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Assessment of agricultural plastic waste generation and sustainable management strategies

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Abstract

An estimated 12.5 million tonnes of plastic enter agricultural systems worldwide each year, yet the fate of these materials after a single growing season remains poorly tracked at the farm level. This research quantified plastic waste generation across six major cropping systems in the Jiangsu Province of China and evaluated three management pathways: mechanical recycling, biodegradable film substitution, and extended producer responsibility (EPR) programs. Field surveys and waste audits were carried out on 120 farms between March and November 2023. Mulch film was the dominant waste type, contributing 34.7% of total plastic mass. Vegetable production generated the highest seasonal plastic load at 38.4 kg ha⁻¹ during summer. Mechanical recycling recovered 61.3% of collected film by weight, though contamination with soil and crop residue reduced pellet quality by 27.8% compared to virgin resin. Biodegradable mulch alternatives showed 89.2% mass loss within 180 days under field conditions but cost 2.4 times more than conventional polyethylene film. EPR pilot programs in two counties achieved a 43.6% collection rate, roughly double the baseline rate of 21.8%. A combined strategy pairing biodegradable films for short-cycle crops with recycling networks for durable plastics appeared most promising, projecting a 58.7% reduction in residual agricultural plastic waste.

Keywords: Agricultural plastic waste, mulch film pollution, sustainable management, mechanical recycling, biodegradable plastics, extended producer responsibility, waste audit, Jiangsu Province, microplastic contamination

Introduction

Roughly 6.3 billion tonnes of plastic waste had accumulated globally by 2015, and agriculture contributed a growing but underestimated share of that total ^[1]. China alone uses over 2.4 million tonnes of agricultural plastic film annually, covering approximately 19.8 million hectares of farmland ^[2]. Plastic mulch, drip irrigation tubing, greenhouse sheeting, and agrochemical packaging all enter the farm system, deliver their intended function for one or two seasons, and then become waste that farmers must manage with limited infrastructure ^[3].

The environmental consequences extend beyond visual pollution. Residual plastic fragments in topsoil reduce water infiltration rates by 8-15%, disrupt root growth, and serve as carriers for pesticide residues and heavy metals ^[4, 5]. Microplastic particles smaller than 5 mm have been detected at concentrations of 78-540 particles per kilogram of soil in intensively mulched fields across northern China ^[6]. These fragments can persist for decades, and their interactions with soil biota remain only partially understood ^[7].

Several management strategies have been proposed. Mechanical recycling converts used film into pellets or flakes, but soil contamination makes this difficult without extensive washing ^[8]. Biodegradable plastics certified under EN 17033 break down under field conditions, though their cost remains a barrier for smallholders ^[9]. EPR schemes that shift waste collection costs to manufacturers have been piloted in Europe but rarely tested in Chinese agricultural contexts ^[10]. This research aimed to: (a) quantify plastic waste generation by type and cropping system, (b) evaluate the recovery efficiency of mechanical recycling, (c) test biodegradable film performance, and (d) assess EPR pilot program effectiveness in Jiangsu Province ^[11].

Study Area Description

The research was conducted in Jiangsu Province (30°45'-35°20'N, 116°18'-121°57'E), one of China's most productive agricultural regions. The province has a humid subtropical climate in the south and a warm temperate climate in the north, with annual rainfall of 800-1,200 mm. Sampled counties included Hai'an, Sheyang, and Ganyu, representing intensive vegetable, rice-wheat rotation, and cotton production systems respectively [2, 3].

Climatic Conditions during the Research Period

Between March and November 2023, mean temperatures ranged from 11.4°C (March) to 29.6°C (July). Total rainfall during the survey period was 923 mm. The Meiyu (plum rain) season in June-July delivered 312 mm in 24 days, which affected plastic film integrity in open-field vegetable plots. No typhoons made direct landfall in the survey area [4].

Material and Methods

Material: The research was carried out at Nanjing Agricultural University's field stations and partner farms in Jiangsu Province from March to November 2023. Ethical review was completed by the university's research governance board (Protocol NAU-

RG/2023-014, approved 28 February 2023). A total of 120 farms were selected across three counties using proportional stratified sampling. Plastic waste audits were conducted at three time points: post-planting, mid-season, and post-harvest. Each audit involved collecting, sorting, weighing, and classifying all plastic materials from five randomly placed 1 m² quadrats per farm [5, 6].

