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Editorial

Technologies for Environmental Ecological Restoration and Agricultural Sustainability Are the Focus of Future Safeguarded Agriculture Development

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Abstract: Global agricultural production is facing unprecedented challenges as the environment becomes increasingly polluted. Governments, scientists, companies and farmers are beginning to focus on appropriate environmental remediation and sustainable agricultural technologies and practices. Innovative environmental adaptation/remediation technologies have been developed and validated, including physical/chemical remediation, green sorbents and bioremediation. The development of environmental remediation technologies has provided additional tools and methods for global agri-environment and food security. The aim of this Special Issue is to bring together 21 cutting-edge research papers covering the latest developments in soil conditions, inorganic pollution, organic pollution, remediation technologies and monitoring methods. The four themes of the Special Issue are "Improvement of agricultural soil properties", "Remediation of potentially toxic element pollution", "Remediation of organic pollution" and "Ecosystem and crop assessment". Based on the results of this Special Issue, we find that combining the latest environmental pollution problems with advanced remediation technologies, continuously promoting technological innovation and policy support, and developing integrated new technologies for environmental protection will be future areas of research for sustainable agro-environmental development.

Keywords: agri-environmental technology innovation; sustainable ecosystems; green remediation technologies; co-remediation; artificial intelligence assessment

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1. Introduction

Increasing environmental pollution poses unprecedented challenges to global agriculture. To address these pressures, suitable environmental ecological restoration and sustainable agricultural technologies and methods have gradually gained attention from governments, scientists, businesses, and farmers. Green and low-cost environmental remediation technologies are bound to become the direction of future development. So far, various innovative environmental adjustment/remediation technologies have been developed and validated, including physical/chemical remediation, green adsorbents, and biological remediation, among others. These technologies play a crucial role in environmental remediation by effectively reducing pollutant concentrations and restoring the health of ecosystems. Additionally, macro-level environmental and ecological planning play increasingly important roles in guiding environmental restoration. The latest artificial intelligence and big data analysis not only greatly improve the accuracy of pollution monitoring in agricultural environments but also enable the prediction of environmental risks caused by pollutants. Overall, the development of environmental remediation technologies provides more tools and methods for global agricultural environments and food security. However, the complexity of pollution and the diversity of application issues in agricultural environments present significant challenges in practical remediation work. Therefore, there is an urgent need to combine the latest environmental pollution issues with advanced remediation technologies, continuously promote technological innovation and policy support, and develop integrated new technologies to protect the environment.

This Special Issue aims to provide the latest emerging perspectives based on the cutting-edge methods of "environmental ecological restoration and agricultural sustainability" and focuses on the current status of agricultural environmental ecological restoration and sustainable development, helping to alleviate environmental pollution from both micro and macro perspectives. Specifically, this compilation includes 21 cutting-edge studies covering the latest soil conditions, inorganic pollution, organic pollution, remediation technologies, monitoring methods, and other aspects.

2. Improvement of Agricultural Soil Properties Is the Main Objective of Agri-Environmental Remediation

The dual pressure of environmental pollution and food demand has made global food security an important issue for mankind today. Soil quality is the guarantee of stable and high production of food crops, and soil productivity determines the quality of soil. According to Zhang et al. (2023), soil productivity consists of four dimensions: limiting, available, inherent, and depleting [1]. Intrinsic soil productivity plays an important role in crop production, in which the synergistic effects of soil organic matter, nutrients, aggregates, and microorganisms provide a suitable environment with high buffering capacity and stability for crop growth, contributing to the sustainable development of agriculture. However, soil productivity is gradually weakening at present due to the overuse of fertilizers and monoculture. Therefore, efforts should be made to develop green technologies related to the use of organic fertilizers, straw mulching, microbial activators, tillage management, and cover cropping in order to ensure the sustainability of agricultural soils. For example, the research of several scholars in this Special Issue has yielded corresponding research results.

2.1. Does Straw Returning Amended with Straw Decomposing Microorganism Inoculants Increase the Soil Major Nutrients in China's Farmlands?

Based on the application of straw-decomposing microbial inoculants (SDMI) in agricultural soils, He et al. (2022) revealed the significance of straw incorporation strategies (Figure 1A) [2]. A meta-analysis study was conducted using 1214 paired observations from 132 field trials in China. The results showed that SDMI significantly increased the total and available concentrations of nitrogen, phosphorus, and potassium in the soil ($p < 0.05$). Mean annual precipitation was identified as a key environmental factor influencing the effects of SDMI-amended straw on soil total nitrogen ($p = 0.008$) and available nitrogen ($p = 0.0006$). Soil organic matter was found to be the main factor influencing the effects of SDMI-amended straw on soil total phosphorus, while MAP played a significant role in the effects on available potassium ($p = 0.032$ and $p = 0.049$, respectively). The findings indicate that the incorporation of SDMI-amended straw can have measurable impacts on the status of soil major nutrients. Overall, applying SDMI-amended rice straw with an initial C/N ratio of ≤ 15 in neutral soils within temperate and subtropical monsoon climates is a promising strategy to maximize the total and available concentrations of nitrogen, phosphorus, and potassium in the soil.

