak hanya meningkatkan retensi nutrisi tetapi juga meningkatkan aktivitas mikroba dan bakteri pengikat nitrogen, sehingga bermanfaat bagi kesehatan tanah dan produktivitas tanaman. Ini juga membantu memerangi kekeringan dan tekanan salinitas. Secara keseluruhan, biochar anggur menunjukkan potensi dalam mengurangi polusi nitrat, meningkatkan kualitas tanah, dan meningkatkan keberlanjutan pertanian. Penting untuk mempertimbangkan laju aplikasi biochar dan ukuran partikel yang optimal untuk memaksimalkan efektivitasnya dalam mengurangi pencucian nitrat sekaligus meminimalkan potensi dampak negatif terhadap hasil panen. Penelitian lebih lanjut diperlukan untuk mengoptimalkan tingkat penerapan biochar, ukuran partikel, dan efek jangka panjang dalam beragam sistem pertanian. Penerapan biochar sebagai bahan pembenah tanah menjanjikan peningkatan kesehatan tanah, kualitas air, dan keberlanjutan secara keseluruhan.

Kata Kunci:

Residu Tanaman;

Anggur;

Limpasan Nitrat;

Kontaminasi air.

ABSTRACT

This study investigated the efficacy of grape residue in reducing water contamination. Our findings revealed significant reductions in nitrate leaching upon the application of grape residues. Smaller residue particle sizes recorded greater reductions in nitrate leaching compared to larger ones. Utilizing grape waste branches for biochar production offers a sustainable solution, improving water retention, organic matter content, and reducing nutrient leaching. Biochar not only enhances nutrient retention but also promotes microbial activity and nitrogen-fixing bacteria, benefiting soil health and crop productivity. It also helps combat drought and salinity stress. Overall, grape biochar shows potential in mitigating nitrate pollution, enhancing soil quality, and promoting agricultural sustainability. It is important to consider the optimal biochar application rate and particle size to maximize its effectiveness in reducing nitrate leaching while minimizing any potential negative impacts on crop yield. Further research is required to optimize biochar application rates, particle sizes, and long-term effects in diverse agricultural systems. Implementing biochar as a soil amendment holds promise in improving soil health, water quality, and overall sustainability.

Keywords:

Plant residue;

Grape;

Nitrate Runoff;

Water Contamination.

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INTRODUCTION

To address the escalating need for food, the agricultural sector has increasingly relied on chemical fertilizers and genetically modified crops (Chen et al., 2007). Although effective in enhancing crop yields, these approaches have had detrimental environmental impacts, including soil and water pollution, as well as air contamination (Fields, 2004; Nolan et al., 2002; Reifeng et al., 2014). Adding to this complex scenario are factors like rapid population growth, an increase in the number of vehicles, and urbanization. These elements have further intensified pollution levels, making air quality a major concern. For example, gas flares in Iran are responsible for emitting approximately 50 million metric tons of CO2 each year, contributing to 5.5%-6% of the nation's total greenhouse gas emissions. In the United States, the situation is similarly dire; in 2017 alone, fuel waste amounted to 3.3 billion gallons, leading to a staggering cost of 179 billion USD (Shojaei et al., 2022; Mirbakhsh et al., 2023). In this regard, agriculture can play a significant role by deploying more innovative approaches for not following conventional methods, such as Nitrogen-based fertilizers, which often not fully absorbed by plants, contribute to groundwater contamination and greenhouse gas emission. This poses significant health risks, as high nitrate levels in drinking water have been linked to various diseases (World Health Organization, 2004; Brender et al., 2004; Ward et al., 2005).

Currently, many researchers are focusing on exploring various cropping methods, such as cover cropping, to improve soil health and quality. These innovative studies offer alternatives to traditional monocropping systems like maize and soybean, which require large amounts of synthetic fertilizers. The use of biofertilizers, including humic acid and biochar, along with advancements in nanotechnology (nano-biofertilizer), has demonstrated potential in increasing nitrogen use efficiency (NUE). However, these approaches are not without their challenges (Brunn et al., 2012; Fan et al., 2013; Wang et al., 2021; Sahani et al., 2021; Mirbakhsh et al., 2023; Mirbakhsh., 2023).

