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Assessing Agricultural Plastic Waste Through Sustainable Management Scenarios

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ABSTRACT

Agricultural plastics play a vital role in improving agricultural productivity; however, their increasing use has resulted in significant environmental challenges associated with plastic waste generation and disposal. This study aimed to assess agricultural plastic waste across major agricultural production systems and evaluate the effectiveness of alternative sustainable management scenarios using a quantitative secondary dataset. The dataset comprised eight agricultural production systems and included cultivated area, plastic waste intensity, annual plastic waste generation, covering-film waste, and four management scenarios. Descriptive statistics, percentage contribution analysis, comparative scenario evaluation, and scenario ranking were performed to quantify waste generation patterns and compare management performance. The results indicated that orchards and vineyards were the dominant contributors to agricultural plastic waste, together accounting for the majority of total annual waste generation. Plastic waste intensity varied considerably among production systems, with greenhouse cultivation exhibiting the highest intensity. Comparative analysis demonstrated that the combined management scenario achieved the greatest reduction in annual agricultural plastic waste, followed closely by the first management scenario, while the second scenario showed only minimal improvement over the existing management condition. These findings highlight the importance of integrated waste management approaches for reducing agricultural plastic waste and improving resource efficiency. The study provides quantitative evidence to support environmental engineering decision-making and emphasizes the need for targeted, crop-specific waste management strategies to advance sustainable agriculture and circular economy practices

Key words: Agricultural plastic waste; Sustainable waste management; Environmental engineering; Plastic waste intensity; Management scenarios

1. Introduction

The use of agricultural plastics has become an integral part of modern agriculture systems due to their contribution to improving the productivity of crops, increasing resource-use efficiency and promoting intensive agricultural production. Mulch films, greenhouse films, irrigation pipes and silage films are widely employed to improve growing conditions, reduce water loss, prevent weed growth and boost yields, while seedling trays and protective nets are used to grow seedlings and protect crops from damage during the set-up phase. These applications have played a significant role in enhancing food security worldwide by allowing for cultivation throughout the year and boosting the agricultural resilience in the face of climate variability. But as the use of plastic has increased in agriculture, so has the amount of plastic waste produced, making it a new environmental issue in agriculture that could jeopardize the sustainability of the agricultural ecosystem. Agricultural plastics have a long lifespan and are hard to break down – when they are not managed properly, they stay in the environment for a longer time causing soil contamination, deposition of microplastics, degradation of the ecosystem and the non-optimal use of valuable material resources (Schettini et al., 2022).

The environmental impacts of plastic waste in agriculture are not limited to production, but cover the whole life cycle of the plastic material. The challenges associated with conventional plastics involve greenhouse gas emissions, fossil resource depletion, and environmental pollution, from raw material extraction through manufacturing, to use in the field, as well as their end-of-life disposal. Managing agricultural plastics after they are used has a significant impact on their environmental performance (Bénard and Malet-Damour, 2022). Comparative life cycle analysis has shown that recycling and alternatives that are biodegradable generally have lower environmental impacts than uncontrolled disposal techniques like landfill or open burning. Therefore, choosing proper waste management technologies is now a key issue in mitigating the environmental impacts associated with agricultural production and ensuring sustainable use of resources (Dong et al., 2022).

With rising environmental knowledge, there has been a growing interest in sustainable solutions for agricultural plastic waste management. Despite the lack of collection systems, used plastic contamination, limited recycling capacities, and the economic barriers to waste recovery, conventional disposal is still prevailing in many agricultural areas. Such difficulties can lead to illegal dumping, open burning of fields or the improper storage of plastic residues, which will cause air pollution, soil pollution, and water pollution. The continuous tightening of environmental laws and the growing importance of the circular economy concept will create a growing demand for shifting to waste management systems that will move away from linear product disposal systems and strive for waste reduction, reuse, recycling, and resource recovery. These strategies not only help reduce the ecological footprint but also enhance the efficiency of materials used and foster sustainable practices in agricultural production systems (Pratelli et al., 2022).