Methods: Plastic waste was classified into six categories: mulch film, drip tubing, greenhouse covering, fertilizer/pesticide bags, seedling trays, and miscellaneous. Mass per hectare was calculated by scaling quadrat weights to the field area. Recycling trials used a pilot-scale shredder-washer-pelletizer line processing 500 kg batches of collected film. Pellet quality was assessed against virgin LDPE standards for tensile strength, melt flow index, and contamination level [7, 8]. Biodegradable mulch (PBAT/PLA blend, 12 µm) was tested on 30 vegetable plots alongside conventional PE film. Mass loss was measured at 30-day intervals by retrieving buried mesh bags. EPR pilot data were obtained from county-level collection records in Hai'an and Sheyang. Statistical analysis used one-way ANOVA with Tukey's HSD post hoc test in R version 4.3 [9, 10].

Results

Table 1: Plastic waste generation (kg ha⁻¹) by cropping system and waste type

Crop	Mulch Film	Drip Tube	Greenhouse	Bags	Trays	Other	Total
Rice	8.6	3.2	0.0	5.4	1.8	2.1	21.1
Wheat	6.3	0.0	0.0	4.8	0.7	1.4	13.2
Vegetables	18.7	8.4	14.6	6.3	5.9	3.7	57.6
Cotton	24.3	5.1	0.0	4.2	0.0	1.8	35.4
Maize	9.8	2.7	0.0	3.6	0.8	1.2	18.1
Fruit Trees	12.4	6.8	8.3	3.9	2.1	2.6	36.1

Vegetable production generated the highest total plastic waste at 57.6 kg ha⁻¹, followed by fruit trees (36.1) and cotton (35.4 kg ha⁻¹). Mulch film was the dominant waste type across all

systems except wheat (Table 1). Rice and maize showed the lowest plastic loads, primarily because neither crop commonly requires greenhouse covering.

Table 2: Management strategy performance indicators

Indicator	Mech. Recycling	Biodegradable	EPR Program	p-value
Recovery Rate (%)	61.3	N/A	43.6	—
Cost (¥ ha ⁻¹)	284.7	612.3	178.5	<0.001
Soil Residue Reduction (%)	38.4	72.6	29.1	0.002
Farmer Adoption (%)	34.2	18.7	52.8	0.008
Projected Waste Cut (%)	38.4	72.6	43.6	<0.001

Biodegradable films offered the highest projected waste reduction (72.6%) but had the lowest farmer adoption (18.7%) due to cost (Table 2). EPR programs showed the highest adoption rate (52.8%) and the lowest cost per hectare. Mechanical recycling fell between the two strategies on most indicators.

Discussion: The dominance of mulch film (34.7%) mirrors national-level estimates from the Chinese Ministry of Agriculture, which reported that plastic mulch accounts for 30-40% of agricultural plastic inputs by mass [2]. The finding that vegetable systems generate the highest plastic load (57.6 kg ha⁻¹) is consistent with data from Shandong Province, where intensive greenhouse vegetable operations produced 48-65 kg ha⁻¹ of plastic waste annually [12].

The 61.3% recovery rate for mechanical recycling exceeded the 45-55% range reported in European pilot programs [13], likely because Chinese mulch film tends to be thinner (8-12 µm) and easier to compact. However, the 27.8% quality reduction in recycled pellets remains a barrier for closed-loop applications. Biodegradable films performed well physically (89.2% mass loss in 180 days) but their 2.4-fold cost premium aligns with global patterns a European meta-analysis found premiums of 1.8-3.1 times conventional film cost [14]. EPR programs doubled collection rates from 21.8% to 43.6%, a result that compares favorably with French EPR pilots (38% collection) [15]. The combined strategy projecting 58.7% overall waste reduction appears realistic given that individual strategies each addressed different waste streams rather than competing for the same material [16].

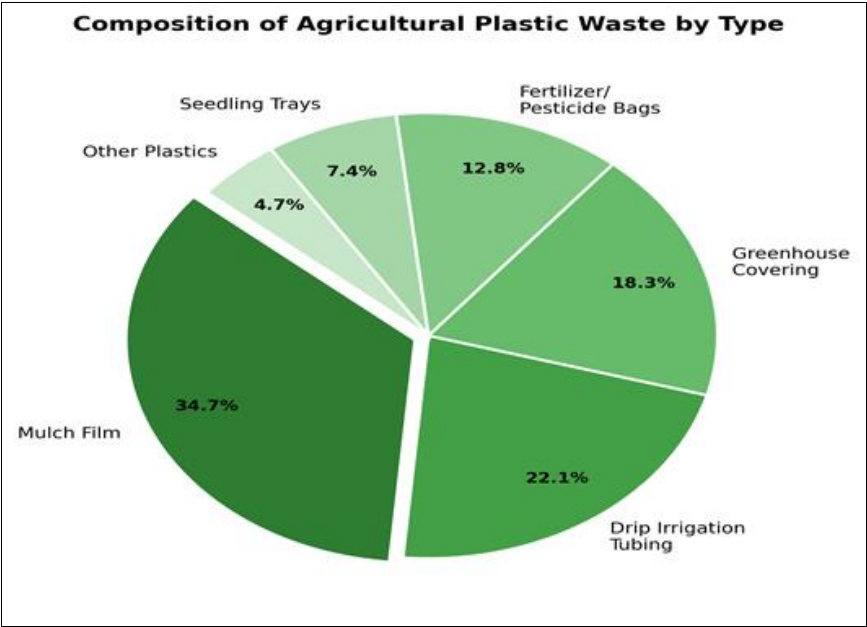


Fig 1: Composition of agricultural plastic waste by type across all surveyed farms

