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Agricultural plastics in Canada and the globe: a cross-sectoral analysis of usage patterns, socioeconomic impacts, environmental risks, and policy responses

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This study provides a comprehensive assessment of agricultural plastic use and waste management in Canada, based on Cleanfarms data (2014–2024) and international comparisons. More than 61 000 tonnes of agri-plastics are produced annually, largely in the Prairie provinces (Alberta, Saskatchewan, and Manitoba), with field crops contributing the most through bale wraps, grain bags, and trays. Recovery remains limited, with most waste landfilled or disposed of on-farm. While plastics improve efficiency and yields, they generate environmental risks including soil and water contamination, greenhouse gas emissions, and microplastic accumulation. Policy responses are fragmented: Saskatchewan and Quebec have stronger Extended Producer Responsibility (EPR) models, while education and infrastructure remain limited elsewhere. Compared with the European Union (EU), Australia, and Japan, Canada lags in recycling rates, though it performs better than the United States of America (USA) and many developing countries. The study calls for a harmonized national framework, stronger incentives, and cooperative approaches to advance a circular economy in Canadian agriculture.

Environmental significance

This research provides a critical, cross-sectoral analysis of agricultural plastic waste in Canada, revealing a significant gap between plastic consumption and sustainable management. By quantifying the 61 000 tonnes of agri-plastics generated annually and identifying key waste streams such as bale wrap and grain bags, this study highlights the extensive yet largely unmanaged environmental burden. As can be extensively observed in the specific scientific literature, current disposal, dominated by land filling and on-farm burning, contribute directly to soil and water contamination, greenhouse gas emissions, and the proliferation of microplastics in terrestrial ecosystems. By benchmarking Canada's fragmented policies against more harmonized international frameworks, this work underscores the urgent need for a unified national strategy to mitigate these pervasive environmental risks and advance a circular economy in North American agriculture.

1 Introduction

The term agri-plastics encompasses all plastic-based products used during production, harvesting, storage, and distribution processes in agriculture.[1] Globally, about 12.5 million tonnes are utilized annually, with plastic films accounting for nearly 60%.[2] Demand for greenhouse, mulching, and silage films is projected to rise by 50% between 2018 and 2030. Crop and livestock sectors are the largest users, followed by fisheries, aquaculture, and forestry.[1]

In Canada, agriculture represents one of eight sectors that together account for about 1% of national plastic use. In 2016, the sector generated roughly 45 kt of plastic waste, with only 10% value recovery through recycling or energy recovery.[3,4]

"Cleanfarms", a non-profit stewardship organization supported by Environment and Climate Change Canada, which tracks the characterization and management of agricultural plastics. By 2021, Cleanfarms reported that approximately 61 754 tonnes of agricultural plastic waste were being generated annually across Canada, Fig. 1. A significant portion of this waste (around 53%) originated from the Prairie provinces (Alberta, Saskatchewan, and Manitoba), while Ontario and Quebec together accounted for an additional 37% of the national total, British Columbia 7% and the lowest percentage (3%) has belonged to the Maritimes.

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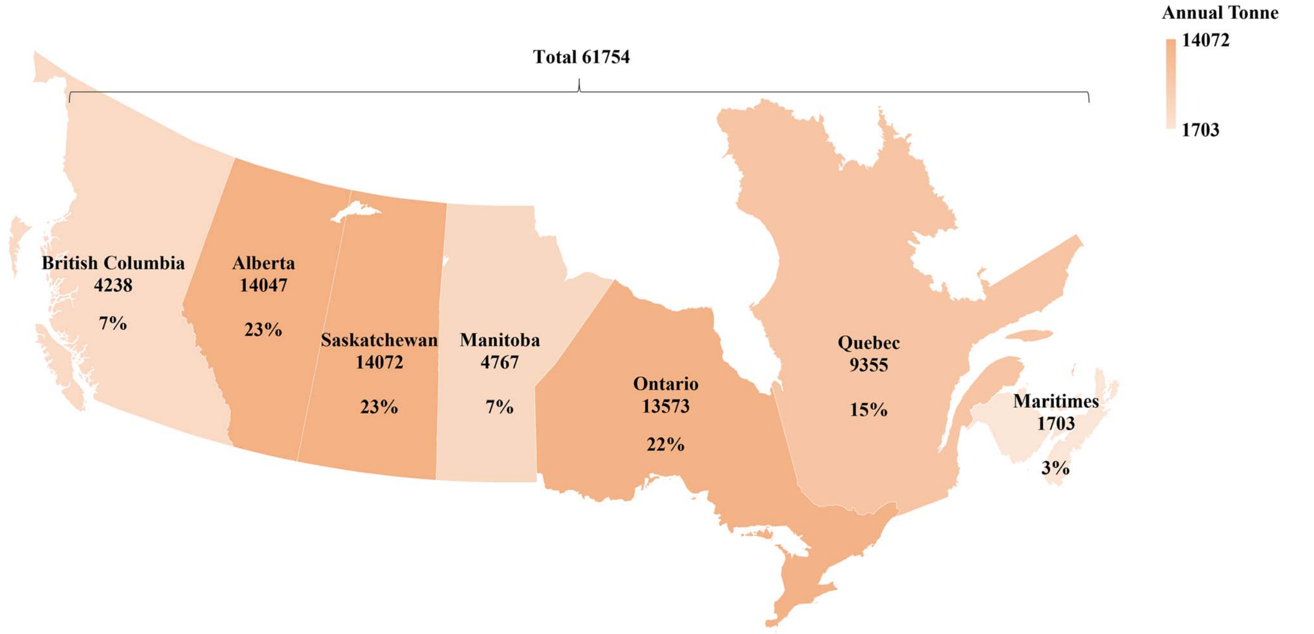

Fig. 1 Geographical distribution of the 61 754 tonnes of agricultural plastic waste generated annually in Canada (2021). Values for each region are shown in tonnes and as a percentage of the national total. Data are taken from Cleanfarms.[5]

The Canadian agricultural sector has increasingly relied on plastics for seed and grain transport, input packaging, greenhouses, mulching, silage, bale twines, and irrigation systems.[3,6] These applications enhance productivity by improving water efficiency, protecting crops, and extending growing seasons, making plastics a key component of modern agriculture.[7–9] For example, greenhouse applications regulate temperature and moisture, protect crops from environmental stress and pests, and extend the growing season, leading to increased productivity.[10] Plastic mulch films raise soil temperature, enabling earlier planting and harvesting, which can offer farmers a competitive market advantage.[11] Amare and Desta[12] showed that plastic mulches significantly reduce soil evaporation, boost soil moisture, and increase water-use efficiency by up to 31% in potato crop trials.

Gao *et al.*[13] indicated that plastic mulch increases crop yield and water use efficiency by over 24% and 27% respectively. Additionally, Ingman *et al.*[8] illustrated farmers perceive up to 26% water savings when using plastic mulch. They are also valued in organic farming for their ability to control weeds and pests.[12,14,15] In China, widespread mulch adoption eliminated the need for millions of hectares of farmland while boosting food production.[16]

However, these benefits are counterbalanced by waste management challenges and environmental risks, including soil and water contamination, greenhouse gas emissions, and microplastic accumulation.[6,17] Most agricultural plastics remain unrecovered due to high costs of collection and recycling, leading to improper disposal practises (such as on-farm burning, burial in soil, or illegal dumping).[9] Their impacts extend beyond the environment, influencing both farm productivity and rural livelihoods.[6,18,19]

Given the urgency of sustainable agricultural practices, an integrated review of agricultural plastic use, waste management, and their socio-economic and environmental impacts in Canada is needed. Previous research has often focused on narrow waste streams or framed plastics only within climate change debates. A comprehensive analysis that combines environmental, socio-economic, and policy perspectives, and situates Canada within an international context remains lacking. The present study addresses this gap by systematically reviewing agri-plastic use and waste generation across Canadian provinces, comparing practices internationally, and evaluating policy tools. It provides a clear overview of Canada's position relative to other countries and identifies pathways for advancing sustainable management.

The present study outlines the main types and functions of agricultural plastics in Canada, examines their environmental, social, and economic implications, and evaluates existing policies and regulatory mechanisms worldwide. It offers a comprehensive overview of Canada's status relative to other countries, clarifying their role in the agricultural system and progress in end-of-life management. Drawing on national and provincial initiatives, the study highlights the mix of regulatory, voluntary, and economic frameworks supporting recycling and stewardship programs, while identifying gaps to guide policymakers and future research.