In recent years, a growing number of studies have been dedicated to identifying effective management strategies that can help reduce agricultural plastic waste while ensuring economic and environmental sustainability. Closed loop recycling systems have proved to be very promising in recycling valuable plastic materials and reducing the reliance on virgin polymer production, which not only benefits the economy but also the environment (Mayanti & Helo, 2022; Aryan et al., 2019). Likewise, the development of geographical information systems (GIS) has spurred spatial planning and optimization of agricultural plastic waste collection and management, allowing for more efficient allocation of plastic recycling infrastructure and transportation networks (Convertino et al., 2025). The environmental impact assessments have also demonstrated that the systematic comparison of different waste management scenarios can help to provide evidence for determining environmentally preferred waste management scenarios under various regional conditions (Zhang et al., 2023). On the other hand, new trends in the development of bio-based and biodegradable plastics have provided some potential solutions to mitigate the environmental footprint of traditional agricultural plastics, but the widespread adoption of these alternatives involves further economic, waste management, and life cycle assessment analyses to ensure their practical viability (Mousavi et al., 2024; Yadav & Nikalje, 2024).

Although these progressions have taken place, there are still gaps in knowledge regarding the assessment of agricultural plastic waste. Most of the present studies are focused on the individual waste treatment technology, life cycle assessment (LCA), or recycling practices at the regional level, while few studies contain quantitative assessments of the generation of agricultural plastic waste from several agricultural production systems under various waste management scenarios

(Thomopoulos et al., 2026). In addition, there has been little consideration of linking the waste intensity of the crop with scenario comparisons in order to pinpoint realistic waste reduction potential to enable environmentally engineered decisions (Antelava et al., 2019). Without these comparative assessments, policy makers, environmental managers and agricultural stakeholders cannot compare different interventions to prioritize the ones that will produce measurable reductions in plastic waste.

To cope with these challenges, conclusive quantitative assessments are needed that can quantify agricultural plastic waste from various production systems and systematically compare different management scenarios. This evidence can contribute to the development of sustainable waste management strategies by identifying sectors with high waste generation, estimating the effectiveness of alternative pathways for waste management, and provide practical guidance to enhance waste collection, waste recycling, or waste resource recovery systems. Scenario-based assessments also provide useful tools to support decision-makers in the promotion of circular economy concepts, in supporting environmental policy development, and in making agricultural production systems more sustainable.

Considering these aspects, the current study is focused on measuring the agricultural plastic waste in the main agricultural production systems and the efficiency of the alternative sustainable management scenarios through quantification based on the data set. The results will be expected to give evidence-based insights that can help in environmental engineering practice, in planning sustainable waste management and policy development for responsible agricultural plastic waste management. The objectives of this study are:

- To quantify agricultural plastic waste generation and plastic waste intensity across different agricultural production systems using crop-specific data.
- To compare the effectiveness of alternative agricultural plastic waste management scenarios in reducing overall plastic waste generation.
- To identify sustainable management strategies that support environmentally responsible agricultural plastic waste management and informed environmental decision-making.

2. Materials and Methods

2.1 Dataset Description

The secondary data used in this study includes quantitative data on agricultural plastic waste produced in various agricultural production systems (Vox et al., 2024). The data are related to eight different categories of agricultural activity: cereals, greenhouses, ornamental nurseries, vegetable nurseries, olive groves, orchards, vegetables and vineyards. The data sets for each category comprise of the cultivated area (ha), plastic waste intensity (kg/ha/year), annual agricultural plastic waste (kg/year), covering-film waste, and four alternative management scenarios along with the current management practice. The dataset was chosen for its direct relevance to the quantitative estimation of the amount of agricultural plastic waste generated, and for its capacity to be compared to assess sustainable management scenarios. All variables used were left in their original units to allow uniformity throughout the analysis.

2.2 Data Preparation and Quality Assessment

The data set was entered into MS Excel for initial processing and then analyzed statistically. Data quality assessment consisted of checking the names of the variables, the units used to measure the variables, the numerical consistency and the completeness of the observations. No duplicated entries were found when looking at the duplicated records. The missing values, identified in the covering-film waste variables, were retained as structural missing values instead of being imputed as they were related to agricultural sectors which did not apply to covering films. The consistency of data for cultivated area, plastic waste intensity, and annual plastic waste generation was confirmed in a mathematical manner to ensure data reliability. All variables were standardized to a common measurement unit, such as hectares (ha), kilograms per hectare per year (kg/ha/year), and kilograms per year (kg/year) for uniformity in all the subsequent analyses.