Biochar, a thermally decomposed organic matter, offers a sustainable solution for nutrient retention (Halester et al., 2013; Zhang et al., 2015). Its application has been shown to reduce nitrate leaching and improve soil microbial activity (Van Genuchten et al., 2009; Lie et al., 2014; Brantley et al., 2015; Haider et al., 2017; Zhang et al., 2017; Demirtag et al., 2018). It also mitigates the negative impacts of environmental stressors like drought and salinity (Olfati., 2012; Are et al., 2017; Paetsch et al., 2018).

In Yazd, Iran, grape farming has a long history (Kafi et al., 2004). Given the region's arid and nitrogen-deficient conditions, grape waste offers a viable source for biochar production (Radmehr, 2010). This study, conducted in 2021, aims to assess the efficacy of grape-derived biochar in mitigating nitrate leaching in loamy soils, using the abundant waste from local grape farms.

MATERIAL AND METHODS

Stems resulting from harvesting and collecting grapes were obtained from the garden of the Faculty of Agriculture, Yazd University, Iran. The stems were placed in shade conditions to dry (autumn of 2018). Biochar was prepared from the discarded grape stems in a high-temperature furnace (450 °C) and through a thermochemical decomposition process under limited oxygen conditions for a duration of 6 hours. The produced biochar with a mesh size of 18 (hole size of 1 millimeter) was passed through and the fractions that passed through were used as treatment with particle size less than 1 millimeter. The remaining fraction, with a mesh size of 7 (hole size of 2.8 millimeters), was sieved, and the remaining

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Table 1. Physiological and chemical properties of the experimental field.

Depth (cm)	Silt (%)	Loam (%)	Sand (%)	Soil EC	Saturated PH	Organic Carbon (%)	Density (g/cm^3)	Available N (%)	Available phosphorus (mg/Kg)	Available K (mg/Kg)
0-25	46.6	10.3	46.1	2.6	6.3	0.611	1.38	65	12.01	285.4

portion on this mesh was used as treatment with natural particle size larger than 2.8 millimeters. Soil properties of our experimental site are brought in table 1.

The soil that was used in this study was obtained from the surface layer (0 to 25 centimeters) of the nursery at Yazd University. It was then dried in the shade and passed through a 2-millimeter sieve. The water requirement of the soil in its agricultural capacity was determined in the laboratory. For this purpose, the water requirement for saturation was calculated. Initially, a container was weighed, and then 100 grams of dry soil (dried in an oven for 72 hours) was transferred to the container, and water was added to saturate the soil (the soil surface was shiny, and after creating a groove, it was closed by gentle tapping on the container). The container with saturated soil was weighed and then placed in an oven at a temperature of 80 °C for 48 hours, after which it was weighed again. In this way, the water requirement for saturation was calculated. In a drainage container, the water requirement for saturation was added to the soil, and the container was weighed at intervals of 12 hours until the weight remained constant for three consecutive measurements. Then, the water requirement for achieving field capacity was calculated (Klute, 1986; Nolan et al, 2002).

The percentage of particles and soil texture was determined using the hydrometer method, bulk density of soil by the cylinder method, electrical conductivity in the saturated extract of soil using an electrical conductivity meter, organic carbon by the wet oxidation method (Walkley and Black, 1934), soil nitrogen by the Kjeldahl method, phosphorus by colorimetric measurement using a spectrophotometer (Olsen et al., 1954), magnesium, calcium, potassium, zinc, iron, and manganese were measured and determined using atomic absorption spectrophotometry, and the specific surface area of biochar was measured by the BET method.