2 Methodology

A descriptive-analytical approach was applied through presented an integrative literature review[20–22] of scientific studies

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published between 2014 and 2025, developed following Page *et al.* protocol and the PRISMA 2020 flow diagram template.[23] Electronic resources included Web of Science and Google Scholar. Initially, studies were retrieved from Web of Science using the keywords listed in the Table 1, and Google Scholar was subsequently used for cross-referencing and to supplement information from FAO and OECD, UNEP, and regional case studies (2014–2025) *etc.* The document types included articles, books, reports and web sites, Fig. 2.

Secondary data[24] (2014–2024) collection to assess agricultural plastics, their management, and impacts across Canadian provinces conducted from the main Canadian data source "Cleanfarms".[5] Countries were chosen based on data reliability and strategic relevance, enabling comparative insights on regulatory frameworks, recycling outcomes, and farming practices. Data were visualized in Excel through charts and tables, focusing on:

- Types and functions of agricultural plastics,
- Volume of waste by province in Canada,
- Canadian policy measures (2014–2024),
- Global comparison of agricultural plastic use and waste management.

3 Types and usage trends of agricultural plastics in Canada

3.1 Categories of agricultural plastics and waste generation

The agricultural sector uses various plastic polymers engineered with specific properties for their applications, including: polyethylene (PE), polypropylene (PP), expanded polystyrene (EPS), ethylene-vinyl acetate copolymer (EVA), polyvinylchloride (PVC), polyethylene terephthalate (PET), polycarbonate (PC), polymethylmethacrylate (PMMA), thermoplastic polyurethane (TPU), polyamide (PA; nylon), acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyhydroxyalkanoates (PHA), polybutylene succinate (PBS), starch blends, polybutylene adipate terephthalate (PBAT), and polycaprolactone(PCL).[10,25] In Canada, agricultural plastics are categorized by function, physical properties, regional climate, farming methods, and crop type. Annual reports from Cleanfarms[5] and Environment and Climate Change Canada[3,4] list the common categories Table 2. Cleanfarms report[5] estimated that over half of Canadian agricultural plastics are low density polyethylene (LDPE) by resin type.

Fig. 3, shows the largest annual agricultural plastic waste was from field crops (36 767 tonnes), followed by non-greenhouse vegetables (6099 tonnes), greenhouse vegetables (5876 tonnes), and pesticide/fertilizer packaging (4761 tonnes). Cannabis production generated the least (633 tonnes). The rest came from fruit, berries, nuts, maple syrup, cattle, nursery production, ornamental plants, and horticultural flowers.[5]

Within this informative scenario just shown, based on data from 2021, Cleanfarms identified 26 categories of agricultural plastic generation based on resin composition and functional application. According to these estimates, the highest annual tonnage was associated with linear low-density polyethylene (LLDPE) bale wrap, amounting to 15 055 tonnes. This was followed by LDPE grain bags (6.950 tonnes), mixed plastics and net wrap (6.946 tonnes), PS trays (6.464 tonnes), high density polyethylene (HDPE) drums (1.515 tonnes), metallocene PE tubing (1.332 tonnes), LDPE bags (1.306 tonnes), LDPE silage tarps (1.150 tonnes), and LLDPE mulch film (1.143 tonnes). The remaining categories were below 1000 tonnes, including: greenhouse hardware, HDPE drip tape, HDPE IBCs, PP pots, LLDPE bale tubes, PVC trays, HDPE pots, LDPE silage bags, nylon fittings, PP film tear strips and LDPE tubing. In contrast, the lowest tonnage was recorded for Mylar Canada and the globe bags - LDPE and foil (2 tonnes).[5]

3.2 Trends in agricultural plastics and waste generation by province

In the previous sections of this study, it was noted that the overall volume of agricultural plastic waste produced annually across Canada was approximately 61 754 tonnes,[5] consisting of various types based on their functional applications. This section provides a more detailed analysis of the amount annually generated in each province and compares their respective contributions.

3.2.1 Maritimes (New Brunswick, Nova Scotia, and Prince Edward Island). LLDPE bale wrap recorded the highest annual production tonnage (433 tonnes) across these provinces for preserving livestock feed, followed by PS trays (226 tonnes) for packaging freshness and PP woven bags (137 tonnes) for durable transport and storage. In general, LLDPE resin-based materials represented the most extensively used category, with subsequent contributions from PP, HDPE (for versatile and robust applications), PS, and mixed plastics using a diverse collection of farm essentials.

3.2.2 Quebec. In Quebec, the highest volumes were recorded for PS trays (2465 tonnes) for food packaging and presentation and seedling cultivation, LLDPE bale wrap (1885 tonnes) to preserve livestock feed and silage production, and metallocene PE tubing (1206 tonnes) for maple sap collection,

Table 1 Keywords and Boolean expressions used for research

ID	Keywords and Boolean
1	TITLE-ABS-KEY ("Agricultural Plastics" OR "Plastic Waste" OR "Plastic Use") AND ("Waste Management")
2	TITLE-ABS-KEY ("Canadian Agricultural Plastic Utilization" AND "Waste Generation" AND ("Waste Management")
3	"Agricultural Plastic in Canada" AND "The Globe"
4	TITLE-ABS-KEY ("Agricultural Plastic Socio-Economic Impacts" AND "Agricultural Plastic Environmental Impacts")
5	TITLE-ABS-KEY ("Agricultural Plastic Management")

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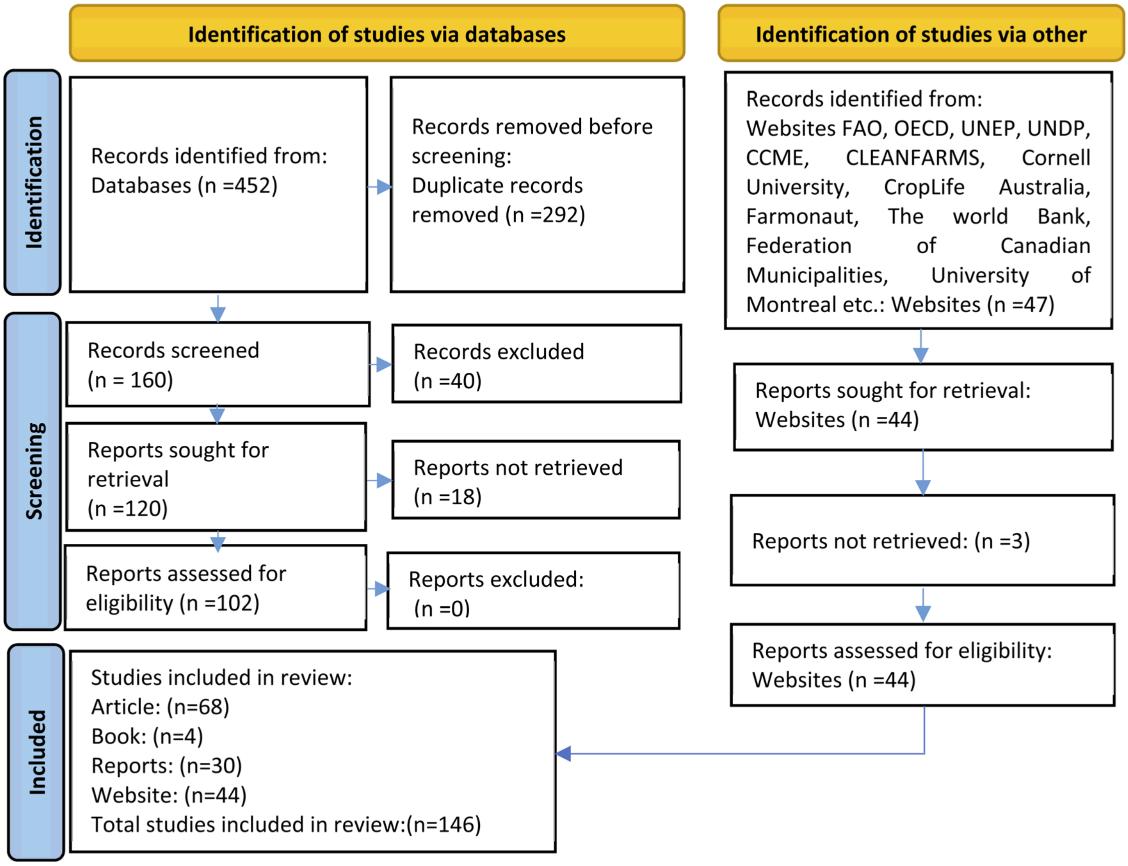

Fig. 2 The PRISMA flow diagram shows the flow of information through the different phases of this systematic review, including study identification, screening, eligibility, and inclusion. The design is redrawn by authors from Page *et al.*[23]

whereas resin-based materials such as nylon and EPS accounted for comparatively lower quantities.