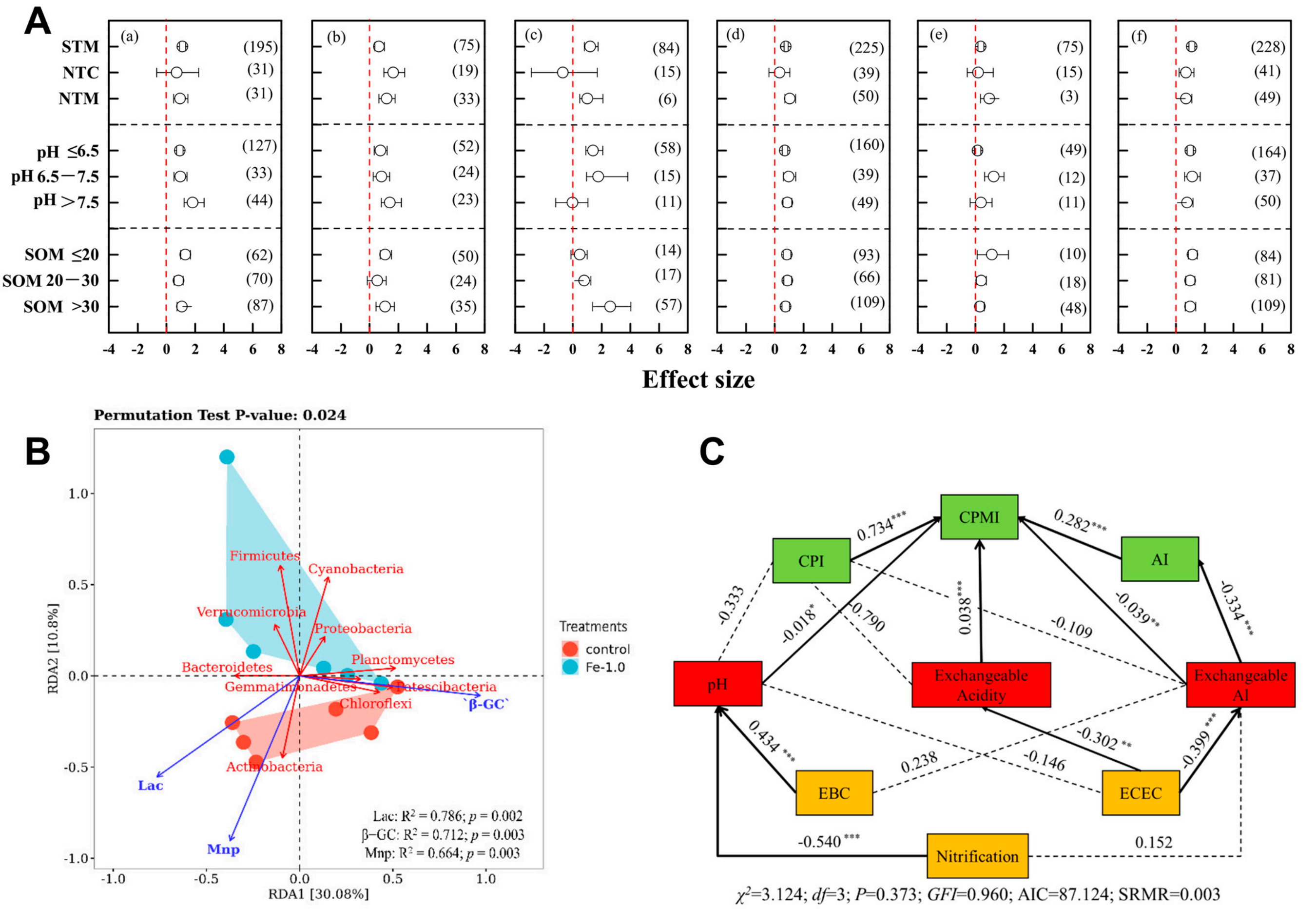

Figure 1. (**A**) Effects of SDMI application on soil total N (**a**), available N (**b**), total P (**c**), available P (**d**), total K (**e**), and available K (**f**) under different agricultural management practices, expressed as the mean effect size with bootstrapped 95% confidence intervals [2]. (**B**) Redundancy analysis depicting the relationship between the bacterial phyla and enzyme activities [3]. (**C**) Structural equation modeling (SEM) of the effects of submergence on organic carbon pool as a result of submergence-induced changes in soil acidification and soil environment [4]. "*" represents the level of significance, with a greater number of "*"s representing greater significance.

2.2. High Level of Iron Inhibited Maize Straw Decomposition by Suppressing Microbial Communities and Enzyme Activities

Jin et al. (2022) investigated the relationship between crop straw decomposition rate and changes in soil biological properties after straw return in soils with different iron (Fe^{2+}) contents through a 180-day incubation experiment (Figure 1B) [3]. The results demonstrated that the addition of Fe^{2+} significantly inhibited the decomposition of maize straw (MS). Bacterial communities were found to be more sensitive to high iron levels compared to fungal communities, and the inhibition of bacterial growth due to iron was the main reason for the decrease in overall microbial abundance. High concentrations of Fe^{2+} (1.0 mg g^{-1}) reduced the relative abundance of *Actinobacteria* and suppressed the activity of laccase (Lac), thereby inhibiting the decomposition of hemicellulose, cellulose, and lignin in MS. Controlling high iron content is an important parameter for crop straw return in soils.

2.3. Alleviating Soil Acidification and Increasing the Organic Carbon Pool by Long-Term Organic Fertilizer on Tobacco Planting Soil

In order to mitigate soil acidification caused by long-term tobacco cultivation, Dai et al. (2021) conducted a 10-year field experiment in a brown soil tobacco continuous cropping system in East China, using different fertilization treatments (no fertilization

(CK), chemical fertilizer (CF), organic–inorganic compound fertilizer (OCF), and organic fertilizer (OF)) (Figure 1C) [4]. The results showed that long-term application of OF and OCF significantly alleviated soil acidification caused by chemical fertilizer application, manifested by increased soil pH, decreased electrical conductivity (Ec), and exchangeable acid content (especially exchangeable aluminum). Compared to chemical fertilizer application, organic fertilizer application significantly reduced soil nitrification and increased EBC. RDA analysis indicated that NP, NH_4^+-N, and NO_3^--N were important factors indicating soil acidification, while EBC and exchangeable K were significant factors limiting soil acidification. Additionally, the addition of organic fertilizer significantly increased the organic carbon pool and soluble organic carbon pool. The structural equation model (SEM) showed that OCF treatment primarily increased the soil organic carbon pool by inhibiting soil nitrification and reducing the content of exchangeable Al. In conclusion, both OF and OCF treatments are effective methods for alleviating tobacco planting soil acidification, but OCF has more advantages in improving the soil organic carbon pool.

3. Potentially Toxic Element Pollution of Soils Is the Most Urgent Problem in Agriculture

Soil potentially contaminated by toxic elements mainly refers to the phenomenon that is confirmed by professional risk assessment to be when the concentration in the soil exceeds the thresholds set by national authorities and/or background levels. Common soil potentially toxic elements include Cd, As, Cr(VI), etc., which are classified as Group 1 carcinogens by the International Agency for Research on Cancer (2012). Potentially toxic elements are not biodegradable and can enter the human body through accumulation in the food chain, causing irreversible damage. Common methods for managing potentially toxic element contamination in soil can be divided into two categories. One is the traditional chemical and chemical remediation methods based on solidification and leaching, such as calcium sulphate, magnesium oxide, slag, biochar, etc. [5]. The other category is ecological remediation methods based on adsorption and transfer, such as phytoremediation and microbial remediation. Traditional chemical methods usually utilize direct reactions between chemical reagents and potentially toxic element ions, such as chelation, electrostatic adsorption, ion exchange, mineral precipitation and redox. Although the traditional methods are faster, they often suffer from high costs, secondary pollution, and alteration of the original soil structure. In recent years, ecological remediation has been widely used due to its low cost, non-polluting nature and multiple landscape, environmental and social benefits. The use of microbial remediation has become increasingly common, and its excellent compatibility allows it to be used in conjunction with other technologies. In particular, green remediation technology, which combines functional microbial remediation and organic solid wastes from agriculture and forestry, has become the focus of new research and development in potentially toxic soil element remediation technology. For example, phosphorus solubilizing functional microorganisms have received more attention in this Special Issue.