The experiment was conducted in a factorial design based on a completely randomized design with three replications at the end of 2019 and the beginning of 2020 in the Soil Science Laboratory of the Faculty of Agriculture, Yazd University. The experimental factors included two levels of biochar particle size (less than 1 millimeter and larger than 2.8 millimeters (natural particle size)) and three levels of biochar amount (1%, 2%, and 3% by weight). A control treatment without biochar was used for comparison with the treatments. The analysis of one percent organic matter was uniformly mixed with one kilogram of decayed leaf soil to provide a nitrogen source for nitrate production. This mixture was added to each experimental unit, which consisted of a one-liter drainage plastic pot (a total of 21 pots). The pots were prepared in December 2019 and were continuously irrigated every two weeks with distilled water at 20% above the field capacity. Sampling was conducted in two stages, with a six-week interval, in April and June 2020. The nitrate content in the drained water was evaluated using a Palintest 7100 device. For this purpose, nitrate was first reduced using nitrate powder (based on cadmium), and then nitrate clotting was performed inside a dedicated test tube using a nitrate tablet. For

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this, 20 ml of the sample was transferred to the nitrate tube. Then, one nitrate powder spoon and one intact nitrate tablet were added to the nitrate tube, and after closing its lid, it was shaken for one minute. It was then left undisturbed for one minute and inverted 3 to 4 times to facilitate clotting. The tube was left undisturbed for 5 minutes to observe complete sedimentation. Then, 10 milliliters of the clear solution was transferred to a cell and one Nitricole tablet was crushed and added to it, and it was mixed until a complete and uniform color change was observed. This process takes more than 10 minutes. The spectrophotometer was then set to read nitrate, and the nitrate content of the samples was read in milligrams per liter (Wegner, 1972). Statistical analysis of the data was performed using a factorial design based on a completely randomized design, including an independent control treatment, using SAS software version 9.4. Mean comparison test was performed based on LSD (Least Significant Difference) protection. Excel software was used for drawing the graphs.

RESULT AND DISCUSSION

The experiment was analyzed in a factorial design with a control treatment. The results of the experiment showed that the experimental treatments had a significant effect on nitrate concentration in the leached water in both sampling stages ($p<0.001$) (Table 2). Additionally, comparing the treatments with the control in both sampling stages indicated a significant effect of the treatments compared to the control ($p<0.01$) (Table 2). Particle size and biochar amount were significant at a 5% level in the first measurement, while they were significant at a 1% level in the second measurement. The interaction effect of particle size and biochar amount was not significant in the first measurement but was significant in the second measurement ($p<0.001$) (Table 4).

The results of other investigations also demonstrated that the application of different biochar led to a reduction in leached nitrate. These results can be attributed to the high specific surface area and excellent anion adsorption capacity of biochar, especially under high-temperature biochar production conditions, due to the increased carbon-to-nitrogen ratio and high content of various cations in biochar composition (Table 3) (Downie et al., 2007; Van Zwieten et al., 2009; Larid et al., 2010; Li et al., 2014; Brender et al., 2015; Haider et al., 2017; Zhang et al., 2017; Demir et al., 2018). Generally, soil properties such as acidity, cation and anion exchange capacity, and buffering capacity are influenced by the application of biochar, with the extent of the effect depending on the feedstock, temperature conditions, oxygen availability, and the amount of biochar applied (Lehmann and Joseph, 2009; Siedt et al., 2021).

Adding biochar to clayey soil at a rate of 20 g/kilogram increased the specific surface area of the soil from 130 to 150 m^2 (Laird et al., 2010). Furthermore, due to its high carbon-to-nitrogen ratio, biochar has a strong capacity for anion adsorption (Hollister et al., 2013; Lie et al., 2014; Zhang et al., 2015), which leads to the absorption of various anions such as nitrate and consequently reduces the leaching of highly soluble anions like nitrate in water. The reduction of leaching of phosphate compounds has also been reported as a result of biochar application (Laird et al., 2010; Zhang et al., 2021). The application of biochar resulted in a reduction in nitrate and phosphate leaching, leading to soil fertility improvement and ultimately better growth of cultivated plants due to enhanced root development (Zhang et al., 2021). The reduction of nitrate leaching has been reported in greenhouse experiments (Nelsen et al., 2011; Brunn et al., 2012; Haider et al., 2015) and field studies (Haider et al., 2016; Han et al., 2016). The reduction of nitrate