3.2.3 Ontario. The highest estimated volumes of agricultural plastic generation in Ontario, based on functional application, were associated with PS trays (2964 tonnes) to protect, display, and preserve food products, LDPE roof film (2277 tonnes) to cover the vast acreage of greenhouses producing, LLDPE bale wrap (2035 tonnes) to preserve and ferment livestock feed, and EPS trays (91 348 tonnes) also for food-related uses, respectively. The volume attributed to PVC was comparatively low across resin categories.

3.2.4 Manitoba. Based on the application of agricultural plastics in Manitoba, LLDPE bale wrap (1480 tonnes) to preserve livestock feed and mixed plastics, net wrap (786 tonnes) had the highest levels of use for packaging (such as net wrap for hay

Table 2 Categories of agricultural plastics used in Canada in 2021, table drawn from Cleanfarms[5] and ECCC annual reports[3,4]

Plastic application	Resin type(s)	Primary use
Silage bags and bunker covers	LDPE	Livestock farming and animal feed
Bale Wraps	LLDPE	Wrapping hay and forage
Grain bags	LDPE	Temporary grain storage
Greenhouse roof films	LDPE	Vegetable greenhouses
Mulch films	LLDPE	Weed control and soil warming
Drip irrigation tubes	HDPE	Water delivery systems
Pesticide and fertilizer containers	HDPE	Chemical storage
Netting	Mixed plastic	Binding bales and plants
Twines	PP	Binding bales and plants
Trays	PP, EPS, PS, PVC	Propagation
Green house hardware	PP	Clips, supports and spools
Woven bags	PP	Fertilizer and seed bags
Maple syrup tubing	mPE	Maple syrup
Maple syrup taps and spiles	Nylon	Maple syrup

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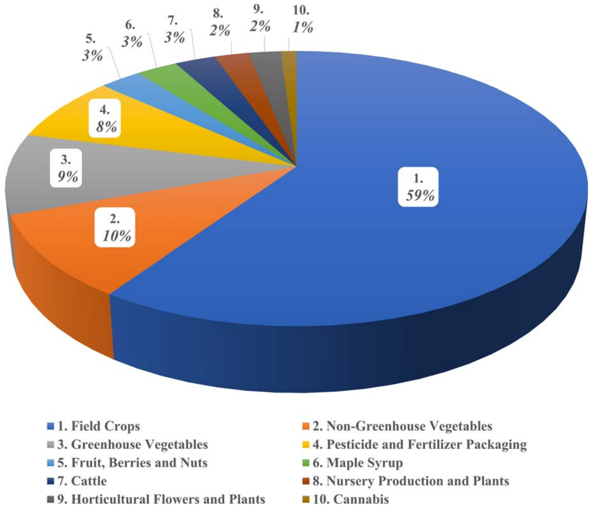

Fig. 3 Annual agri-plastic waste by sector (tonnes) in 2021. Data are taken from Cleanfarms.[5]

bales), storing, and transporting various agricultural products and materials, whereas PS resin showed the lowest utilization.

3.2.5 Saskatchewan. The most widely used agricultural plastic in Saskatchewan was LDPE grain bags, with a volume of 4203 tonnes to provide a flexible, temporary storage solution for harvested grains. This was followed by LLDPE bale wrap (3180 tonnes) for preserving livestock feed and mixed, net wrap (2166 tonnes) to contain and secure round bales of hay or straw. The usage of products based on PS resin was considerably lower compared to LDPE in this province.[26]

3.2.6 Alberta. LLDPE bale wrap (4998 tonnes) to preserve high-moisture forage crops, mixed plastics, net wrap (2460 tonnes) to contain and secure round bales of hay and straw, and LDPE grain bags (1980 tonnes) a flexible and temporary on-farm storage system for grain represented the most widely used agricultural plastics in Alberta. In contrast, products based on PS and EPS resin showed significantly lower levels of usage.

3.2.7 British Columbia. As illustrated in Fig. 4, plastic usage in British Columbia shows distinct patterns based on agricultural needs. Data indicates that LLDPE bale wrap had the highest level of use (1043 tonnes) for preserving high-moisture forage crops. This was followed by LDPE roof film (691 tonnes) for greenhouse coverings, PS trays (684 tonnes) for retail packaging, and PP twine (323 tonnes) for binding purposes. In contrast, the use of EPS resin-based plastics was relatively limited.

3.2.8 Canada. Regarding the broader context of Canada, Fig. 4 also highlights regional distributions. The highest annual amount of agricultural plastic generated was LLDPE bale wrap, with the largest shares produced in the provinces of Alberta (4998 tonnes) and Saskatchewan (3180 tonnes). Additionally, LDPE grain bags (6950 tonnes) emerged as the second most widely used plastic, predominantly utilized in the Prairie provinces. With the 3rd, 4th, and 5th most common agricultural plastics being mixed plastics – net wrap, PS trays, and PP twine, respectively. These five types of agricultural plastics collectively accounted for approximately 64% of the total national tonnage generated in Canada.

4 Environmental impacts of agricultural plastic

In this context, waste mismanagement refers to any handling of agricultural plastics that falls outside of formal recycling, landfill or energy recovery streams, including long-term stockpiling, illegal dumping/burying and uncontrolled open-air burning. Extensive use of agricultural plastics, though only 2–3.5% of global plastic production, leads to high waste mismanagement (16–50%) and contributes significantly to soil contamination and marine litter, mostly from land-based sources.[27] Released plastics harm soil, water, and air physically, chemically, and biologically.[14,28]

The release of harmful chemicals, such as phthalates from mismanaged plastics, poses significant risks in the Canadian context.[25,29] In Canada, LDPE, PVC, EVA, and LLDPE are predominant in soils.[30] The size of the plastic material plays a crucial role in determining the type and severity of these impacts.[30] Microplastics (<5 mm) from mulch films persist in soil, enter food chains, and reduce yields, affecting wildlife.[29,31–34]

The durability of plastics creates a significant environmental burden, contributing to long-term pollution, greenhouse gas emissions, and public health risks.[1,28,32,35] Once in the environment, plastics release contaminants through various pathways. For instance, the open burning of plastic waste releases toxic pollutants into the air, while the leaching of chemical additives directly contaminates surrounding soil and water.[36,37] Furthermore, plastic fragments are easily dispersed across large areas by wind, water movement, and soil erosion, spreading contamination far beyond the initial disposal site.[14]

This widespread dispersal has made plastic one of the most pervasive forms of soil contamination today.[1] Common agricultural sources, such as polyethylene mulching films, ground covers, and seed casings, are major contributors that degrade over time.[38–40] As these plastics break down into persistent micro- and nano plastics, they fundamentally alter the soil's physical, chemical, and biological properties. These residues can hinder water infiltration, reduce moisture retention, and release toxic additives, which in turn reduces soil fertility and negatively impacts essential organisms such as earthworms and nematodes.[14,41] Ultimately, when plastic waste is improperly managed near water sources, this contamination extends into aquatic systems and groundwater, posing a serious threat to biodiversity and human health.[6,42–46]

5 Social impacts of agricultural plastic

The adoption of agri-plastics significantly enhances agricultural productivity by increasing crop yields, improving farmer income, and ensuring livelihood stability, which in turn enables greater investment in education, healthcare, and community well-being.[1,47,48] These materials also strengthen food security