3.1. Combination of Biochar and Phosphorus Solubilizing Bacteria to Improve the Stable Form of Toxic Metal Minerals and Microbial Abundance in Lead/Cadmium-Contaminated Soil

Lai et al. (2022) proposed a combined remediation technique using biochar and phosphate-solubilizing bacteria (PSB) to address Pb/Cd co-contaminated soil (Figure 2A) [6]. The pot experiment results showed that under high concentrations of toxic metal stress, the physical/chemical and biological properties of the original soil were significantly reduced, such as pH (decreased by 11.31%) and total microbial biomass (decreased by 44.93%). The combined remediation of PSB and biochar effectively reduced the unstable forms of toxic metals (water-soluble fraction: Pb decreased by 41.00% and Cd decreased by 91.49%; exchangeable fraction: Pb decreased by 85.01% and Cd decreased by 69.33%), and increased the stable forms of toxic metals (acid-soluble fraction: Pb increased by 5 times and Cd increased by 15 times; non-bioavailable fraction: Pb increased by 14 times and Cd increased by 6 times), resulting in a much better remediation effect compared to single remediation.

Furthermore, the combination of biochar and PSB mainly formed two minerals, lead phosphate and cadmium carbonate, within a short period of time (30 days), thereby alleviating the microbial stress caused by toxic metals and restoring the microbial biomass of the contaminated soil to its original state.

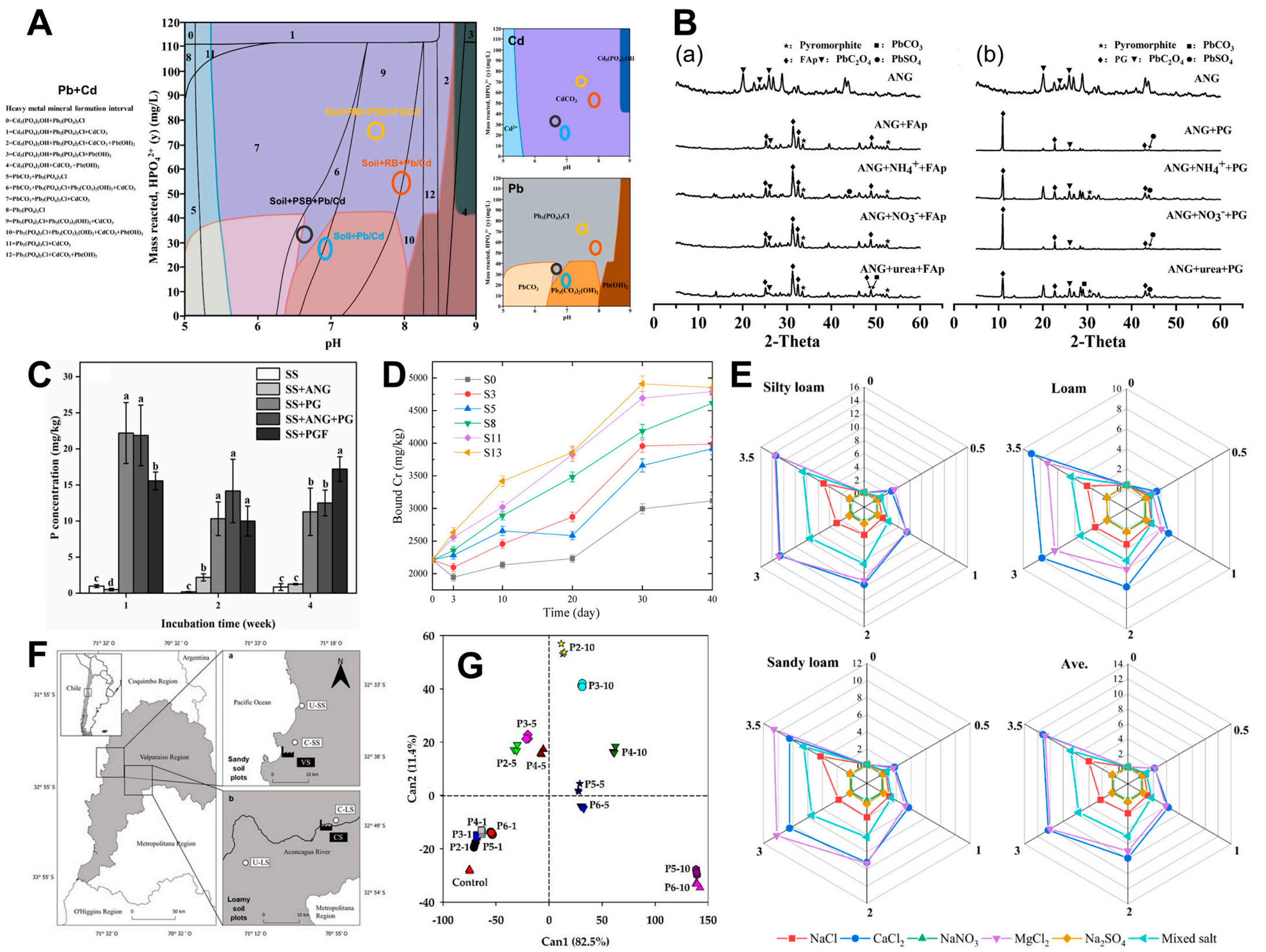

Figure 2. (**A**) Final minerals (Pb + Cd) formed by different treatments in the GWB model (RB—rice husk biochar, PSB—*Enterobacter* sp.) [6]. (**B**) XRD patterns of precipitation in the FAp (**a**) and PG (**b**) treatments after six days of incubation [7]. (**C**) The soluble P concentration in soil between SS, SS + ANG, SS + PG, SS + ANG + PG, and SS + PGF treatments during incubation (1, 2, 4 weeks) [8]. (**D**) Concentrations of the bound fraction during remediation [9]. Different letters represent significant differences between treatments. (**E**) Effects of different salt types and salt concentrations (0, 0.5%, 1.0%, 2%, 3%, and 3.5%) on the Cd desorption rates (%) [10]. (**F**) The geographical location of the studied areas and the main trace element sources: (**a**) sandy soils area; and (**b**) loamy soils area [11]. (**G**) Canonical scores of the first two canonical discriminant functions (Can) of the control and PLB treatments (1, 5, and 10 = 1%, 5%, and 10%) [12].