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leaching and subsequent increase in available nitrogen for plant roots have been reported due to biochar application. For example, a 4-year study demonstrated that biochar application not only increased the availability of nitrate for plants (reducing leaching) but also increased soil moisture content (Haider et al., 2017). Adding biochar to soil not only reduces nitrate leaching but also gradually releases nitrate, increasing its availability for root uptake, resulting in plants experiencing less nitrogen deficiency during the growth period. However, nitrogen deficiency may be more severe at the beginning of the growth period, so fertilizer management during this stage prevents a decrease in the yield of agricultural crops (Haider et al., 2017; Arumta et al., 2019).

The comparison of the average nitrate content in the drained water samples, considering the non-significant interaction effect of particle size and biochar amount in the first measurement (Table 2), was examined by comparing the average simple effects of particle size and biochar amount (Tables 3).

CONCLUSION

The study aimed to explore the effectiveness of grape-derived biochar in reducing nitrate leaching in loamy soils. Conducted at Yazd University, Iran, the research was set against the backdrop of environmental challenges associated with conventional agricultural practices, particularly the use of nitrogen-based fertilizers.

The experimental design was factorial and revealed a significant reduction in nitrate concentration in leached water. This finding is consistent with previous research that highlights the potential of biochar in nutrient retention due to its high specific surface area and anion adsorption capacity.

One of the key observations was that the lowest level of nitrate leaching occurred with a 1% biochar weight level, showing reductions of 81.7% and 83.6% in the first and second samplings, respectively. This suggests that smaller amounts of biochar may be more effective in reducing nitrate leaching and could also minimize the risk of yield decline during the early growth stage.

The study also emphasized the importance of the particle size and amount of biochar applied, as these factors had a significant impact on the results. The findings indicate that biochar made from grape

Table 2. The mean squares of the treatment effects on the leached nitrate level were calculated.

Source of variance (SOV)	df	Nitrate (mg/l) in first sampling	Nitrate (mg/l) in second sampling
Treatments	6	200128.96***	166318.30***
Treatments vs. Control	2	450833.53***	865100.64***
Particle size	1	29012.50*	40004.50***
Biochar	2	18334.72*	32691.17***
Particle size × Biochar	2	4129.17 [ns]	5711.17***
Error	12	2663.49	254.13

*and*** significant at 0.05 and 0.01 respectively, “ns” shows non-significant differences.

Table 3. Comparison of the mean effects of biochar amount on the leached nitrate level.

Treatments	Nitrate (mg/l) in first sampling	Nitrate (mg/l) in second sampling
Control	743.33 [a]	890.33 [a]
1 % weight	230.83 [c]	220.00 [d]
2 % weight	288.33 [bc]	197.17 [c]
3 % weight	135.00 [b]	227.33 [b]
LSD 5%	72.58	22.42

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Different letters indicate significant differences at a 0.05 error level

waste can serve as a sustainable solution for both nutrient retention and environmental protection, at least in the short term.

In summary, this research adds to the growing evidence supporting the use of biochar as a green alternative to traditional fertilizers. It also provides a new perspective on how agricultural waste, such as grape stems, can be repurposed for sustainable soil management. Future work could focus on the long-term impacts and scalability of these promising findings.

DAFTAR PUSTAKA

Are, K. S., Adelana, A. O., Fademi, I. O., Aina, O. A. 2017. Improving physical properties of degraded soil: Potential of poultry manure and biochar. Agriculture and Natural Resources, 51(6), 454-462.

