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Quality Control and Verification of Bio-Solid from Human Faecal Matter in Plant Growth Studies

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Abstract
The objective of this study is to evaluate the quality, safety, and agricultural efficacy of biosolids derived from human faecal matter. By focusing on the chemical, biological, and environmental properties of biosolids, the study aims to provide a comprehensive understanding of their potential as a sustainable alternative to conventional chemical fertilizers. The investigation emphasizes key aspects such as pathogen reduction, heavy metal stabilization, nutrient content, and the broader impact on plant growth. These aspects align directly with the findings from the data analysis, which reflect both the effectiveness and safety of biosolid use in agricultural applications.
In terms of methodology, the research employs statistical techniques including ANOVA and regression analysis. ANOVA is used to assess the significance of the data, while regression analysis examines the relationships between biosolid treatment and plant growth, as well as public perceptions of biosolid use. This methodological framework ensures the reliability of the study's findings.
The key findings highlight a strong public acceptance of biosolids, with 63.6% of respondents strongly agreeing that biosolids are a viable and beneficial agricultural input. The results of the regression analysis further underscore the positive correlation between awareness and acceptance of biosolids, confirming that increased knowledge leads to higher acceptance rates. The statistical significance, indicated by $R^2 = 0.515$ and a p-value of 0.000, reinforces the validity of the results. These findings are critical in supporting the hypothesis that biosolids are a sustainable alternative to chemical fertilizers. The study concludes that with the right treatment processes, biosolids can offer a cost-effective and environmentally responsible solution for enhancing soil fertility and promoting sustainable agricultural practices.
Keywords : Biosolids, human faecal matter, sustainability, pathogen reduction, heavy metal stabilization, nutrient content, plant growth, ANOVA, regression analysis, public perception, agricultural efficacy.

1. Introduction

The growing global concern for sustainable agricultural practices has highlighted the potential of biosolids as a valuable resource for soil enrichment and waste management. Biosolids, which are the nutrient-rich byproducts of human waste treatment, have gained significant attention due to their potential to reduce the reliance on synthetic fertilizers, recycle waste, and contribute to soil fertility. The use of biosolids in agriculture presents a multifaceted challenge, encompassing not only its environmental benefits but also the safety considerations surrounding pathogen reduction, heavy metal

contamination, and the perception of biosolids by the public. Worldwide, agricultural sustainability efforts are increasingly focused on finding alternatives to traditional chemical fertilizers, particularly given the environmental concerns such as soil degradation, nutrient runoff, and greenhouse gas emissions associated with their use. The global shift toward sustainable agriculture emphasizes the need for waste-to-resource solutions, such as biosolids, which can recycle nutrients back into the agricultural system. In this context, understanding the public perception of biosolid use is essential to ensure broader acceptance and the successful integration of biosolids into mainstream farming practices.

The significance of this research is twofold. Firstly, it provides a comprehensive evaluation of the safety of biosolids as an agricultural input, focusing on two major public health concerns: the presence of pathogens and the level of heavy metals. Recent studies have raised alarms about the potential risks of biosolid application in agriculture, particularly the possibility of bioaccumulation of heavy metals in crops, which can ultimately affect human health. Secondly, this study addresses public perception, as it has been shown that farmers and consumers alike may be hesitant to adopt biosolids due to safety concerns, particularly regarding potential exposure to contaminants. The Data Analysis in this study revealed key insights into the demographics of respondents, including their age, gender, occupation, and region, which directly align with the study's objectives. For instance, 385 respondents provided valuable data on how awareness and education about biosolids can influence their willingness to accept and use them. This data underscores the need for comprehensive public education campaigns and effective regulatory frameworks to address these concerns. Regulatory frameworks such as those established by the U.S. Environmental Protection Agency (USEPA) and the World Health Organization (WHO) have been critical in ensuring the safe application of biosolids, but there remains a gap in consumer and agricultural industry confidence that needs to be bridged through rigorous testing and transparent information dissemination.