3.2. *Remediation of Lead Contamination by Aspergillus niger and Phosphate Rocks under Different Nitrogen Sources*

Feng et al. (2022) investigated the remediation of Pb using two types of phosphate rocks, fluorapatite (FAp) and phosphogypsum (PG), in the presence of three different forms of nitrogen (ammonium, nitrate, and urea) conditions (Figure 2B) [7]. The study found that the combined application of *Aspergillus niger* (*A. niger*) with FAp and PG promoted the formation of pyromorphite (Pyro) and lead oxalate, leading to enhanced removal of lead. PG was more effective than FAp for Pb remediation by *A. niger* through the formation of lead sulfate. Among the different nitrogen forms, nitrate showed a greater ability to stimulate the production of oxalic acid by *A. niger* compared to ammonium and urea. Therefore, the co-application of *A. niger* with PG and nitrate is a cost-effective method for Pb remediation.

3.3. The Utilization of Phosphogypsum as a Sustainable Phosphate-Based Fertilizer by Aspergillus niger

Tian et al. (2022) investigated the P release capacity between tricalcium phosphate and phosphogypsum (PG) by *Aspergillus niger* (ANG) (Figure 2C) [8]. The study found that ANG can survive in the PG environment and not only promote the release of phosphorus from PG but also reduce environmental risks by forming Pb oxalate. Therefore, the combination of ANG with PG to produce PG fertilizer is a feasible pathway for the reuse of PG, which can reduce the consumption of phosphate mineral resources.

3.4. Transformation of Chromium Speciation during High Hexavalent Chromium-Contaminated Soil Remediation by CPS and Biostimulation

Wu et al. (2022) addressed the secondary pollution problem of chemical reduction and the long bioremediation period for the soil around a chromium (Cr) salt plant in China by using calcium polysulfide (CPS) combined with biostimulation (adding nutrient solution with glucose and urea) to reduce and stabilize hexavalent chromium [Cr(VI)] in the soil (Figure 2D) [9]. The results showed that the combined effect of CPS and microbial nutrient solution was significantly better than that of reduction by CPS alone for Cr(VI)-contaminated soil. The experimental groups containing nutrient solution achieved a reduction rate of Cr(VI) exceeding 97%. With the participation of microorganisms, the Cr in the soil was transformed from highly toxic, mobile water-soluble, and exchangeable fractions to Fe-Mn oxide-bound and organic matter-bound fractions, which are relatively stable, as well as a less toxic carbonate-bound fraction, thereby reducing the environmental risks of Cr.

3.5. Responses of Soil Cadmium Desorption under Different Saline Environments and Its Controlling Factors

Zheng et al. (2021) conducted batch adsorption tests with eight soil samples and investigated the amount of Cd desorbed and the influence of different saline environments on soil Cd release (Figure 2E) [10]. The study found that increasing the concentration of salts, except for $NaNO_3$, significantly promoted Cd release ($R^2 > 0.9$, $p < 0.01$). The competitive adsorption of cations and the complexation by chloride ions, which are highly sensitive to changes in salt solution concentration, significantly impact the competitive desorption of Cd. Additionally, the results of the PCA analysis showed that the level of Cd release was mainly influenced by the soil particle size distribution, CEC, SIO, TOC content, and BET surface area. Among them, soil particle size had the greatest impact on Cd desorption. Therefore, the higher the proportion of clay in soils, the greater the Cd desorption level.

3.6. Remediation of Agricultural Soils with Long-Term Contamination of Arsenic and Copper in Two Chilean Mediterranean Areas

Mondaca et al. (2022) validated the remediation effects of several soil amendments, including diammonium phosphate (DP), iron sulfate (IS), ferrous phosphate (FP), calcium peroxide (CP), and organic matter (OM), in contaminated sandy and loamy soils under field conditions (Figure 2F) [11]. The study found that phosphate amendments (DP and FP) reduced the foliar arsenic (As) concentration in lettuce grown in both areas, while CP only reduced it in the sandy soils. Consequently, a diet based on lettuces grown in amended soils would result in a 30% reduction in As intake compared to unamended ones. The use of DP showed good efficacy in reducing As accumulation in lettuce, increasing productivity, and having low investment costs. However, caution should be taken due to potential soil acidification. On the other hand, FP exhibited good efficacy with no apparent side effects, and the investment required was slightly higher. This study identified FP as a promising compound that has not been studied before as a soil amendment. Despite high concentrations of copper (Cu) in soils and lettuce leaves, Cu phytotoxicity was not observed, which differed from similar studies conducted in growth chambers. In conclusion, soil amendments can contribute to productivity in agricultural soils with long-term contamination of arsenic and copper. This study provides valuable insights into improving agricultural productivity in central Chile, an important agricultural area, while also raising scientific questions.

3.7. Poultry Litter Biochar as a Gentle Soil Amendment in Multi-Contaminated Soil: Quality Evaluation on Nutrient Preservation and Contaminant Immobilization

Tsai et al. (2022) utilized poultry litter biochar (PLB) for the short-term remediation of a multi-contaminated soil containing chrome (Cr), copper (Cu), nickel (Ni), and zinc (Zn) (Figure 2G) [12]. The research findings indicated that PLB pyrolyzed at temperatures above 400 °C and applied at a weight ratio of 5% to the soil demonstrated the best performance. This is because it exhibited greater stability and less decomposition during incubation, in addition to increasing the availability of nutrients and decreasing the solubility of potentially toxic elements. The application of PLB in the soil can reduce potential environmental risks, aid in achieving and supporting sustainable soil management, and contribute to multiple sustainable development goals.

4. Organic Soil Pollution Will Be a Focal Point for the Agri-Environment in the Future and in the Long Term

Besides potentially toxic element pollution, organic contaminants (OCs) are another common pollutant in agriculture. A wide variety of organic pollutants exist, most of which are caused by human activities. Various organic pollutants are prevalent in agricultural soils across the globe. These pollutants not only adversely affect soil properties but also enter the food chain and pose a risk to human health. Organochlorine pesticides, polychlorinated biphenyls (PCBs), phthalates, polycyclic aromatic hydrocarbons (PAHs) and petroleum hydrocarbons (PHAHs) are common organic pollutants that commonly contaminate the agricultural environment during agricultural fertilization and industrial processes [13,14]. Therefore, it is crucial to reduce and eliminate organic pollutants and reduce the pollution already present in the environment. Numerous studies have been conducted on the remediation of organic pollutants, involving physical, chemical, and biological treatments. Among them, the latest development direction in agricultural remediation technology is the utilization of waste resources for treatment and environmental improvement. Some research in this Special Issue also focuses on the development of recyclable remediation materials, with the aim of enhancing their ecological friendliness, non-toxicity, biodegradability, and affordability for addressing agricultural organic pollution in the future.