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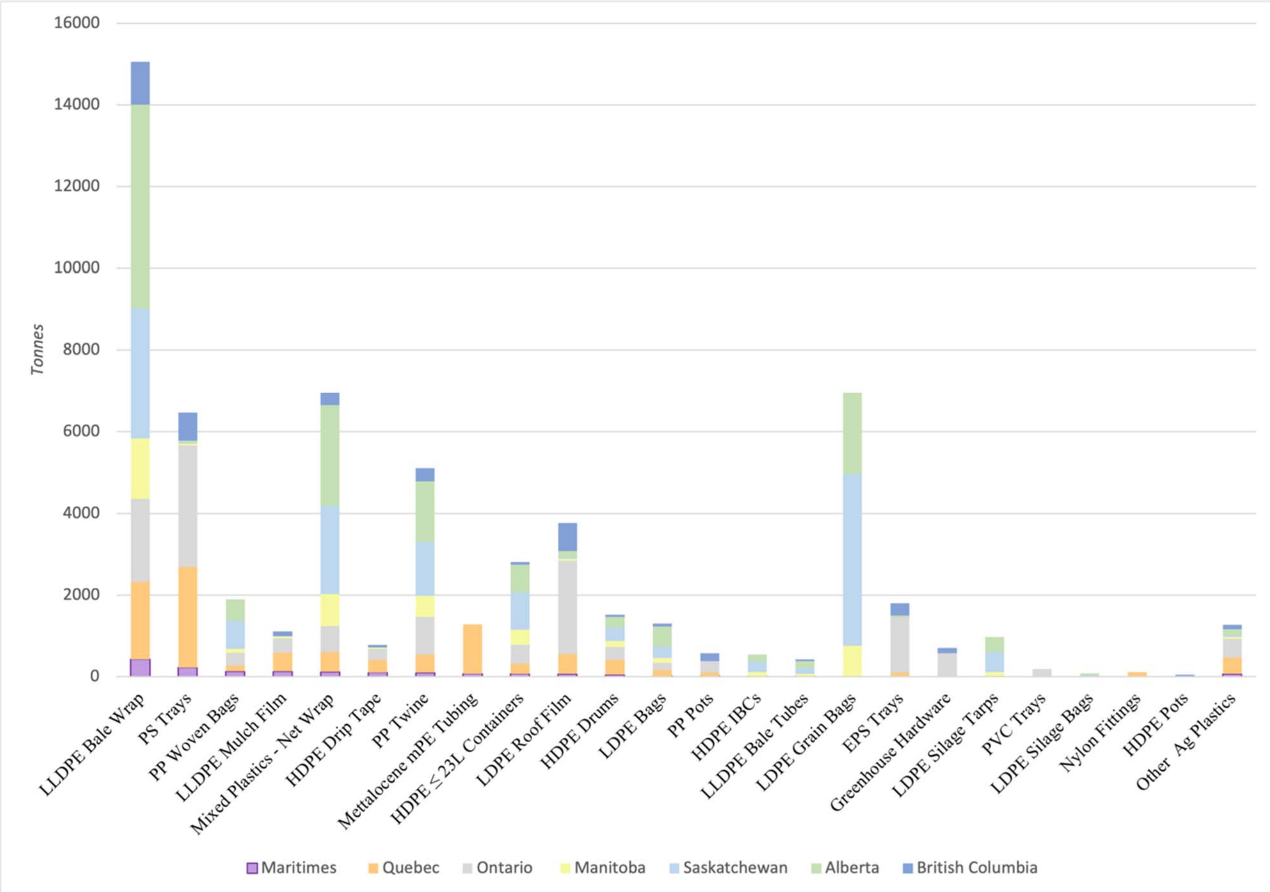

Fig. 4 Estimated annual agricultural plastic generation by resin composition and functional application, by region in Canada as of 2021 (tonnes), data are taken from Cleanfarms.[5]

by extending growing seasons, stabilizing production, and reducing post-harvest losses, particularly in remote or harsh climates.[49–51] However, these benefits are contrasted by potential social and health risks; for instance, microplastics entering the food chain through crops and fish pose serious public health concerns.[13,34,52,53]

The social dimension of plastic waste is further complicated by logistical burdens. Limited recycling services often require farmers to manually handle waste, adding significant time and labor costs. In many remote Canadian areas, the lack of waste management infrastructure raises concerns about environmental injustice and rural marginalization.[33,54] Challenging local conditions often hinder "waste diversion" which refers to the strategic redirection of waste from landfills toward recycling or recovery. In contrast, some urban and semi-urban municipalities, such as Quebec's Coaticook, have successfully developed eco-centres for agricultural plastics with federal support, aiming for 70% waste recovery.[55]

Furthermore, social behaviors and perceptions play a vital role in plastic management.[43,44] Awareness, education, and peer influence significantly shape farmers' practices.[56–58] While some see plastics as essential modern tools, financial constraints often push farmers toward cheaper, non-biodegradable alternatives. Despite recognizing environmental harms, many farmers view waste management as a burden due to financial barriers, sometimes leading to improper disposal practices such as on-site burning or burial.[6,59] To address these challenges, community-driven initiatives and local participation are crucial for rural revitalization.[60] For instance, Ontario beef farmer Lynn Leavitt developed a decentralized system using a compactor to manage bale wrap waste. By partnering with neighboring farmers and local stores, this grassroots approach fostered community cooperation. Similar practices adopted by other local practitioners, such as Ontario grain and beef farmer Don Badour, demonstrate that strengthening local engagement is both practical and socially beneficial.[61]

Ultimately, a visible commitment to responsible agri-plastic use enhances public trust and promotes sustainable agriculture while creating rural employment across the agri-supply chain.[1,14,17,62]

6 Economic impacts of agricultural plastic

Plastic pollution imposes both direct and indirect economic burdens.[63] The management of agricultural plastic waste presents significant economic challenges for farmers, local waste

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Table 3 Dual environmental and socio-economic impacts of agricultural plastics use

Indicator	Effect	References
Environmental	**Positive**	
	Water conservation	7, 8, 12, 13, 15 and 75
	Soil control and fertilizer efficiency	11, 12 and 76
	Weed and pest suppression	12, 14, 76 and 77
	Land conservation	13, 16 and 76
	Temperature and nutrient control	11, 12, 14, 15 and 77
	Negative	
	Soil pollution	1, 14, 30–32, 37, 38 and41
	Water pollution	6, 32, 37, 42 and 78
	Greenhouse gas emissions	1, 28, 35 and 36
	Reducing plant growth	1, 39, 41, 75 and 79
	Threatens biodiversity	44–46
Social	**Positive**	
	Food security	47–51
	Improving livelihood stability	1
	Public trust and promote sustainable agriculture	1, 60 and 62
	Enhanced collaboration in the community	60 and 61
	Employment generation	1, 14, 17 and 80
	Negative	
	Food insecurity	6, 17 and 52
	Threats to consumer health	16, 29, 34, 75 and 78
	Increased labour and potential transfer	6 and 77
	Increased extension services for awareness and education	14 and 56–59
	Social inequity	33, 54 and 55
	Change in consumption patterns and usage culture	57, 58 and 81
Economic	**Positive**	
	Enhancing crop yields and productivity minimal inputs	16, 52, 75, 77 and 79
	Job creation and new market	1, 77 and 80
	Animal care (security, feed, fodder production)	1
	Negative	
	Reduce crop yields and productivity	7, 8, 32 and 39
	Landfill tipping fees for plastic waste	68 and 81
	Higher rural collection costs	64
	Downcycling of recycled plastic	10 and 65
	Reduced liquidity for farmers	17
	Indirect economic burdens on public sectors	68 and 81
	Additional financial strain on provinces without EPR	19, 72 and 81
	Decreased tourism industry	72

management systems, and municipal governments. The costs associated with collection, transportation, and proper disposal or recycling of agri-plastics often exceed the financial capacities of rural communities and individual farmers.[64] In provinces without active EPR schemes, these financial burdens are even greater. A field study conducted in Almeria, Spain, showed a clear link between the cost of raw materials for plastic production and the amount of plastic recycled. In general, recycling post-consumer plastics poses significant time and financial challenges for farmers.[65] Additionally, the adhesion of agricultural plastics to soil and plant roots complicates recycling and processing efforts, leading to increased costs.[18,59,65,66] Agricultural plastics impose significant direct and indirect economic burdens on farmers and rural communities. Direct costs include collection fees, such as $50 CAD per tonne in Oxford County, Ontario[67] and landfill tipping fees ranging from $80 to $160 per tonne which accumulate given farms generate tens of thousands of tonnes of plastic annually. Nationally, plastic waste management is costly, with sector expenditures reaching $5.9 billion in 2019, while economic losses due to plastic waste were estimated at $7.8 billion in 2016 and projected to rise to $11.1 billion by 2030.[68]