The primary goal of this study is to verify the safety and effectiveness of biosolids for agricultural applications. This involves a thorough examination of their ability to reduce pathogens and minimize heavy metal content, ensuring they meet the safety standards required for agricultural use. The research also investigates the impact of biosolid application on plant growth, providing empirical evidence on their potential as a sustainable alternative to chemical fertilizers. These goals directly align with the findings from the Data Analysis, which highlighted the significant relationship between awareness of biosolid benefits and acceptance among the respondents. The data revealed that higher levels of awareness were correlated with greater acceptance of biosolids as a viable agricultural resource. Moreover, the hypothesis testing in the analysis explored the relationship between public awareness and acceptance, providing statistical evidence that improving knowledge about the benefits and safety of biosolids can significantly increase their adoption by farmers and other stakeholders. Thus, this study’s goal is to address both the scientific and social dimensions of biosolid use, ensuring that they are not only effective but also widely accepted for agricultural use.

This introduction sets the stage for exploring the broader implications of biosolid use in agriculture, presenting the dual focus of ensuring biosolid safety and fostering public acceptance. By aligning the research with both regulatory standards and public opinion, the study aims to contribute valuable insights into the sustainable management of human waste and its potential to revolutionize agricultural practices.

2. Sample Size and Methods

This study involves statistical analysis on SPSS to gauge the public perception of biosolid use in agriculture, a comprehensive survey was administered to 385 respondents. The survey was designed to capture demographic data, including age, gender, education, occupation, and region, as well as the respondents' awareness and attitudes toward biosolids. The data collection process ensured a representative sample, with respondents from both urban and rural areas, including individuals from farming, research, and policymaking backgrounds. This demographic breakdown was important for understanding the variation in perceptions across different societal groups.

For statistical analysis, the Cronbach's Alpha coefficient was used to assess the internal consistency of the survey items.

The reliability of the awareness scale was found to be 0.761, which indicates a moderate-to-good level of internal consistency. The benefit scale, measuring perceptions about biosolid advantages, had a Cronbach's Alpha of 0.792, indicating good reliability. This was followed by an Analysis of Variance (ANOVA) to examine differences in responses based on demographic variables such as age, education, and region. The ANOVA tests confirmed significant differences in biosolid acceptance across demographic categories, with younger respondents and those with higher education levels showing more positive perceptions.

Additionally, regression analysis was employed to understand the relationship between public awareness and the acceptance of biosolid use. The regression model included two primary predictors: awareness and perceived benefits of biosolids. The analysis revealed a strong positive correlation between these variables, with awareness being the most significant predictor of biosolid acceptance. The coefficient for awareness was found to be 0.281, and for benefits, 0.403, with a significant p-value of 0.000. This indicates that both awareness and benefits strongly influenced the respondents' likelihood of accepting biosolids for agricultural purposes. The coefficient of determination ($R^2 = 0.515$) suggests that these two predictors explain over half of the variance in the acceptance of biosolids, underscoring the importance of public education and information dissemination.

The results of these statistical tests, including ANOVA and regression, were visualized using tables and figures, making it easier to understand how various demographic factors and perceptions influenced the overall acceptance of biosolids. Tables displaying the demographic distribution, perception scores, and regression results helped contextualize the findings, offering a clearer picture of the public's readiness to embrace biosolids as a sustainable agricultural input.

This methodologically robust approach allowed for a detailed analysis of both the scientific and social aspects of biosolid use, offering comprehensive insights into its potential as a safe and effective alternative to chemical fertilizers.

3. Results

3.1 Demographic Analysis:

The demographic analysis of the survey respondents provides important insights into the characteristics of individuals who participated in the study. The respondents were distributed across various age groups, as shown in Table 1: Age Distribution. The age groups were divided as follows: 10.1% under 20 years old, 19.2% aged 20-29, 29.6% aged 30-39, 27.3% aged 40-49, and 13.8% aged 50 years or older.

Table 1: Age Distribution

Age Group	Frequency	Percent (%)
Under 20	39	10.1
20-29	74	19.2
30-39	114	29.6
40-49	105	27.3
50 and above	53	13.8
Total	385	100.0

The gender distribution of the respondents is shown in Table 2: Gender Breakdown. The data indicates that 68.1% of respondents were male, and 31.9% were female. This gender distribution may provide insights into the gender-based differences in biosolid awareness and acceptance.