4.1. Application of Cogon Grass (Imperata cylindrica) as Biosorbent in Diesel-Filter System for Oil Spill Removal

Khalid et al. (2021) investigated the use of Imperata cylindrica, commonly known as cogon grass (CG), as a natural sorbent for oil spill cleanup (Figure 3A) [15]. They examined the effects of temperature, time, packing density, and oil concentration on the efficiency of oil absorption using the one-factor-at-a-time (OFAT) and response surface methodology (RSM) approaches. The study found that under the conditions of 128 °C temperature and 36 (v/v)% oil concentration, CG demonstrated an efficiency of 93.54% in absorbing 22.45 mL of oil, while keeping the packing density and time constant at 30 min and 0.20 g/cm^3, respectively. Compared to other natural sorbents, CG's oil/water selectivity properties make it a cost-effective method with high potential for combating oil spills.

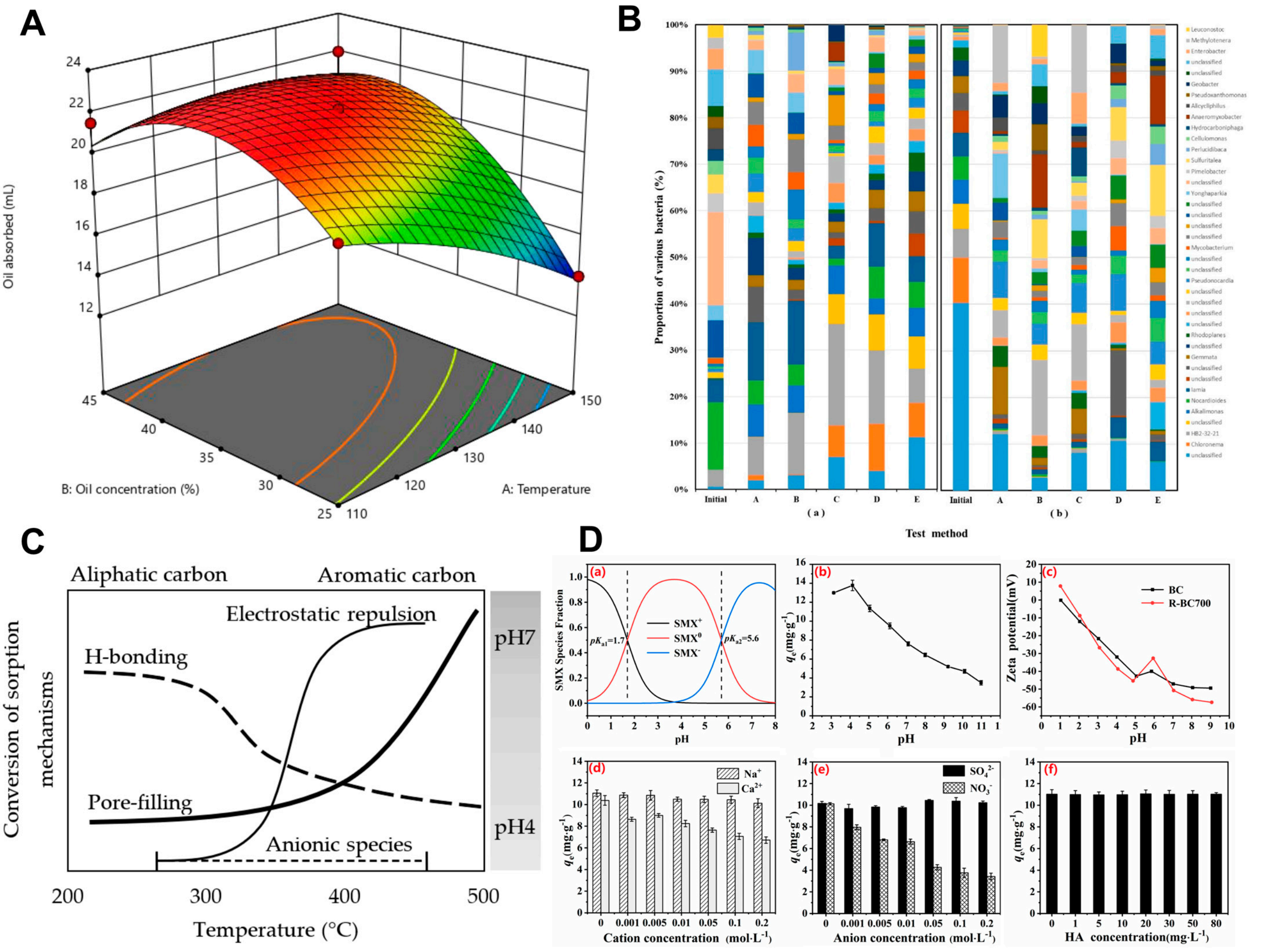

Figure 3. (**A**) Three-dimensional contour plots generated by Design Expert (Stat Ease, Inc.) of the significantly interacting model terms A: Temperature (°C) and B: Oil concentration (v/v)% [15]. (**B**) Changes in bacterial phases in different bioremediation test groups. (**a**) for TPH conc. 3000 mg kg^{-1}; (**b**) for TPH conc. 8000 mg kg^{-1} [16]. (**C**) The concept of possible mechanisms for SMX sorption by carbon phases (aliphatic and aromatic carbons) from lignocellulose pyrolysis [17]. (**D**) (**a**) Species distribution diagram for SMX; (**b**) effects of initial pH on adsorption of SMX on R-BC700 (dosage of adsorbent = 0.5 $\mathrm{g{\cdot}L^{-1}}$, SMX concentration = 15 $\mathrm{mg{\cdot}L^{-1}}$, shaking speed = 180 rpm; t = 24 h; T = 25 °C, initial pH = 3–11); (**c**) zeta potential of BC and R-BC700 (dosage of adsorbent = 0.5 $\mathrm{g{\cdot}L^{-1}}$, initial pH = 1–10); effects of (**d**) cations, (**e**) anions and (**f**) HA on the adsorption of SMX on R-BC700. (Dosage of adsorbent = 0.5 $\mathrm{g{\cdot}L^{-1}}$, SMX concentration = 15 $\mathrm{mg{\cdot}L^{-1}}$, shaking speed = 180 rpm; t = 24 h; T = 25 °C, initial pH = 5.3) [18].