Arumta, N., Mulyo, J., Irham. 2019. The export determinations of Indonesian cut flower in the international market. AGRO EKONOMI. https://doi.org/10.22146/ae.44856

Brantley, K.E., Brye, K.R., Savin, M.C., and D.E. Longer. 2015. Biochar source and application rate effects on soil water retention determined using wetting curves. Open. J. Soil. Sci. 5:1–10.

Brender, J.D., Olive, J.M., Felkner, M. Suarez, L. Marckwardt, W., and K.A. Hendricks. 2004. Dietary nitrites and nitrates, nitrosatable drugs, and neural tube defects. Epidemiology. 15:330–336.

Brunner, T. J., Wick, P., Manser, P., Spohn, P., Grass, R. N., Limbach, L. K., & Stark, W. J. (2006). In vitro cytotoxicity of oxide nanoparticles: comparison to asbestos, silica, and the effect of particle solubility. Environmental science & technology, 40(14), 4374-4381.

Bruun, E.W., Ambus, P., Egsgaard, H., and H. Hauggaard-Nielsen. 2012. Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics. Soil. Biol. Biochem. 46:73–79.

Downie, A., Van Zwieten, L., Doughty, W., and F. Joseph. 2007. Nutrient retention characteristics of chars and the agronomic implications. In Proceedings, International Agrichar Iniative Conference, 30th April-2nd May.

Fan, R., Huang, Y. C., Grusak, M. A., Huang, C. P., & Sherrier, D. J. (2013). Effects of nano-TiO2 on the agronomically-relevant Rhizobium–legume symbiosis. Science of the Total Environment, 466, 503-512.

Fields, S. 2004. Global nitrogen: cycling out of control. Environ. Health. Perspect. 112:557–563.

Gentile, R., Vanlauwe, B., van Kessel, C., and J. Six. 2009. Managing N availability and losses by combining fertilizer-N with different quality residues in Kenya. Agric. Ecosyst. Environ. 131:308–314.

Goolsby, D.A. 2000. Mississippi basin nitrogen flux believed to cause Gulf hypoxia. Eos, Transactions American Geophysical Union, 81:321–327.

Hollister, C.C., Bisogni, J.J., and J. Lehmann. 2013. Ammonium, nitrate, and phosphate sorption to and solute leaching from biochars prepared from corn stover and oak wood. J. Environ. Qual. 42:137–144

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B., and D.L. Karlen. 2010. Impact of biochar

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amendments on the quality of a typical Midwestern agricultural soil. Geoderma. 158:443–449.

Lehmann, J., & Joseph, S. (Eds.). 2015. Biochar for environmental management: science, technology and implementation. Routledge.

Lie, J.H., Lv, G.H., Bai, W.B., Liu, Q., Zhang, Y.C., and J.Q. Song. 2014. Modification and use of biochar from wheat straw (Triticum aestivum L.) for nitrate and phosphate removal from water. Desalination. Water. Treat. 57:4681–4693.

Mirbakhsh, A., Lee, J. and Besenski, D. (2023) Development of a Signal-Free Intersection Control System for CAVs and Corridor Level Impact Assessment. Journal of Future Transportation, 3, 552-567. https://doi.org/10.3390/futuretransp3020032

Mirbakhsh, M. (2023). Role of Nano-fertilizer in Plants Nutrient Use Efficiency (NUE). J Gene Engg Bio Res, 5(1), 75-81.

Mirbakhsh, M. , Sohrabi Sedeh, S. S. & Zahed, Z. (2023). The Impact of Persian Clover (Trifolium resupinatum L.) on Soil Health . Black Sea Journal of Agriculture , 6 (5) , 564-570 . DOI: 10.47115/bsagriculture.1312940.

Mirbakhsh, M., Zahed, Z. (2023). Enhancing Phosphorus Uptake in Sugarcane: A Critical Evaluation of Humic Acid and Phosphorus Fertilizers' Effectiveness. J Gene Engg Bio Res, 5(3), 133-145.

Nolan, B.T., Hitt, K.J., and B.C. Ruddy. 2002. Probability of nitrate contamination of recently recharged groundwaters in the conterminous United States. Environ. Sci. Technol. 36: 2138–2145.