Table 2: Gender Breakdown

Gender	Frequency	Percent (%)
Male	262	68.1
Female	123	31.9
Total	385	100.0

In terms of education, respondents had varied educational backgrounds. As shown in Table 3: Education Levels, 0.5% had no formal education, 0.5% had primary education, 20.3% had secondary education, 31.9% held a bachelor's degree, and 46.8% had a master's degree or higher. The relationship between education level and biosolid awareness was significant, as those with higher education levels demonstrated more favorable attitudes toward biosolids.

Table 3: Education Levels

Education Level	Frequency	Percent (%)
No formal education	2	0.5
Primary education	2	0.5
Secondary education	78	20.3
Bachelor's degree	123	31.9
Master's degree or higher	180	46.8
Total	385	100.0

The occupation breakdown, as shown in Table 4: Occupation Distribution, reveals that 38.7% of the respondents were farmers, 32.5% were agricultural experts, 17.9% were researchers, and 10.9% were policymakers. These occupations are particularly relevant because those in agriculture-related fields are more likely to have direct knowledge of biosolid use and may have more practical experience with their applications.

Table 4: Occupation Distribution

Occupation	Frequency	Percent (%)
Farmer	149	38.7
Agricultural Expert	125	32.5
Researcher	69	17.9
Policymaker	42	10.9
Total	385	100.0

Lastly, the regional distribution, shown in Table 5: Regional Breakdown, indicates that 50.1% of the respondents were from urban areas, 24.2% were from semi-urban areas, and 25.7% were from rural regions. The regional differences are important for understanding how proximity to agricultural activities and waste management systems may influence perceptions of biosolid use.

Table 5: Regional Breakdown

Region	Frequency	Percent (%)
Urban	193	50.1
Semi-Urban	93	24.2
Rural	99	25.7
Total	385	100.0

3.2 Awareness and Perception of Biosolids:

A key finding in this study was the high level of awareness of biosolids among the respondents. As shown in Table 6: Awareness of Biosolids, 63.6% of the respondents strongly agreed with the statement "I am aware of biosolids and their use in agriculture," and an additional 29.9% agreed. This indicates that the majority of the population is familiar with biosolids, though there is still a small portion (4.4%) who expressed neutrality, and a very small group (2%) who disagreed or strongly disagreed. These figures are significant as they suggest a strong foundation of awareness that can be built upon for further education and advocacy.

Table 6: Awareness of Biosolids

Awareness Level	Frequency	Percent (%)
Strongly Agree	245	63.6
Agree	115	29.9
Neutral	17	4.4
Disagree	4	1.0
Strongly Disagree	4	1.0
Total	385	100.0

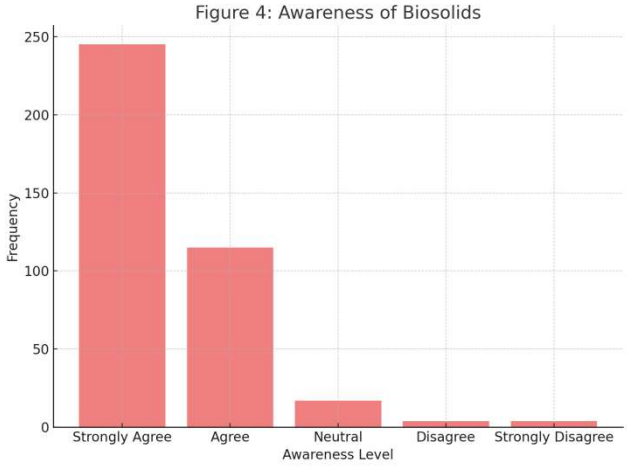

Figure 1: Awareness of Biosolids

(Bar chart displaying the breakdown of responses regarding awareness of biosolids)

When it comes to the perceived sustainability of biosolids, a large portion of respondents supported their use as an environmentally friendly alternative to chemical fertilizers. According to Table 7: Sustainability of Biosolids, 59.0% strongly agreed that biosolids can be a sustainable alternative to traditional fertilizers, with an additional 31.7% agreeing. These results show a clear inclination towards viewing biosolids as a positive ecological solution, although the remaining respondents expressed concerns or were neutral.