4.2. Green Remediation Technology for Total Petroleum Hydrocarbon-Contaminated Soil

In order to enhance the bioremediation efficiency of petroleum-contaminated soil, Lin et al. (2022) selected five test groups for comparison in this study, including native bacteria, *Acinetobacter venetianus* (A.V.), *Vetiveria zizanioides* L., and combinations of *Vetiveria zizanioides* L. with *Acinetobacter venetianus* and biochar (Figure 3B) [16]. The results showed that after six months of bioremediation, there was no significant difference in the removal efficiency of total petroleum hydrocarbons (TPH) between the native bacteria group and the A.V. bacteria group, with approximately 50–70% of degradable TPH being removed. The addition of *Vetiveria zizanioides* L. phytoremediation increased the TPH removal efficiency by 18.1–29%. Cultivating *Vetiveria zizanioides* L. not only stabilized the pH and conductivity of the soil but also increased the abundance of soil bacteria. It was suggested that a combination of native bacteria and *Vetiveria zizanioides* L. planting could be used for bioremediation. Although the addition of biochar improved the remediation effect of *Vetiveria zizanioides* L., it also increased soil conductivity and reduced soil bacterial abundance. Therefore, it is recommended that the biochar conductivity be reduced prior to the application of biochar-assisted phytoremediation to improve the efficiency of co-remediation.

4.3. The Sorption of Sulfamethoxazole by Aliphatic and Aromatic Carbons from Lignocellulose Pyrolysis

Chu et al. (2022) employed various techniques, including thermogravimetric analysis and 13C nuclear magnetic resonance, to investigate the properties of biochars influenced by the pyrolysis of cellulose and lignin in the feedstock (Figure 3C) [17]. Cellulose-derived biochars exhibited a higher abundance of functional groups compared to lignin-derived biochars, indicating the better preservation of groups during carbonization. Cellulose-derived biochars also showed increased sorption of sulfamethoxazole (SMX) due to hydrogen bond interactions. The sorption affinity gradually decreased with the conversion from aliphatic to aromatic carbon, but the enhanced specific surface area (SSA) subsequently promoted SMX sorption, as evidenced by increased SSA-N_2 and SSA-CO_2 from 350 to 450 °C. The decreasing Kd/SSA-N_2 values with increasing pH implied a reduction in sorption per unit area, attributed to enhanced electrostatic repulsion. This research elucidated the impact of carbon phases resulting from the thermal conversion of lignocellulose on the sorption performance of sulfonamide antibiotics, providing insights for the structural design of carbonaceous adsorbents for ionizable antibiotic removal.

4.4. The Effects of Chemical Oxidation and High-Temperature Reduction on Surface Functional Groups and the Adsorption Performance of Biochar for Sulfamethoxazole Adsorption

Hou et al. (2022) prepared oxidation-modified biochar (O-BC) and reduction-modified biochar (R-BCX) and investigated their adsorption mechanism for sulfamethoxazole (SMX) in water (Figure 3D) [18]. The results showed that both O-BC and R-BCX exhibited a significant improvement in the adsorption capacity for SMX. By combining the characterization results of the composition and chemical structure of biochar before and after modification, it was demonstrated that functional groups significantly influenced the adsorption capacity of biochar. The C=O and C=C functional groups, resulting in π–π interactions, facilitated the adsorption of SMX, while the C-O functional group hindered the adsorption of SMX due to steric hindrance and negative surface charge. Additionally, the hydrophobic effect of the biochar also contributed to the adsorption mechanism. This study provides an important theoretical basis for understanding the adsorption mechanism of organic matter on carbon materials. Further research should be conducted to explore the practical application of R-BC700 and investigate the specific contribution of each adsorption mechanism of the adsorbent for organic adsorption.

5. Assessment of Agro-Environmental Ecosystems and Crops Is the Ultimate Key to Agricultural Development

The functional assessment and improvement of soil ecosystems is an important issue in current environmental protection and sustainable agricultural development. In order to better protect soil resources and increase agricultural productivity, we need to assess and improve the functioning of soil ecosystems. Firstly, functional assessment aims to understand the structure, function and dynamic changes of soil ecosystems under different environmental conditions, and to provide a scientific assessment of soil quality through comprehensive analyses of its biodiversity, soil texture, moisture status and other aspects. This process helps us to identify potential problems facing soil ecosystems and provides a basis for effective improvement measures. For the assessment of soil ecosystems, the current use of modern technology, such as the Internet of Things (IoT) and big data, allows for real-time monitoring and precise regulation of soil physical and chemical properties and pollution. Meanwhile, artificial intelligence technology is gradually being applied in agro-ecological assessment to build a model of smart agriculture. The studies in this Special Issue not only assess the current status of soil contamination and crop suitability from a temporal and spatial perspective, but also assess the genetic impact of soil contamination on food crops from a macro and micro perspective.

5.1. Assessment of Soil Contamination Using GIS and Multi-Variate Analysis: A Case Study in El-Minia Governorate, Egypt

Hammam et al. (2022) assessed the soil contamination by potentially toxic elements in the area adjacent to the El-Moheet drainage on the west side of the Nile River, El-Minia governorate, Egypt (Figure 4A) [19]. This area is considered one of the most important obstacles to sustainable development and food security. They randomly selected 60 soil locations and six potentially toxic elements (Cr, Co, Cu, Cd, Pb, and Zn) to generate their spatial pattern maps using ordinary Kriging (OK). Principal component analysis (PCA) and contamination factors (CF) were applied to evaluate the soil contamination levels in the study area. The study showed that the semivariogram models were effective in predicting the spatial distribution maps of potentially toxic elements in the study area. The results revealed three contamination degrees (moderate, considerable, and very high) for the potentially toxic elements. Approximately 70.7% of the study area exhibited considerable contamination, which poses a dangerous threat to the ecosystems in the area. All pollution levels exceeded the threshold of their average concentration in the surface earth crust and parent material. The current findings demonstrate the effects of human negative practices on the land of the study area, such as the use of polluted water for irrigation and the excessive use of mineral fertilizers and pesticides. The study recommends the implementation of agricultural management laws to reduce these negative practices and mitigate environmental pollution.