Pilot programs in Alberta and British Columbia, with budgets of CAD $500,000 and CAD $188,000 respectively, further highlight the financial pressures of managing agri-plastics.[69,70] Compounding these costs, recycling is complicated by contamination and degradation of plastics such as mulch films and silage bags, which results in lower-quality recycled products and limited market value, perpetuating downcycling.[6,10]

Indirect costs also emerge through environmental damage: soil health decline reduces crop productivity[63] while marine plastic pollution undermines tourism.[71,72] Innovative initiatives, such as replacing polystyrene fish boxes with biodegradable

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coconut-husk coolers in the Philippines, demonstrate cost-effective alternatives that reduce ocean plastics by 50 tonnes annually.[73]

Moreover, high recycling costs reduce farmers' liquidity and limit reinvestment in core activities.[17]

Despite these challenges, agricultural plastics also support economic opportunities. Their use in livestock and crop production enhances efficiency and creates employment in handling, storage, and veterinary care.[1,17]

Recycling infrastructure, plastic recovery technologies, and community-led initiatives offer potential to stimulate rural economies, improve waste management, and expand domestic and international plastic markets.[1,74,75]

Table 3, serves as a comprehensive summary of the multi-faceted impacts of agricultural plastics discussed in the text. It organizes the key findings into beneficial (positive) and detrimental (negative) effects across the three main pillars: environmental, social, and economic.

7 Introduction to policy frameworks and approaches to agricultural plastics

The sustainable use of plastics in agriculture relies on the principles of refuse, reduce, reuse, repurpose and recycle, which are more effective than disposal, and requires balancing economic, social, and environmental goals.[1] Two critical factors for end-of-life strategies are the potential for collection after use and the product's lifespan, yet current reuse and recycling rates remain below 10%, highlighting the need for improvement.[14] Dedicated programs, legislative or voluntary, must ensure coordinated and accessible collection systems.[82]

Globally, policy instruments to enhance plastic circularity include regulatory measures (restrictions, bans, standards), economic tools (tax incentives, subsidies, penalties), and voluntary initiatives (certification, awareness, partnerships). EPR is a key example, shifting accountability to producers.[63] In the case of Canada, it has adopted collection and recycling programs to reduce environmental harm.[10] For the EU, the "polluter pays" principle assigns financial and logistical duties to waste generators[83] while countries such as Ireland, Norway, Brazil, and South Korea mandate farmer-led collection. Other methods as seen with China, has enforcement of mulch film thickness standards for easier recovery.[10]

Economic mechanisms such as deposit-return schemes, landfill taxes, and tax credits have been effective[84] while voluntary measures such as labelling, training, and community initiatives, support behavioral change. A shift toward shared responsibility across the plastic value chain, from manufacturers to end-users, represents a more systemic accountability model.[10]

Successful international case studies include Europe's APE Group recycling 38 000 tonnes of farm plastics, Finland's conversion of recovered plastics into farm products, Scotland's Green Sack from recycled bags, and Spain's MAPLA initiative recovering over 100 000 tonnes.[10] These countries' success has been largely attributed to strict and robust legislation combined with high recycling rates achieved through harmonized EPR schemes. Community cleanups and individual responsibility efforts, such as Keep America Beautiful,[85] and Break Free from Plastic,[86] have also gained traction in Canada and beyond.

A comprehensive policy framework requires progress in five areas: transparent data collection, legislation, research and development, business innovation, and capacity building. Open-access platforms to track plastic sales, usage, waste, and recycling are essential for evidence-based policymaking and lifecycle monitoring.[18]

7.1 Policy frameworks and regulatory landscape for agricultural plastics in Canada

The management of agricultural plastics in Canada is guided by a fragmented but evolving framework combining federal strategies, provincial regulations, and voluntary or industry-led initiatives. While no single national law governs agricultural plastic waste, EPR and stewardship programs form the core of current efforts. The Canada-wide strategy on zero plastic waste[87] initially targeted consumer plastics but expanded in 2020 to include industrial and agricultural plastics, promoting a circular economy and EPR development. In 2024, the federal government invested 4.5 million CAD in green agricultural initiatives, including 1.1 million CAD to Cleanfarms to design a national strategy for managing the estimated 60 000 tonnes of plastic waste generated annually on farms.[88]

Canadian policy instruments fall into four categories: regulatory (*e.g.*, provincial recycling and stewardship laws), economic (collection fees, grants), informational (training, reporting), and voluntary tools.[1,89] EPR schemes, first adopted in 1989,[1] are widely implemented at the provincial level.[18] Voluntary EPR programs manage plastics from seed and grain bags, fertilizer and pesticide packaging, and films, mainly HDPE, LDPE, and PP, and continue to expand.[3]

Provincial leadership varies: British Columbia launched a five-year pilot in 2025 (188 000 CAD) for rural recycling.[70] Saskatchewan and Alberta operate EPR-style grain bag and twine programs with Cleanfarms support.[90–92]

Ontario lacks a formal EPR framework but municipalities such as Oxford County charge localized collection fees.[93] Cleanfarms, a national non-profit, operates 1300+ collection sites, running voluntary and regulated programs for pesticide containers, silage plastic, grain bags, and bale wrap.[94]

Canadian efforts emphasize five strategies: recycling 23 l pesticide/fertilizer containers, large-scale Prairie recycling of grain bags and twine, safe management of bulk containers, Quebec's programs for maple sap tubing and feed bags, and national education campaigns.[95] Recovery rates illustrate progress: 2000 tonnes recycled in 2015 grew to 6000 tonnes by 2020; by 2021, farmers returned 2.25 million kg of containers, achieving a 77% recovery rate, rising to 87% in 2023.[96–99]

Three main trends emerge from 2014–2024 initiatives: (1) nationwide expansion from small containers to diverse plastics such as grain bags, bale wrap, and sap tubing; (2) proliferation of provincial pilot and regulated programs, *e.g.*, Saskatchewan's grain bag recycling surpassing 1 million kg annually and

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Table 4 Main regional policy measures to address agricultural plastics management in Canada from 2014 to 2024 [a], data are taken from[66,100–109]

Program	Year	Where	Result/effect
Empty container recycling program	2014	Across the country	4.5 million empty pesticide and fertilizer containers were retuned to collection sites to be recycled; 206 170 kg of empty bulk pesticide containers (>23 lit) were collected for recycling[100]
Obsolete pesticide and livestock medication collection program	2014	BC, SK, QC & PE	223 831 kg of obsolete pesticides have been collected and 5051 kg of livestock medication returned[100]
Empty seed and pesticide bag program	2014	ON, QC & Atlantic	162 000 empty seed and pesticide bag returned and converted into energy in southwestern Ontario and Quebec and 35 000 in Atlantic[100]
Empty container recycling program	2015	Across the country	In Alberta, the total volume of 23 lit and less pesticide and fertilizer containers recycled was 4,66 million and more than 6500 containers of non-refillable bulk was recovered[101]
Obsolete pesticide and livestock medication collection program	2015	BC, AB, SK, NB & NS	The total volume of obsolete pesticides collected was 213 049 kg, while the number of livestock and equine medications was 4435 kg and properly disposed[101]
Empty seed and pesticide bag program	2015	ON, QC, NB, NS & PE	566 613 empty seed and pesticide bags returned[101]
Empty container recycling program	2016	Across the country	The number of 23 lit and less pesticide and fertilizer containers collected was 5 200 800 and over 34 720 non-refillable bulk containers were collected across all provinces[102]
Obsolete pesticide and livestock medication collection program	2016	Peace region, AB, MB, ON & NF	278 831 kg of obsolete pesticides have been collected and 19 927 kg of livestock medication returned[102]
Empty seed and pesticide bag program	2016	ON, QC, NB, NS & PE	A total of 295 568 kg of pesticide and seed bags were collected and returned[102]
Empty container recycling program	2017	PE, NB, NS, SK, QC, ON, MB, BC & AB	The total volume of 23 lit and less pesticide and fertilizer containers recycled was 5 053 731 and more than 42 732 non-refillable bulk containers were collected[103]
Obsolete pesticide and livestock medication collection program	2017	BC, SK, QC & PE	The total volume of obsolete pesticides collected was 269 749 kg, while the number of livestock and equine medications was 5050 kg and properly disposed[103]
Empty seed and pesticide bag program	2017	PE, NS, NB, QC & ON	298 925 kg empty seed and pesticide bag returned[103]
Empty small container recycling program	2018	PE, NS, NB, ON, QC, MB, SK, BC & Alberta	The number of 23 lit and less fertilizer and pesticide containers recycled was 5 777 030 (ref. 104)
Collection program of non-deposit bulk container	2018	Across the country	A total of 44 367 non-refillable bulk pesticide containers, with capacities ranging from just over 23 litres up to 1000 litres, were gathered[104]
Seed, pesticide and fertilizer bag collection program	2018	PE, QC, NS, NB & ON	A total bag of fertilizer, pesticide and seed gathered were 365 792 kg[104]
Expired pesticides and livestock medications collection program	2018	BC, SK, AB, NS & NB	The total volume of 181 362 kilograms of outdated and unwanted pesticides were retrieved and 2483 kg livestock, equine medications collected[104]
Saskatchewan provincially regulated grain bag recycling program	2018	SK	A total of 1 291 010 kg bags of grain, twine, and film were recovered[104]
Pesticide and fertilizer containers recycling program	2019	BC, SK, MB, ON, QC, NB, NS & PE	5 464 470 containers returned[105]
Non-deposit bulk containers collection program	2019	BC, SK, MB, ON, QC, NB, NS & PE	55 369 totes and drums ranging in size from more than 23 litres to 1000 litres collected[105]
Seed pesticide and fertilizer bag collection program	2019	PE, NS, NB, QC & ON	The number of 429 288 kg seed, pesticide and fertilizer bags returned[105]
Expired pesticides and livestock/equine medications collection program	2019	BC (Peace region), AB (Peace region), AB (North), MB, ON & NF	A total of 214 618 kg expired pesticides recovered, 5842 kg old obsolete livestock/equine medications collected[105]
Saskatchewan provincially regulated grain bag recycling program	2019	SK	2256 tonnes grain bag collected for recycling[105]
Manitoba agricultural plastics recycling pilot program	2019	MB	51 tonnes plastics collected[105]