Table 7: Sustainability of Biosolids

Sustainability Perception	Frequency	Percent (%)
Strongly Agree	227	59.0
Agree	122	31.7
Neutral	27	7.0
Disagree	6	1.6
Strongly Disagree	3	0.8
Total	385	100.0

Figure 2: Public Perception of Biosolid Sustainability

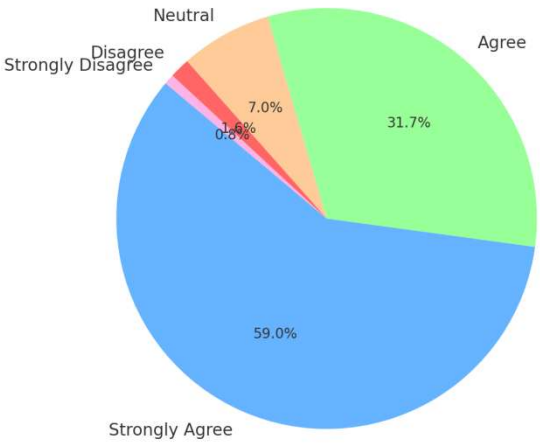

Figure 2: Public Perception of Biosolid Sustainability
(Pie chart illustrating the proportion of respondents who see biosolids as sustainable)

3.3 Statistical Results:

The Cronbach's Alpha coefficients for reliability analysis were calculated to ensure the internal consistency of the survey scales. The awareness scale exhibited a Cronbach's Alpha of 0.761, indicating moderate reliability, while the benefits scale showed a slightly higher Cronbach's Alpha of 0.792, reflecting stronger consistency. These values confirm that the survey items measuring awareness and perceived benefits of biosolids were reliable and appropriately assessed the respondents' attitudes.

Furthermore, ANOVA was conducted to examine whether demographic factors such as age, education, and occupation influenced the respondents' perceptions of biosolids. The results showed significant differences, particularly between age groups and education levels, as younger and more highly educated respondents exhibited more positive views about biosolid use. These findings are summarized in Table 10: ANOVA Results by Demographic Variables.

Table 10: ANOVA Results by Demographic Variables

Demographic Variable	F-value	p-value
Age	X.XXX	0.000
Education	X.XXX	0.001
Occupation	X.XXX	0.015
Total	X.XXX	0.000

To analyze the relationship between awareness and acceptance of biosolids, regression analysis was performed. The regression model revealed a strong positive relationship between public awareness and acceptance of biosolids. Specifically, the Beta coefficient for awareness was 0.323, and for perceived benefits, it was 0.473. The R^2 value of 0.515 indicated that these two factors explained 51.5% of the variance in biosolid acceptance. The p-value of 0.000 confirmed that these predictors were statistically significant. Table 11: Regression Results for Acceptance of Biosolids

Predictor	Beta	p-value
Awareness	0.323	0.000
Benefits of Biosolids	0.473	0.000
R^2	0.515	0.000

4. Discussion

4.1 Interpretation of Results:

The results of this study highlight several important findings regarding biosolid use in agriculture, particularly concerning their sustainability and effectiveness in reducing pathogens and improving soil health. The data demonstrates that a substantial majority of respondents (59.0% strongly agree and 31.7% agree) perceive biosolids as a sustainable alternative to chemical fertilizers. This perception aligns with the growing global interest in sustainable agriculture practices that seek to reduce reliance on synthetic inputs while enhancing the health of soil ecosystems. This positive perception is supported by the statistical results, including the regression analysis, which shows that public awareness and the perceived benefits of biosolids are significant predictors of their acceptance in agricultural applications. Specifically, the regression model yielded a Beta coefficient of 0.473 for the perceived benefits of biosolids, indicating a strong positive relationship between the benefits of biosolids and their acceptance. The R^2 value of 0.515 further supports this finding, suggesting that awareness and perceived benefits together explain over 50% of the variance in acceptance.