5.2. Suitability Evaluation of Tea Cultivation Using Machine Learning Technique at Town and Village Scales

Xing et al. (2022) selected Xinming Township in Huangshan City, Anhui Province, as the study area (Figure 4B) [20]. They proposed a machine learning-based tea cultivation suitability evaluation model by comparing logistic regression (LR), extreme gradient boosting (XGBoost), adaptive boosting (AdaBoost), gradient boosting decision tree (GBDT), random forest (RF), Gaussian Naïve Bayes (GNB), and multilayer perceptron (MLP) to calculate the weight accuracy of the evaluation factors. They then selected 12 factors, including climate, soil, terrain, and ecological economy factors, using the RF with the highest accuracy to calculate the evaluation factor weights and obtained the suitability evaluation results. The results showed that the highly suitable area, moderately suitable area, generally suitable area, and unsuitable area land categories for tea cultivation were 14.13%, 27.25%, 32.46%, and 26.16%, respectively. Combined with field research, the highly suitable areas were mainly distributed in the northwest of Xinming Town, which aligns with the distribution of tea cultivation at the Xinming township level. The results provide a scientific reference to support land allocation decisions for tea cultivation and sustainable green agricultural development at the town and village scales.

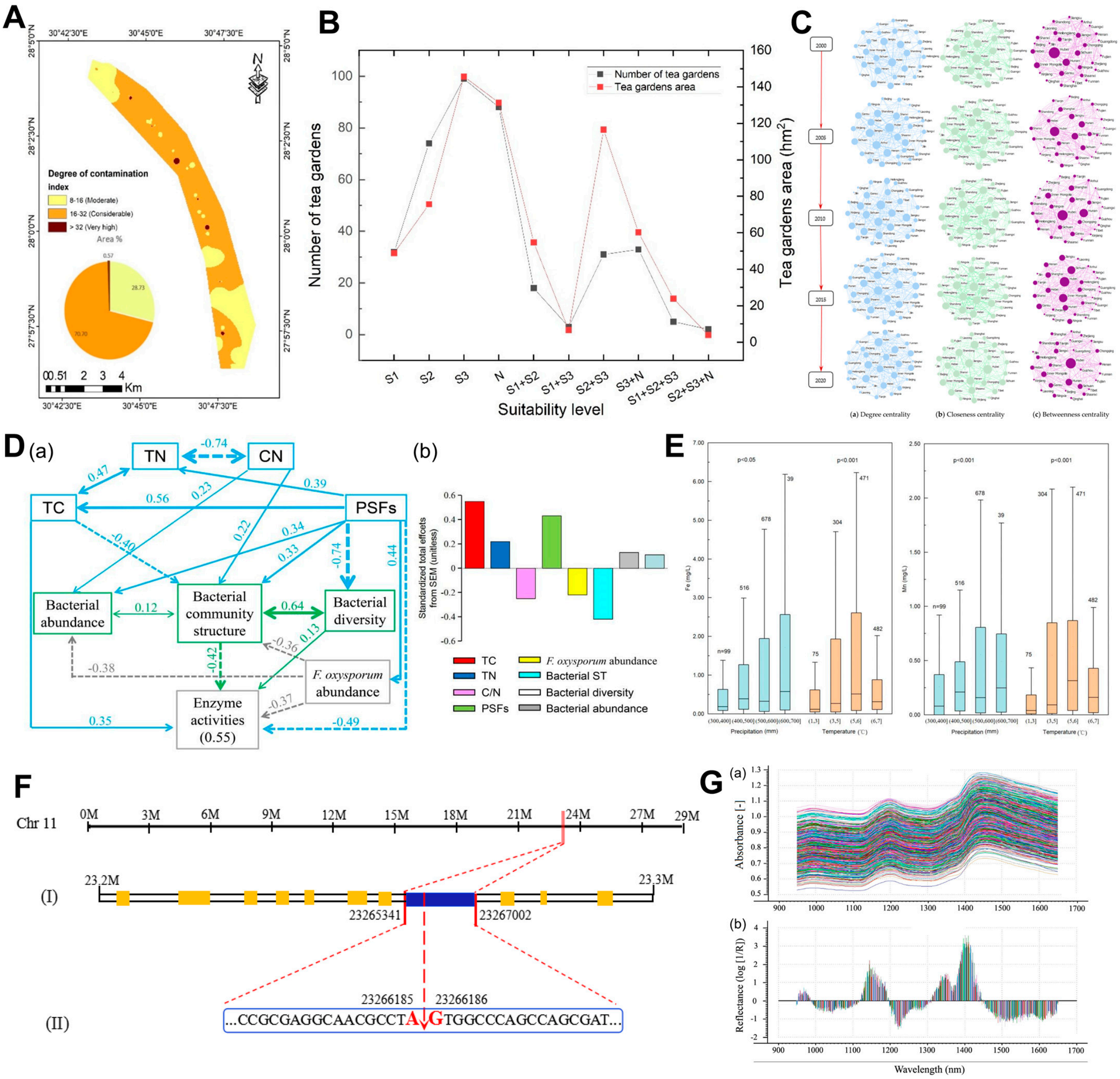

Figure 4. (**A**) Map of degree of contamination in the study area [19]. (**B**) Distribution diagram of suitability evaluation results of existing tea gardens, where S1, S2, S3, and N represent highly suitable area, moderately suitable area, generally suitable area, and unsuitable land area [20]. (**C**) Individual network characteristics [21]. (**D**) Structural equation modeling (SEM) shows the direct and indirect effects of the bacterial diversity, abundances and community structure on enzyme activities in the soils, in panel (**a**). Panel (**b**) shows the standardized total effects of each individual driver [22]. The blue, green and gray arrows represent the paths of the physiochemical factors, bacterial diversity, abundance and community structure, and the F. oxysporum abundance that affects the enzyme activities, respectively. Numbers following the included variables show the explained percentage of its variance by its predictors. The numbers on the arrows are the standardized path coefficients. (**E**) Fe and Mn distributions in groundwater from areas with different climates. 'Precipitation' and 'temperature' mean annual meteorological precipitation and annual average meteorological temperature, respectively, in 2015 [23]. (**F**) Accurate insertion location positioning of m-1a strain. Chr 11 = chromosome 11; M = Mega base pair [24]. (**G**) Analysis of single maize kernels by NIR spectral analysis. Example of the direct NIR spectra (**a**); raw NIR spectrum data treated by SNV and SG first derivative (**b**). The horizontal axis shows the wavelength and the vertical axis shows the reflectance (log [1/R]) [25].