2.3 Agricultural Plastic Waste Assessment

The assessment of agricultural plastic waste was based on the agricultural production systems and the cultivated area, plastic waste intensity and the annual generation of plastic waste reported for each agricultural production system. The quantity of plastic wastes generated per unit of agricultural area was assessed by the intensity of plastic waste, hence it was possible to compare the amount of plastic waste generated per cultivated area among various categories of crops without considering the differences in the agricultural area. Annual agricultural plastic waste was estimated at the production-system level and then the relative contribution of each category to the total plastic waste produced for the study dataset was calculated. Covering-film waste was also looked at in isolation and the amount quantifiable wherever possible was added to the total agricultural plastic waste. The percentage contributions and ranking of the agricultural sectors were used to find the main sources of plastic wastes in agriculture.

2.4 Sustainable Management Scenario Framework

A dataset comprising four management scenarios (different approaches for agricultural plastic waste management) was created. The first one was the current waste management situation and was used as the baseline case. The other three scenarios were alternative pathways for management, two independent scenarios for intervention and a combined management scenario that combined several waste reduction strategies. For each scenario reported the estimated annual agricultural plastic waste produced in the scenario under the management condition. These scenarios were compared and assessed for their effectiveness in reducing plastic waste generation compared to the base scenario. A composite scenario was also analysed to investigate if integrated management practices were more effective at reducing waste than individual intervention practices.

2.5 Comparative Scenario Evaluation

Comparative evaluation was carried out based on the comparison of the annual agricultural plastic waste for each management scenario. Absolute differences between the waste generated at baseline and alternative scenarios were determined in order to quantify the reduction of waste for each management strategy. The amount of reduction was then calculated as a percentage of the baseline agricultural plastic waste. The different management scenarios were then compared on their waste reduction performance and the most effective management scenario in order to reduce the generation of agricultural plastic waste was determined. For each crop and scenario, the results were also analyzed to uncover agricultural sectors with the highest potential for waste reduction under better management practices.

2.6 Statistical Analysis

Descriptive statistical analysis was carried out to summarize the cultivated area, plastic waste intensity, annual plastic waste generation and covering film waste in agricultural production systems in the dataset. To find out the relative share of each agricultural category in generation of plastic waste by the use of percentage contribution analysis. The differences among the four management scenarios were evaluated by absolute and percentage waste reduction. A scenario ranking was carried out to determine the management scenario that would be most effective at reducing waste. All calculations, descriptive summaries and graphical visualizations were done in the Microsoft Excel spreadsheet, and results presented in tables and figures to facilitate interpretation of agricultural plastic waste distribution and performance of the management scenarios.

3. Results

3.1 Characteristics of Agricultural Plastic Waste

The dataset included eight agriculture production systems, covering an agricultural area of 32,229.78 ha. In the all production systems, the estimated agricultural plastic waste in the actual management situation was 11,103,347.94 kg/year. There was also significant differences between the crop categories, as plastic waste intensity varied from 3.30 kg/ha/year for cereals to 1,078.96 kg/ha/year for greenhouses. Owing to their greater size and dependence on plastic materials, orchards, vineyards and olive groves were mostly linked with high plastic waste production per year. The dataset also comprised four management scenarios (actual, first, second, and combined) along with estimates of the plastic waste generated by agriculture and the potential for reducing plastic waste with the use of alternative management strategies, in the covering film.

Table 1. Characteristics of agricultural plastic waste across agricultural production systems.

Agricultural production system	Area (ha)	Plastic waste intensity (kg/ha/year)	Annual plastic waste (kg/year)
Cereals	9,067.19	3.30	29,921.73
Greenhouses	86.78	1,078.96	93,632.15
Ornamental nurseries	32.63	724.60	23,643.70
Vegetable nurseries	13.89	886.98	12,320.15
Olive groves	12,609.61	80.33	1,012,929.97
Orchards	6,696.98	1,005.31	6,732,540.96
Vegetables	2.69	389.55	1,047.89
Vineyards	3,720.01	859.49	3,197,311.39
Total	32,229.78	—	11,103,347.94

3.2 Crop-wise Distribution of Agricultural Plastic Waste

The distribution of agricultural plastic waste production was not equal across the production systems. The orchards accounted for 60.64% of the overall annual agricultural plastic waste, followed by the vineyards (28.80%) and the olive groves (9.12%). Combined together, these three production systems accounted for over 98% of the total plastic waste produced in the database. Individual cereal crops, greenhouses, ornamental nurseries, vegetable nurseries and vegetables, on the other hand, accounted for less than 1% of the annual plastic waste. From this distribution, it can be seen that the production of agricultural plastic waste is very concentrated among a small number of crop categories.