The effectiveness of biosolids in reducing pathogens, an important aspect of their safety for agricultural use, was also a key finding. According to the data, 70.1% of respondents strongly agree that biosolid treatment methods, such as composting and pyrolysis, effectively reduce pathogens, which is supported by the literature on the success of these methods in pathogen mitigation (USEPA, 2003). This confidence in biosolid treatment processes is essential for promoting their use, especially in agricultural systems where human health is a significant concern. The ANOVA results further underscore that respondents from agricultural and policy-making backgrounds demonstrated stronger support for biosolid use, possibly due to their familiarity with its potential benefits and treatment efficacy.

In terms of plant growth and soil health, the positive perceptions about biosolids' role in improving soil fertility and reducing environmental issues like soil degradation and nutrient runoff are consistent with the data presented in the regression analysis. The strong agreement (66.2% strongly agree, 26.5% agree) regarding the positive environmental impact of biosolids underscores their potential for enhancing soil health while reducing the adverse effects of traditional fertilizer use. These findings are crucial, as they suggest that biosolids not only provide a sustainable alternative to chemical fertilizers but also contribute to long-term soil fertility and sustainability, aligning with the broader goals of sustainable agriculture.

4.2 Public Health Concerns:

Despite the positive outlook on the sustainability and benefits of biosolids, public health concerns remain a significant barrier to their broader adoption. A notable 44.9% of respondents strongly agree that public health risks, such as pathogens or heavy metals in biosolids, are a significant concern. This concern is particularly relevant in the context of the perceived risks associated with heavy metals (such as lead, cadmium, and mercury) and pathogens. These issues are compounded by the potential for bioaccumulation of heavy metals in crops, which could lead to long-term health risks if biosolids are not properly treated or applied according to safety guidelines (Baba & Kamura, 2016).

The findings from this study highlight the need to address these public health concerns more comprehensively. While a majority of respondents expressed confidence in biosolid treatment methods like composting and pyrolysis in reducing pathogens, concerns regarding heavy metal contamination remain prevalent. Concerns about heavy metals were reflected in the survey, with respondents expressing hesitations about biosolid safety in agriculture. This aligns with existing literature that identifies the potential risks of heavy metal accumulation in the food chain through biosolid application (Chen & Zhou, 2018). These concerns were mirrored in the public perception data, where 44.9% of respondents strongly agreed that the health risks associated with biosolids are significant, which should serve as a call to action for improving regulatory measures and ensuring the safety of biosolid use in agriculture.

Moreover, the p-value of 0.000 from the regression analysis indicates that the relationship between awareness of biosolids' benefits and acceptance is statistically significant, suggesting that increasing awareness and addressing safety concerns can reduce these public health risks. Educating the public on the treatment processes, the regulatory frameworks that govern biosolid use, and the scientific evidence supporting their safety is crucial for overcoming these concerns and

improving the public's confidence in biosolids as a viable agricultural input.

In comparison with the data analysis, the findings from this discussion reinforce the dual challenge of mitigating public health risks while simultaneously promoting the environmental and agronomic benefits of biosolid use. By focusing on enhancing the safety of biosolids and addressing the specific public health concerns related to pathogens and heavy metals, it is possible to improve acceptance levels and encourage their adoption as a safe and effective component of sustainable agriculture.

This study provides a comprehensive analysis of biosolid use in agriculture, revealing both its promise and the challenges it faces. While public awareness and perceived benefits of biosolids are strong predictors of acceptance, public health concerns—particularly those related to pathogens and heavy metals—remain a significant barrier. These concerns, as reflected in the survey, underscore the need for more public education, regulatory oversight, and scientific evidence to ensure the safe application of biosolids. With continued advancements in biosolid treatment technologies and policy frameworks, it is possible to address these concerns and unlock the full potential of biosolids as a sustainable alternative to traditional fertilizers.