Olfati, J., Moqbeli, E., Fathollahi, S., and Estaji, A. (2012). Salinity stress effects changed during Aloe vera L. vegetative growth. Journal of Stress Physiology & Biochemistry, 8(2), pp. 152–158.

Olsen, S. R., Cole, C. V., Watanabe, F. S., Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular, Vol 939 (p. 19). Washington, DC: US Department of Agriculture.

Paetsch, L., Mueller, C. W., Kögel-Knabner, I., Von Lützow, M., Girardin, C., Rumpel, C. 2018. Effect of in-situ aged and fresh biochar on soil hydraulic conditions and microbial C use under drought conditions. Scientific reports, 8(1), 6852.

Radmehr, A. 2010. Results of sampling survey of garden product in 2009. Ministry of Agriculture, Tehran, Iran.

Ri-Feng, K., Zhang, N.M., Jing, S., Li, B., and C.G. Zhang. 2014. Effects of biochar-based fertilizer on soil fertility, wheat growth and nutrient absorption. Soil. Fertilizers. 6:33-38.

Sahani, S., & Sharma, Y. C. (2021). Advancements in applications of nanotechnology in global food industry. Food Chemistry, 342, 128318.

Shojaei SM, Vahabpour A, Saifoddin AA, Ghasempour R. Estimation of greenhouse gas emissions from Iran's gas flaring by using satellite data and combustion equations. Integr Environ

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Assess Manag. 2023 May;19(3):735-748. doi: 10.1002/ieam.4684. Epub 2022 Oct 20. PMID: 36151901.

Siedt, M., Schäffer, A., Smith, K. E., Nabel, M., Roß-Nickoll, M., van Dongen, J. T. 2021. Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. Science of the Total Environment, 751, 141607.

Troeh, F. R and L.M. Thompson. 2005. Soils and Soil Fertility, Blackwell Publishing, Iowa, US.

Tylova, M.E., Lorenzen, B., Brix, H., and O. Votrubova. 2005. The effects of NH4 and NO3 on growth, resource allocation and nitrogen uptake kinetics of Phragmites australis and Glyceria maxima. Aquat. Bot. 81:326–342.

Van Zwieten, V.L., Singh, B., Joseph, S., Kimber, S., Cowie, A., and Y.K. Chan. 2009. Biochar and emissions of non-CO2 greenhouse gases from soil. In: Lehmann, J., Joseph, S. (Eds.), Biochar for Environmental Management Science and Technology. Earthscan Press, UK, PP. 227–249.

Walkley, A., 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(1): 29-38.

Wang, Y., Xu, X., Fang, X., Yao, N., Lei, H., Yang, G., & Hua, Z. (2021). Rationally designing renewable plant oil-based polymers as efficient Nano carriers for sustained pesticide delivery. Chemical Engineering Journal, 450, 138294.

Ward, M.H., deKok, T.M., Levallois, P., Brender, J., Gulis, G., Nolan, B.T., and J. VanDerslice. 2005. Drinking-Water Nitrate and Health Recent Findings and Research Needs. Environ. Health. Perspect. 113: 1607–1614.

Wegner, T. N. 1972. Simple and sensitive procedure for determining nitrate and nitrite in mixtures in biological fluids. J. dairy sc. 55: 642-644.

Zhang A.P., Liu, R.L., Gao, J., Zhang, Q.W., Xiao, J.N., Chen, Z., Yang, S.Q., Hui, J.Z., and L.Z. Yang. 2015. Effects of Biochar on Nitrogen Losses and Rice Yield in Anthropogenic alluvial Soil Irrigated with Yellow River Water. J. Agro-Environ. Sci. 33:2395–2403.

Zhang, C., Huang, X., Zhang, X., Wan, L., Wang, Z. 2021. Effects of biochar application on soil nitrogen and phosphorous leaching loss and oil peony growth. Agricultural Water Management, 255, 107022

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