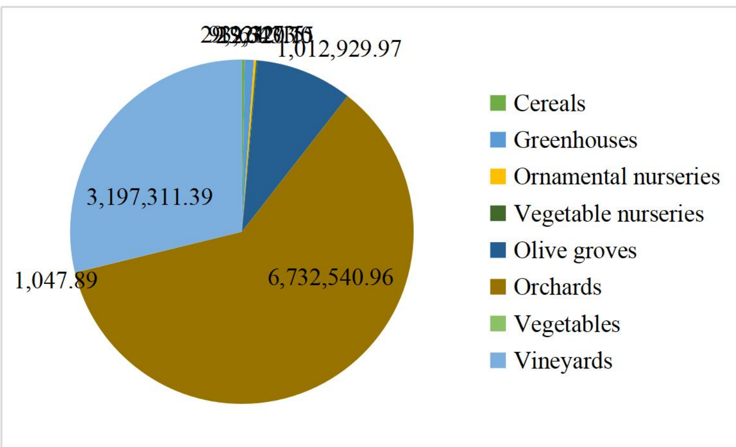

Figure 1. Distribution of agricultural plastic waste across crop categories.

3.3 Assessment of Plastic Waste Intensity

Agricultural production systems had significant variation in plastic waste intensity. The plastic waste intensity in greenhouses was 1,078.96 kg/ha/year, which is the highest among all the other types of crops, followed by orchards (1,005.31 kg/ha/year), vegetable nurseries (886.98 kg/ha/year), and vineyards (859.49 kg/ha/year). Ornamental nurseries had a moderate plastic waste intensity (724.60 kg/ha/year), vegetables (389.55 kg/ha/year) and olive groves (80.33 kg/ha/year) while cereals had a lower value (3.30 kg/ha/year). From the plastic waste intensity point of view, the most plastic-intensive production system is the greenhouse, as indicated by the ranking.

Table 2. Plastic waste intensity among agricultural production systems.

Rank	Agricultural production system	Plastic waste intensity (kg/ha/year)
1	Greenhouses	1,078.96
2	Orchards	1,005.31
3	Vegetable nurseries	886.98
4	Vineyards	859.49
5	Ornamental nurseries	724.60
6	Vegetables	389.55
7	Olive groves	80.33
8	Cereals	3.30

3.4 Comparative Assessment of Management Scenarios

The four management scenarios led to measurable differences in the quantity of plastic waste generated in agriculture each year. The highest plastic waste recorded in a year was in the actual management scenario (11,103,347.94 kg/year). The first management scenario reduced the annual waste generation to 8,343,022.26 kg/year, while the second management scenario reduced the waste to 11,056,121.16 kg/year. The lowest total annual agricultural plastic waste (8,295,797.22 kg/year) was generated for this combined scenario. The combined management scenario had the lowest total annual waste generation, among the evaluated scenarios.

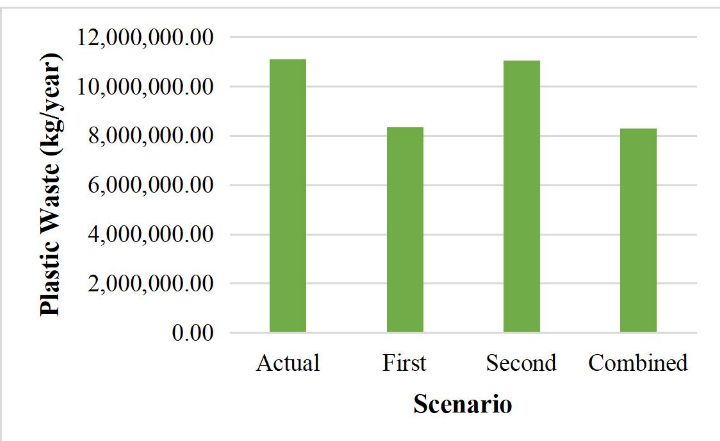

Figure 2. Agricultural plastic waste under different management scenarios.