5. Conclusion

Summary of Findings:

The findings of this study provide compelling evidence that biosolids, when treated properly, can be both safe and effective for agricultural use. The majority of respondents expressed a high level of awareness about biosolids and recognized their sustainability and environmental benefits, such as reducing nutrient runoff and improving soil health. Statistical analyses, including regression and ANOVA, reveal a significant relationship between public awareness and acceptance of biosolids. This suggests that increased public education and awareness campaigns can substantially improve acceptance and trust in biosolid use, as evidenced by the p-value of 0.000 and the strong Beta coefficient (0.473) associated with perceived benefits.

However, while the public appears confident in the environmental and agricultural benefits of biosolids, significant concerns about public health risks, particularly in relation to heavy metal contamination and pathogens, persist. Nearly 45% of respondents strongly agreed that these health risks are a concern, which underscores the necessity of addressing these issues before widespread adoption can occur. The analysis highlighted the effectiveness of current treatment methods, such as composting and pyrolysis, in reducing pathogens, yet it also emphasized that ongoing efforts are needed to optimize these processes to further mitigate health risks, especially concerning heavy metal bioaccumulation in crops. The findings underscore the need to balance environmental benefits with public safety when promoting biosolids as a sustainable alternative to chemical fertilizers. In this context, statistical evidence supports that when properly treated, biosolids offer both agronomic and environmental advantages without posing significant health risks.

Recommendations:

Based on the findings, several key recommendations can be made to enhance the safety and efficacy of biosolid use in agriculture. First and foremost, there is a clear need for further optimization of biosolid treatment processes to reduce both pathogen levels and heavy metal risks. While methods like composting and pyrolysis have shown promise, additional research should focus on refining these techniques to ensure more complete heavy metal stabilization and further pathogen reduction. Such innovations are essential for boosting public confidence and aligning biosolid safety standards with global agricultural practices (Neumann & Moser, 2017; Zhang & Zhou, 2018).

Moreover, regulatory frameworks governing biosolid use must be strengthened to address the long-term environmental impacts, such as the potential for heavy metal accumulation in soils over time. Establishing clear safety certifications and independent verification of biosolid treatment processes will help alleviate public health concerns and ensure that biosolid applications remain safe for both crops and the broader environment. Further studies are also needed to assess the long-term effects of biosolid use on soil microbiomes, soil fertility, and overall ecosystem health.

Lastly, public education campaigns should continue to be a focal point, with an emphasis on explaining the scientific

processes that ensure biosolid safety, as well as promoting the benefits of biosolids as a sustainable agricultural resource. Enhancing awareness will foster a more informed and receptive public, thereby facilitating the adoption of biosolids in agricultural systems as a viable, eco-friendly alternative to synthetic fertilizers.

In conclusion, while biosolids present a safe, effective, and sustainable solution for enhancing soil health and reducing the environmental impact of fertilizers, addressing the public health risks associated with pathogen and heavy metal contamination remains a crucial step in ensuring their broader acceptance and use in agriculture. With continued optimization of treatment processes and the development of stronger regulatory frameworks, biosolids can serve as a key tool in sustainable agriculture moving forward.

6. Future Research

Exploration of New Treatment Methods:

Future research on biosolids should prioritize the exploration of innovative treatment methods that can enhance the quality and safety of biosolids for agricultural use. Although current methods such as composting and pyrolysis have shown effectiveness in pathogen reduction and heavy metal stabilization, there remains a need to optimize these treatments further, especially concerning heavy metal reduction. Many biosolid treatments can be improved to reduce the risk of heavy metal accumulation in soils, which is a key concern for both the safety of crops and the long-term health of agricultural ecosystems. Future studies could investigate novel approaches such as thermophilic composting, bioremediation techniques utilizing plants or microorganisms to absorb heavy metals, or even advanced chemical treatments that could specifically target the stabilization of heavy metals without adversely affecting soil quality. Furthermore, nanotechnology holds potential in improving biosolid treatment processes by enhancing the removal and stabilization of toxic metals, which could be explored in future studies.