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Table 4 (*Contd.*)

Program	Year	Where	Result/effect
Pesticide and fertilizer small container recycling program	2020	SK, BC, AB, QC, MB, ON, PE, NS & NB	The number of fertilizer and pesticide containers ranging in size from more than 23 litres to 1000 litres gathered and recycled was 5 547 079 (ref. 106)
Non-deposit bulk container program	2020	BC (Peace region), AB, SK, MB, ON, QC & Maritimes	A total of bulk containers without a refundable deposit recovered was 61 979 (ref. 106)
Program for collecting seed, pesticide, and fertilizer bags	2020	PE, NS, NB, QC (fertilizer bags collected only in Quebec) & ON	By province, a total of 420 830 kg of seed, pesticide, and fertilizer bags were recovered[106]
Collection program for obsolete pesticides and livestock/equine medications	2020	BC (Vancouver Island & Fraser Valley), SK (South) & QC PE	298 127 kg unwanted pesticides collected recovered, 3389 kg old obsolete livestock/equine medications collected recovered[106]
Saskatchewan provincially regulated grain bag recycling program	2020	SK	2536 tonnes grain bags collected in Saskatchewan for recycling collected[106]
Manitoba agricultural plastics recycling pilot program	2020	MB	In Manitoba, the volume of grain bags, bale and silage wrap and twine recovered were 38,4 tonnes[106]
Pilot program for recycling agricultural plastics in Alberta	2020	AB	In Alberta, the number of grain bags gathered was 505 tonnes while 18 tonnes baler twine returned[106]
Quebec agricultural plastics recycling pilot program	2020	QC	82.1 tonnes of plastic products used in silage and hay production, including film, twine, netting, tarps, and silo bags, were recovered[106]
Small containers collected	2021	BC, SK, AB, MB, QC ON, PE, NB & NS	6 245 000 units small containers collected[66]
Non-deposit bulk container recycling program	2021	BC, AB, SK, MB, QC, ON & Maritimes	71 000 units containers collected[66]
Collection program for obsolete pesticides and livestock/equine medications	2021	BC (Okanagan, Interior, Kootenay), Northern SK, NB, Southern AB & NS	201 000 kg unwanted pesticides collected and 5550 kg old obsolete livestock/equine medications collected[66]
Saskatchewan provincially regulated grain bag recycling program	2021	SK	2114 tonnes grain bags collected for recycling[66]
Seed and pesticide bags collection program	2021	PE, NB, NS, QC, ON, SK, MB, & AB	A total of 473 000 kg of seed, pesticide, and fertilizer bags were collected, with fertilizer bag collection occurring exclusively in Quebec. Additionally, 49 000 kg of seed, pesticide, and inoculant bags were gathered across the Prairie provinces[66]
Quebec agricultural plastics recycling pilot program	2021	QC	A total of 311 000 kg of agricultural plastics, including plastic film for silage and hay bales, baler twine, netting, and tubing used for maple sap collection, were gathered. Additionally, 259 000 kg of bale wrap, tarps, silage bags, twine, and netting were collected, along with 52 000 kg of maple sap tubing[66]
Manitoba agricultural plastics recycling pilot program	2021	MB	The number of baler twine, grain bags, bale and silage wrap gathered were 76 tonnes[66]
Agricultural plastic recycles it pilot project in Alberta	2021	AB	Collection programs gathered 784 tonnes of grain bags and 160 tonnes of baler twine[66]
Small agricultural plastic container recycling	2022	AB, BC, SK, QC, MB, PE, NB & NS	The total number of containers ranging in size from more than 23 litres to 1000 litres recycled was 5625.000 unite[107]
Non-deposit bulk container recycling	2022	BC, ON, AB, QC, SK, Maritimes & MB	Recycling efforts recovered 74 100 non-deposit totes and drums used for bulk pesticide and fertilizer storage, with volumes ranging from 23 l to 1,000 l[107]
Unwanted pesticides collection program	2022	BC (Peace region), AB (Peace region), AB (North), MB, ON & NF	323 500 kg outdated pesticides gathered[107]
Collection program for expired and unused livestock/equine medications	2022	AB (peace region), AB (North), MB, ON, NF	9700 kg expired livestock/equine medications gathered[107]
Saskatchewan provincially regulated grain bag recycling program	2022	SK	881 tonnes grain bags collected[107]
Manitoba's newly launched grain bag and twine recycling program under provincial regulation	2022	MB	The number of baler twine and grain bags returned was 29 100 kg[107]
Quebec's permanent and pilot initiatives for agricultural plastic recycling	2022	QC	In total, 864 000 kg of waste materials were gathered, comprising 574 000 kg of bale-related plastics and 290 000 kg of maple sap tubing[107]
	2022	AB, QC, SK, PE, MB, NB, ON & NS	

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Table 4 (*Contd.*)