3.5 Waste Reduction Performance Across Scenarios

The reduction of waste in performance was diverse across the management scenarios. In comparison with the current management situation, the first scenario resulted in a reduction of 2,760,325.68 kg of agricultural plastic waste per year (24.86%) and the second scenario obtained only 47,226.78 kg of plastic waste per year reduction (0.43%). The total picture showed the maximum reduction of 2807550.72kg/year (25.29%) in the annual amount of agricultural plastic waste. The combined scenario performed best with regard to waste reduction performance, closely followed by the first scenario, and then only slightly better than existing management for the second scenario.

Table 3.Comparative waste reduction achieved under different management scenarios.

Management scenario	**Annual plastic waste (kg/year)**	**Absolute reduction (kg/year)**	**Reduction (%)**	**Rank**
Actual scenario	11,103,347.94	—	—	—
Combined scenario	8,295,797.22	2,807,550.72	25.29	1
First scenario	8,343,022.26	2,760,325.68	24.86	2
Second scenario	11,056,121.16	47,226.78	0.43	3

3.6 Distribution of Covering-Film Plastic Waste

Covering-film plastic waste was reported in greenhouses, ornamental nurseries, vegetable nurseries, orchards and vineyards, and no covering-film waste records were found for cereals, olive groves and vegetables. The amounts of covering-film plastic waste produced in the orchards were the highest (5,117,497.27 kg/year), followed by the vineyards (2,283,342.14 kg/year) and the greenhouses (49,028.96 kg/year). Comparatively smaller amounts of covering-film wastes were provided by ornamental nurseries and vegetable nurseries. The distribution shows that the plastic waste of covering film is mainly contained in the orchard and vineyard production systems.

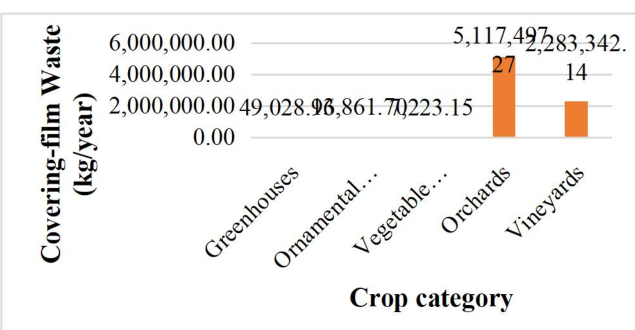

Figure 3. Crop-wise distribution of covering-film plastic waste.

4. Discussion

In the present study, agricultural plastic waste was assessed in different agricultural production systems in quantitative fashion and alternative management scenarios were compared to determine those that can reduce the amount of plastic waste generated in agricultural production. The results showed that agricultural plastic waste are very localized in the limited production systems and orchards and vineyards were the highest proportion of overall waste production. It is a pattern that is typical for peri-annual and horticultural crops which are intensively using plastic materials like mulching films, irrigation components, crop protection covers and packaging materials. On the other hand, cereals and vegetable production produced lower amounts of plastic waste compared to other sectors due to fewer plastic inputs. This observed variability in plastic intensity of the cultivation also proves the impact of the variability of cultivation practices, crop needs and cultivation systems on the plastic consumption and plastic waste. To prioritize waste management interventions that can make significant contributions to reducing agricultural plastic waste, these high-contributing sectors need to be identified. These patterns are also observed in recent global evaluations of plastic waste in agriculture, which classify horticultural production systems as important drivers of agricultural plastic waste, due to their high consumption of agricultural materials made of polymer (Macheca et al., 2024).

The different management scenarios were clearly compared, showing different performance levels in terms of waste reduction. Of the four scenarios, the combined management scenario yielded the highest reduction in the amount of annual agricultural plastic waste and the first management scenario yielded a comparable reduction, with the second scenario showing a negligible difference over the existing management condition. Overall, the results indicate that a comprehensive waste management strategy is much more effective than a single intervention. The use of several management approaches can optimize collection efficiency, recycling potential, and resource recovery and reduce waste leakage into the environment. Integrated management systems are not a one-off intervention, but are an approach that targets multiple points in the waste management chain, making it capable of greater overall plastic waste reduction. Similar results have been observed in recent research works which highlighted the importance of implementing integrated waste prevention and collection, recycling and recovery strategies for sustainable agricultural plastic waste management, rather than single technologies (Manyamba et al., 2026).