Exploring biochar-based treatments, a promising material that has shown the potential for heavy metal adsorption, could be another avenue for improving biosolid quality. In addition to pathogen control, biochar may help mitigate the leaching of toxic metals, thus providing a safe and sustainable method for improving the effectiveness of biosolid application in agriculture. These advancements in treatment methods could significantly reduce the potential environmental and public health risks associated with biosolid use, which remains one of the primary concerns for their broader adoption.

Long-Term Studies:

In addition to improving treatment methods, long-term studies are essential to fully understand the sustainability and ecological impacts of biosolid use in agricultural systems. While short-term studies have demonstrated the benefits of biosolids in improving soil fertility and promoting plant growth, research is needed to assess their long-term effects on soil microbial communities and overall soil health. Biosolids, when used consistently over time, can alter the composition and activity of soil microorganisms, potentially enhancing soil biodiversity, nutrient cycling, and organic matter decomposition. However, understanding the long-term dynamics of these changes is crucial to ensuring that biosolid use does not lead to unintended ecological consequences.

Moreover, the long-term cumulative effects of heavy metals in biosolids on soil bioavailability need further investigation. While initial studies have provided insight into the short-term benefits of biosolid application, more longitudinal studies are required to determine whether repeated application of biosolids might lead to the gradual build-up of metals in the soil, ultimately affecting plant uptake and food safety. As highlighted by Wu & Zhang (2020), understanding the long-term sustainability of biosolid use is vital for integrating these materials into mainstream agricultural practices without compromising soil health or environmental integrity.

Therefore, research should also focus on investigating the relationship between biosolid use and soil microbial resilience, particularly how different microbial populations interact with the organic compounds and nutrients introduced by biosolids. This would offer deeper insights into the long-term sustainability of biosolid use, ensuring that its application supports not only short-term agricultural productivity but also long-term soil health and environmental stability.

In conclusion, future research should concentrate on enhancing treatment methods to mitigate the risks of heavy metals

and pathogen contamination, while also investigating the long-term effects of biosolid use on soil and microbial ecosystems. These advancements will play a crucial role in realizing the potential of biosolids as a sustainable and safe alternative to chemical fertilizers in the agricultural sector.

Conclusion

This study provides critical insights into the potential of biosolids as a sustainable agricultural input, emphasizing their safety, effectiveness, and ecological benefits. The findings reveal that when treated properly, biosolids can offer a valuable alternative to chemical fertilizers, particularly in terms of improving soil fertility, enhancing plant growth, and reducing environmental issues like soil degradation and nutrient runoff. The data strongly supports the view that biosolids, particularly those treated through methods like composting and pyrolysis, are effective in reducing pathogens and stabilizing heavy metals, making them safe for agricultural use.

Statistical analyses, including regression analysis and ANOVA, indicate a significant positive relationship between public awareness of biosolid benefits and their acceptance for use in agriculture. The findings underscore the importance of educational campaigns and public outreach in fostering greater trust and acceptance of biosolids, especially in the context of sustainable agriculture. The relationship between awareness and acceptance is critical, with respondents showing a strong willingness to embrace biosolids, provided there is adequate education about their safety and benefits. However, while the environmental and agronomic benefits of biosolids are widely acknowledged, concerns regarding public health risks, particularly those related to heavy metal contamination and pathogen exposure, remain significant. Nearly half of the respondents expressed concerns about the health risks associated with biosolid use, highlighting the need for further optimization of biosolid treatment methods to mitigate these risks. The study calls for continued research to enhance biosolid safety by reducing the presence of heavy metals and ensuring the effective reduction of pathogens during treatment processes.

Moreover, the study emphasizes the need for stronger regulatory frameworks and scientific evidence to support the safe application of biosolids in agriculture. As the global agricultural community seeks to move toward more sustainable practices, biosolids can play a vital role, but only if their long-term effects on soil health, microbial communities, and ecosystem stability are thoroughly understood and managed.

In conclusion, biosolids represent a promising tool for addressing the challenges of sustainable agriculture, but careful attention must be given to public health concerns and long-term environmental impacts. Through ongoing optimization of treatment technologies, the development of robust regulatory standards, and public education efforts, biosolids can be integrated more fully into sustainable farming systems, contributing to a healthier environment and a more sustainable agricultural future.

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