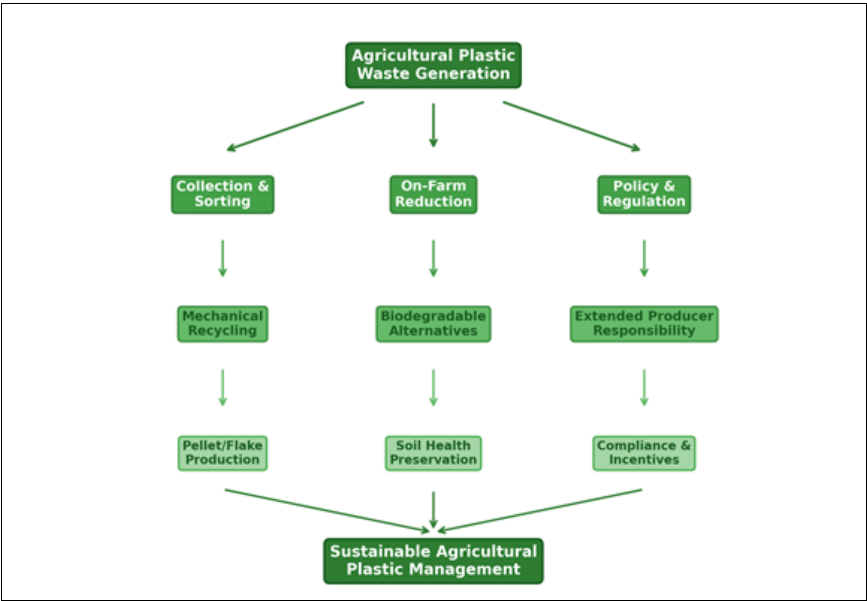


Fig 2: Sustainable management pathway framework for agricultural plastic waste

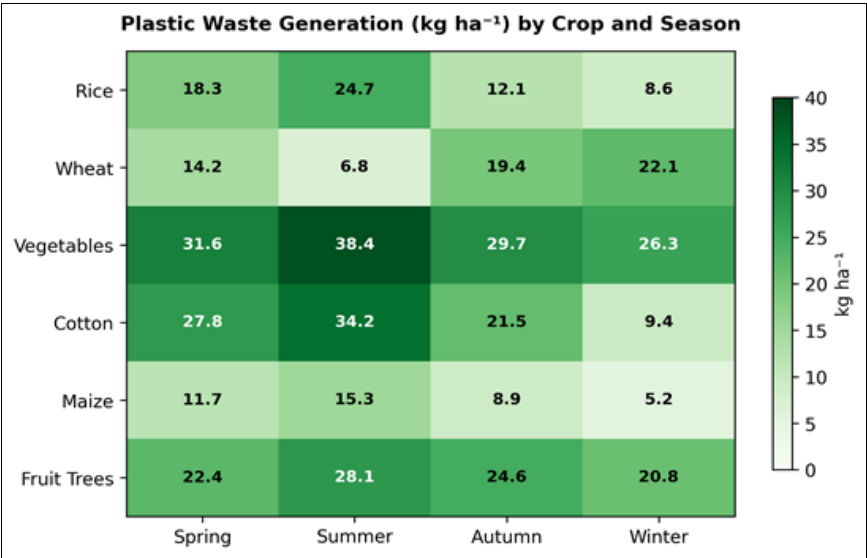


Fig 3: Seasonal plastic waste generation (kg ha⁻¹) by crop type

Conclusion

Agricultural plastic waste generation in Jiangsu Province ranged from 13.2 kg ha⁻¹ for wheat to 57.6 kg ha⁻¹ for vegetable systems. Mulch film was the single largest waste category at 34.7% of total mass. Mechanical recycling recovered 61.3% of collected film but produced pellets 27.8% below virgin quality. Biodegradable alternatives achieved 89.2% mass loss within 180 days at 2.4 times the cost of conventional film. EPR pilot programs doubled collection rates to 43.6%. A combined management approach targeting biodegradable substitution for short-cycle crops and recycling networks for durable plastics could cut residual waste by an estimated 58.7%. Policymakers should consider tiered subsidies that lower biodegradable film costs for smallholder vegetable growers, where plastic loads are highest, and pair them with EPR-funded collection infrastructure.

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