5.3. Spatial Correlation Evolution and Driving Factors of Wheat Production in China Based on Social Network Analysis

Lv et al. (2023) utilized an improved gravity model to calculate the spatial correlation of inter-provincial wheat production in China based on panel data from 2000 to 2020 (Figure 4C) [21]. They analyzed the spatiotemporal evolution characteristics and driving factors of the spatial correlation network using social network analysis (SNA) and a quadratic assignment procedure (QAP). The results showed that the spatial correlation of inter-provincial wheat production exhibited an initial increase followed by a decrease. The network density increased from its lowest value in 2000 to its maximum value in 2016 and then fluctuated. The spatial correlation network displayed a "core-periphery" distribution pattern for major wheat-producing areas (such as Jiangsu, Anhui, and Hubei) and non-major wheat-producing areas (such as Jilin, Qinghai, Guangxi, and Beijing), with varying roles over time and space. The study also found that interactions between internal natural conditions and external socioeconomic factors played a significant role in the construction of the spatial correlation network for wheat production, with factors such as geographical adjacency, land resources, temperature, and sunlight hours having a substantial impact. This study provides valuable insights for promoting cooperative cross-regional wheat production and formulating specific policies for wheat and other grain production.

5.4. Investigating the Responses of Microbial Communities to Banana Fusarium Wilt in Suppressive and Conducive Soils Based on Soil Particle-Size Differentiation

Wang et al. (2022) contrasted the different assemblages of microbial communities between suppressive and conducive soils by differentiating soil particle-size fractions (PSFs) (Figure 4D) [22]. They further examined the direct and indirect interactive associations among soil biotic and abiotic factors using samples from two continuous banana cropping systems. Significant differences were observed in the composition of PSFs, biological traits (microbial communities and enzyme patterns), and physiochemical parameters between suppressive and conducive soils across different soil fractions. For example, suppressive soils exhibited higher nutrient contents, fungal abundance and diversity, and enzyme activities compared to conducive soils, and the extent of these differences varied among fractions of different sizes. Additionally, there were substantial variations in the microbial taxonomic composition between disease-suppressive and disease-conducive soils. Key microbiology communities, such as *Actinobacteria*, *Firmicutes*, *Bacteroidetes*, *Proteobacteria*, and *Ascomycota*, showed significant differences in relative abundance, particularly for antagonistic microorganisms (e.g., *Streptomyces*, *Pseudomonas*, *Trichoderma*), across various soil fractions. Structural equation modeling (SEM) revealed that the complex associations among soil PSFs, physiochemical parameters, and microbial communities were mediated by multiple pathways, which in turn influenced soil enzyme activities and potentially affected the suppressiveness of the soil. These findings highlight the crucial role of resident microbial communities in specific soil particles in the development of soil suppressiveness against banana *Fusarium* wilt disease.

5.5. Elevated Fe and Mn Concentrations in Groundwater in the Songnen Plain, Northeast China, and the Factors and Mechanisms Involved

Zhai et al. (2021) determined the distribution of iron (Fe) and manganese (Mn) concentrations in groundwater in the Songnen Plain, northeast China, and investigated the factors and mechanisms involved in causing the elevated concentrations (Figure 4E) [23]. Chemical and statistical analyses revealed significant correlations between Fe and Mn concentrations in groundwater and climate parameters (precipitation and temperature), surface features (altitude, distance from a river, soil type, soil texture, and land use type), and hydro-geochemical characteristics (chemical oxygen demand and concentrations of NH_4^+, NO_3^-, and P). Specifically, areas with paddy fields and water bodies exhibited higher Fe and Mn concentrations in groundwater compared to other land use types. The distribution of Fe and Mn concentrations in groundwater in the Songnen Plain is influenced by the presence of Fe/Mn mineral-rich strata and soil with abundant organic matter acting as sources of Fe and Mn, as well as the reductive environment in lower terrain and areas containing water bodies that promote Fe and Mn dissolution in groundwater. Inputs of pollutants from agricultural activities, such as COD_{Mn} and NH_4^+, have contributed to the increase in Fe and Mn concentrations in groundwater. It is crucial to determine how to prevent further increases in Fe and Mn concentrations in groundwater and improve the current situation.

5.6. Functional Analysis and Precise Location of m-1a in Rice

Plant genetic engineering can also help plants better resist soil pollution and stress. Dong et al. (2022) obtained rice with a m-1a grain through Agrobacterium-mediated genetic transformation (transfer DNA) (Figure 4F) [24]. It was found that the phenotype underwent significant changes, with the grains becoming chalky, the starch particles loosely arranged, the proteasomes reduced, and the amylose significantly decreased. These results can provide material for exploring new T-DNA insertion sites and serve as a theoretical basis for molecular breeding of rice, thereby improving grain yield and quality.

5.7. Applicability of Near Infrared Reflectance Spectroscopy to Predict Amylose Contents of Single-Grain Maize

Utilizing rapid spectral detection methods to identify grain crops is an effective means of assessing food safety after soil remediation. Dong et al. (2021) utilized near infrared reflectance spectroscopy (NIRS) and reference data to determine the amylose contents of individual maize seeds, enabling the rapid and effective selection of seeds with desired traits (Figure 4G) [25]. This approach assists researchers in determining the quality of individual maize grains.

6. Perspectives

Environmental pollution caused by the uncontrolled use of anthropogenic or natural resources has been a global problem that poses a threat to agro-ecology and food security. Maintaining a healthy agro-ecosystem is crucial for ensuring a sustainable future. Although this Special Issue focuses on the current status of environmental remediation and sustainable agricultural development, it also helps assess the current state of agro-environmental pollution at both micro and macro levels. Furthermore, it explores the latest developments in remediation technologies to mitigate environmental pollution. However, it is important to note that the problem of environmental pollution has not yet been completely resolved.

A variety of innovative environmental mitigation/remediation technologies are reviewed in this Special Issue, including physical/chemical remediation, multi-component adsorbents, and bioremediation technologies. However, there are still several research gaps that need to be addressed. Therefore, future research should focus on expanding interdisciplinary communication and cooperation, integrating theories and methods from biology, geography, environmental science, agronomy, and other multidisciplinary disciplines. It is also important to strengthen technology R&D and application, particularly in the field of intelligent and precise soil monitoring technologies and methods. Moreover, policy guidance, enterprise support, and public participation should be strengthened to promote the protection and sustainable development of the global agro-environment, drawing on international advanced experience and technologies.

In conclusion, agro-environmental protection is a matter of urgency and global food security has long been in need of attention. In future research, we look forward to the emergence of more technologies and strategies to improve the global agro-environment. These technologies and strategies should focus on increasing agricultural productivity while reducing negative impacts on the environment, promoting soil health and restoring biodiversity, reducing pollution and overuse of water resources by agricultural activities, and strengthening climate resilience in response to worsening climate change. We believe that only through global cooperation and continued research and innovation can we achieve sustainable agricultural development and ensure food security and ecological balance for future generations.

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