Program	Year	Where	Result/effect
Seed, pesticide, and inoculant bag recovery programs under permanent and trial phases			The total number of seed, pesticide, inoculant and fertilizer, bags returned were 553 800 kg[107]
Advancing toward zero plastic waste in the agricultural sector	2022	Across country	A total of 127 000 kg of ag plastic film, twine, and grain bags were redirected through pilot collection initiatives[107]
Pilot program for recycling agricultural plastics in Alberta	2022	AB	The Ag-Plastic recycle It pilot initiative in Alberta successfully gathered 477 tonnes of grain bags along with 119 tonnes of baler twine[107]
Dairy farmers of Canada endorse the recycling of agricultural plastic film	2022	MB & BC (Kent district)	Approximately 60 tonnes of bale wrap, silage bags, and bunker covers were collected through DFC-funded pilot initiatives[107]
Gaining improvements in sustainability	2022	ON, MB, BC, PE	In 2022, recycling empty agricultural containers led to carbon dioxide emission reductions equivalent to taking 930 cars off the road for a year, saving 1 820 000 litres of gasoline, preserving carbon sequestration by 71 300 acres of forest for one year, growing 162 000 tree seedlings over ten years, and offsetting the annual energy use emissions of 515 households[107]
Recycling of small ag plastic containers	2023	BC, SK, AB, ON, MB, QC, PE, NS & NB	2.37 million kg containers collected[108]
Non-deposit bulk container recycling	2023	BC, AB, SK, QC, MB, ON, PE, NB & NS	89 300 units containers collected[108]
Quebec agricultural plastics recycling programs	2023	Quebec	Collection efforts yielded 1.47 million kg of agricultural film and twine, in addition to 572 000 kg of tubing used for maple syrup production[108]
Program for collecting unused pesticides and expired livestock/equine medications	2023	BC (Fraser Valley & Vancouver), SK (South), QC & PE	7100 total kg old livestock/equine medications 313 000 total kg unwanted pesticides collected[108]
Saskatchewan's provincial effort to recycle grain bags, with a pilot project for baler twine recovery	2023	SK	Collection programs resulted in the return of 1.52 million kg of grain bags and 21 700 kg of baler twine[108]
Manitoba's regulated program targeting the recovery of grain bags and baler twine	2023	MB	Recycling efforts processed 45 900 kg of grain bags and baler twine[108]
Creating a zero plastic waste roadmap for the agricultural sector (pilot program)	2023	BC, AB, SK, ON, PE	In 2023, pilot projects under the Canadian agricultural strategic priorities program diverted 275 000 kilograms of agricultural plastic, twine, and grain bags from waste[108]
Seed, pesticide, fertilizer and inoculant bags program	2023	AB, SK, MB, ON, QC, PE, NB & NS	Collection efforts recovered 794 000 kg of seed, pesticide, and inoculant bags[108]
Alberta ag-plastic recycle it (pilot) ag plastic, twine and grain bags diverted	2023	AB	Collection efforts gathered 673 000 kg of grain bags along with 95 400 kg of twine[108]
Dairy farmers of Canada: getting results in ag plastic film recycling (pilot)	2023	MB (Kent District) & BC	Pilot programs funded by DFC resulted in the diversion of 53 800 kilograms of bale wrap, silage bags, and bunker covers[108]
New programming rolling out in PEI	2023	PE	67 100 kg bale wrap and silage bags diverted
Sustainability & circularity: better for business, better for Canada (CO_2e emissions avoided are equal to…)	2024	Across the country	The impact is equivalent to removing 2030 cars from the road for one year, growing 353 000 tree seedlings for a decade, saving 3 970 000 litres of gasoline, offsetting the energy emissions of 1120 households annually, and maintaining carbon sequestration on 155 000 acres of forest for one year[109]
Small containers collected for recycling program	2024	BC, SK, AB, ON, MB, QC, PE, NS & NB	2.2 million kg containers collected[109]
Non-deposit bulk container recycling	2024	BC, ON, NS, Alberta, QC, SK, PE, MB & NB	Collection efforts recovered 96 600 bulk containers not subject to deposit fees[109]
Recycling program for seed, pesticide, fertilizer, and inoculant bags	2024	Across the country	996 000 kg bags collected[109]
Quebec agricultural plastics recycling programs	2024	QC	2.32 million kg ag film, silage tarps, silage bags, twine collected[109]
Maple tubing program	2024	QC	733 000 kg tubs collected[109]

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Table 4 (*Contd.*)

Program	Year	Where	Result/effect
Quebec feed, horticulture & bedding bags program	2024	QC	761 000 kg bags collected[109]
Building a zero plastic waste strategy for agriculture	2024	Across the country	91 500 kg ag plastic, twine and grain bags diverted[109]
Manitoba's government-regulated recycling program for grain bags and baler twine	2024	MB	A total of 40 900 kilograms of grain bags and baler twine were recovered[109]
Saskatchewan's official recycling program for grain bags	2024	SK	1.77 million kg grain bags recycled[109]
Unwanted old livestock/equine medications collection program	2024	BC (Okanagan, Kootenay, Interior), AB (South), SK(North), NB, NS	3100 kg old livestock/equine medications collected[109]
Unwanted pesticides collection program	2024	BC (Okanagan, Kootenay, Interior), AB (South), SK (North), NB & NS	210 000 kg unwanted pesticides collected[109]
Alberta's forward-thinking initiative: Ag-Plastic recycle it pilot	2024	AB	648 000 kg twine and grain bags (twine collected 100 000 kg) collected[109]
Dairy farmers of Canada: ongoing successes in the agricultural plastic film recycling pilot	2024	MB, QC & BC	Pilot programs resulted in the diversion of 110 000 kilograms of bale wrap, silage bags, and bunker covers[109]
Leadership & progress in PEI	2024	PE	101 000 kg bale wrap and silagebags diverted[109]

[a] British Columbia (BC), Saskatchewan (SK), Quebec (QC), Prince Edward (PE), Ontario (ON), Manitoba (MB), Alberta (AB), Nova Scotia (NS), New Brunswick (NB), Newfoundland (NF).

Manitoba's 2019 pilot becoming regulated in 2022; and (3) quantified environmental benefits, with Cleanfarms reporting 2022 reductions equal to 930 cars removed from roads or carbon sequestered across 71 300 acres of forest, figures more than doubling by 2024. These achievements highlight Canada's progress toward circular agricultural plastics management and climate-smart farming.

Table 4 and Fig. 5, visualizes the trajectory and intensification of agricultural plastic management programs over a ten-year period, highlighting key developments in regulatory and

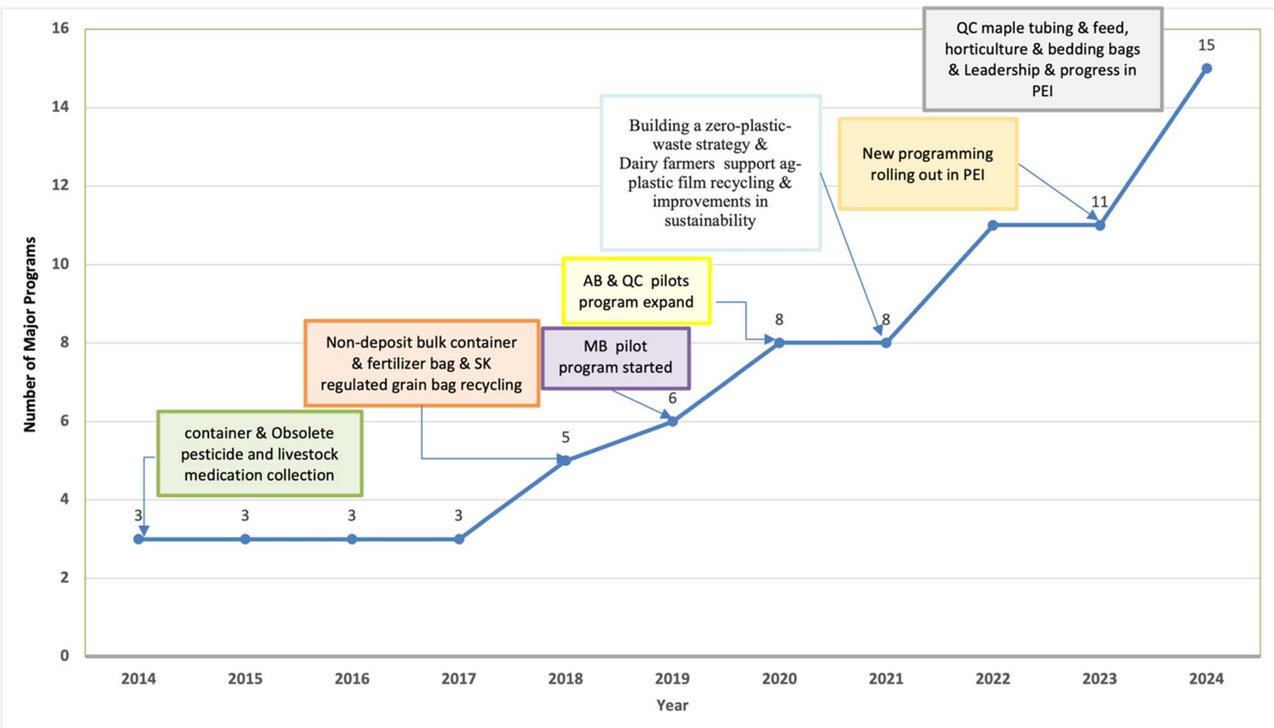

Fig. 5 Trend of agricultural plastic management programs in Canada (2014–2024), data are taken from ref. 66 and 100–109.

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voluntary initiatives directly and economic and informational activates indirectly.

The early years (2014–2017) were characterized by a limited number of programs focused primarily on pesticide and fertilizer containers and obsolete pesticide disposal. These programs laid the groundwork for broader engagement.