The assessment of covering-film plastic waste also helps to provide insights into crop-specific waste management priorities. The most significant amount of covering-film waste was found in orchards and vineyards, highlighting the fact that covering films are a significant fraction of plastic waste produced within these production areas. This is a good indication of the need to establish a target collection programme and recycling programme for high plastic-use agriculture sectors. The focus of these production systems may significantly increase the efficiency of waste recovery and decrease the contamination of the environment with waste from agricultural plastics that are not recovered and disposed of properly. Adopting management strategies specific to the crops being cultivated is therefore more likely to yield environmental benefits than broad-based waste management programs based on an all-inclusive approach.

From the environmental engineering perspective, the results prove the usefulness of quantitative assessment for decision support in sustainable waste management planning in the context of scenarios. An alternative management scenario comparison allows objective evidence to be obtained on the effectiveness of waste reduction options prior to implementation. These analyses help environmental managers to determine management options that can minimize plastic waste and enhance the efficiency of resource use and circular material flows (Niu et al., 2025). The significant pollution avoided in the combined management situation demonstrates the potential of integrated waste management systems to help prevent pollution, conserve resources, and support sustainable agriculture. This study also aligns with previous studies that highlight the need to include a systematic assessment of management alternatives in a sustainability assessment to facilitate environmentally informed decision making and enhance the long-term utilization of resources (Yilan et al., 2023).

The results also have significant policy implications for environmental policies and sustainable use of agriculture. Given the fact that a relatively small number of agricultural production systems account for most of the plastic waste, agricultural policymakers can target them specifically in the development of plastic waste collection systems, recycling infrastructure, and waste management regulations. Incorporating farmer involvement, increasing recycling centers, and promoting responsible plastic use can lead to better plastic waste management in the agricultural sector, thereby minimizing pollution into the environment. Furthermore, it is necessary to develop cooperation between the agricultural sector, the recycling sector and environmental authorities in order to apply circular economy principles in agricultural production systems. These recommendations align with recent evidence that calls for integrated policy frameworks that foster sustainable plastic use, enhance recycling systems, and encourage more environmentally-friendly agricultural practices (Hofmann et al., 2023).

This study has some limitations, although it offers some valuable quantitative evidence. Analysis was conducted on a secondary data set of a limited number of agricultural production systems, in a single territorial context, which could limit the generalizability of the results (Akbarian-Saravi et al., 2025; Hachem et al., 2023). In addition, the data provided were mainly on plastic waste quantity and management scenarios without the inclusion of environmental life-cycle assessment indicators, greenhouse gas emissions, recycling cost, or other wider socio-economic indicators. Therefore, the main method of assessing management performance was the reduction of waste and not the full sustainability assessment. More research is needed on integrating LCA, techno-economic and environmental impact indicators to gain a better understanding of sustainable agricultural plastic waste management. The integration of environmental and economic performance indicators would allow for more comprehensive analysis and comparison of management alternatives and help develop more sustainable waste management systems that balance the environmental and economic aspects.

5. Conclusion

Agricultural plastic waste management is gaining significant importance in the scope of sustainable agricultural production and the reduction of environmental pollution. In this study, agricultural plastic wastes were quantitatively measured in eight agricultural production systems and the scenarios of alternative management were compared to evaluate their effectiveness in reducing plastic wastes in the agricultural sector. The results indicated significant differences in plastic waste intensity and amount of plastic waste produced per year for crop categories – orchards and vineyards accounting for the highest percentage of total plastic waste from agriculture each year. The results show that only a small proportion of production systems contribute to the generation of waste, which means that management interventions should be focused. The results of the comparative scenario analysis showed that agricultural plastic waste is best reduced with an integrated management approach, whereas agricultural plastic waste reductions with individual management approaches were comparatively lower. The results highlight the need for implementing several waste management practices, such as better collection, recycling and resource recovery, to improve the environmental performance and decrease the amount of plastic in agricultural systems. The study also shows the usefulness of the scenario-based quantitative assessment, as a decision-support tool for sustainable waste management planning and sustainable environmental engineering. The analysis was conducted on a secondary data set available, which was limited geographically, but it offers important evidence to highlight priority sectors and assess the management options that can be implemented to limit plastic waste in agriculture. Further research should incorporate life-cycle assessment, techno-economic analysis and other environmental metrics to enhance sustainability assessment and policy relevance. The results encourage the implementation of integrated approach to managing agricultural plastic waste, which can enhance the efficiency of agricultural resource utilization, the use of principles of circular economy, and environmentally responsible practices in agriculture contributing to the sustainability of the environment in the long term and more resilient agricultural production systems.

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