From 2018 onwards, a clear acceleration in both program diversity and provincial engagement is evident. This coincides with Canada's adoption of the phase 2 of the zero plastic waste strategy and increased federal and provincial coordination *via* Cleanfarms.

Between 2020 and 2024, the number of active programs per year peaked, and new materials such as agricultural films, twine, netting, and inoculant bags were incorporated. This period also marks a policy shift, with the emergence of regulated frameworks (*e.g.*, Saskatchewan, Manitoba), increased federal funding, and the institutionalization of pilot programs into permanent systems.

The trend of agricultural plastic management programs not only captures quantitative growth but also reflects a qualitative transformation in Canada's approach, from disjointed, ad hoc collection efforts to a coordinated, circular economy model for agricultural plastics.

Despite these achievements, challenges persist. Out of an estimated 61 754 tonnes of agri-plastics generated annually in Canada, only about 6000 tonnes are diverted through Cleanfarms' initiatives. The remainder is either reused, incinerated or buried on farms, returned to suppliers, or landfilled. Increasing diversion rates, especially for items such as net wrap, propagation trays, and woven bags, requires technological innovation, greater farmer engagement, and robust policy support.[5]

Ultimately, the current policy landscape for agricultural plastics in Canada remains fragmented and unevenly implemented. Achieving a sustainable and circular agricultural economy requires collaboration between federal and provincial authorities, increased investment in rural recycling systems, and more rigorous implementation of EPR policies.

8 Global comparison of agricultural plastic use and waste management practices

Over the past decade, the use of agricultural plastics has grown substantially worldwide, with the global agricultural films market valued at 11.28 billion USD in 2023 and projected to reach 19.66 billion USD by 2032,[110] while another source reported a value of 13.81 billion USD in 2024, expected to rise to 19.49 billion USD by 2029 at a CAGR of 7.1%.[111] The U.S. segment alone is projected to reach approximately 2.57 billion USD by 2032, and Asia–Pacific led the global market in 2023 with a 53.81% share, driven by extensive use of mulch and greenhouse films in countries such as China and India.[110] Key materials include LDPE, LLDPE, EVA, Reclaim, and HDPE, with LLDPE expected to see significant growth due to its durability, flexibility, and cost-effectiveness. Agricultural films are primarily used for greenhouse, mulch, and silage applications, with greenhouse films, enabling controlled environments, year-round production, higher yields, and optimized resource use, representing the second-largest application by value.[111] These figures highlight a clear upward trend in the production and use of agricultural plastics globally, indicating that both their

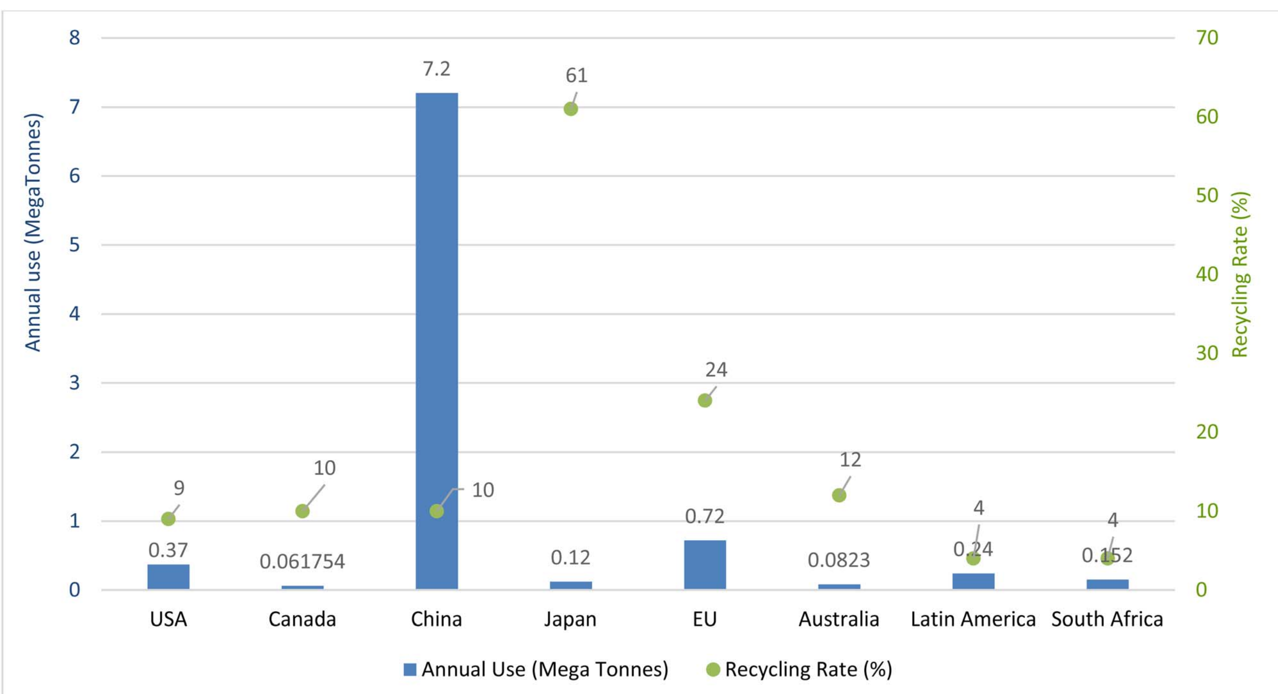

Fig. 6 Agri-plastic use and recycling rate by country or region, data are taken from ref. 5, 113, 114, 118, 122–125, 133, 136, 137 and 144.

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utilization and the associated plastic waste are increasing worldwide.

8.1 USA

In the United States, the annual use of agricultural plastics is estimated at approximately 370 000 tonnes, with a recycling or recovery rate of only about 9%,[113,114] Fig. 6. These plastics, including HDPE pesticide and fertilizer jugs, plastic mulch films, bale wrap, and greenhouse films, are essential components of modern U.S. agriculture. Collection programs managed by the Ag Container Recycling Council (ACRC) have successfully recovered roughly 11 million pounds of HDPE jugs each year, reflecting a gradual increase due to growing awareness and enhanced recycling initiatives.[112] Overall, approximately 0.45 million metric tons of various plastics are used annually in U.S. crop production.[114] Specifically, plastic mulch films represent a major portion of these materials.

According to the Food and Agriculture Organization,[1] global annual use of plastic mulch films exceeds 6.7 million tonnes, with the U.S. share estimated between 350 000 and 370 000 tonnes. Other key agricultural plastics include bale wrap, greenhouse films and irrigation tubing.

In the United States, the management of agricultural plastic waste is primarily implemented at the state and local levels, as federal policies do not directly focus on this area. For instance, in Maryland, compost quality regulations limit the presence of agricultural film plastic residues larger than 4 mm to a maximum of 2% by dry weight, reflecting growing concerns over plastic contamination in organic waste streams. Any sample or batch found to be non-compliant with the regulation may be subject to penalties or a suspension of sale order.[140] Key instruments include EPR, which obliges: (i) producers to collect and recycle their products at the end of their useful life; (ii) state-level collection and recycling programs that often involve collection centers and farmer education; (iii) state regulations that restrict single-use plastics and encourage biodegradable alternatives; and (iv) support for research and innovation in agricultural plastic waste management. Despite their importance in modern farming systems, recycling rates for these films remain low, with disposal predominantly through landfilling or incineration. Recycling programs for these materials are still limited and largely regional. This multi-faceted approach, involving producers, state governments, and recycling facilities, plays a critical role in increasing recycling rates and reducing the environmental impacts of agricultural plastics,[141–143] Table 5.

8.2 Asia

In Asia, China is the largest producer and consumer of agricultural plastics, using over 5.2 million tons annually, including 3 million tons of film and 2 million tons for irrigation equipment, while producing around 150 000 tonnes of empty pesticide containers yearly; however, less than 10% of used plastic films are recycled. Agricultural plastic use is expected to rise due to new greenhouses, thicker mulch film standards, and increased mulching practices. In 2017, South Korea's agricultural sector consumed at least 320 000 tonnes of plastics, mostly PE (97%).

As an example of the implementation of product bans, Bangladesh's Mandatory Jute Packaging Act 2010 requires the use of jute bags for the transport and storage of several bulk commodities, including rice, sugar, and fertilizers, and has recently been expanded to cover additional products.[117]

8.3 China

Plasticulture is a widely practiced agricultural method in China, the world's largest producer and consumer of agricultural plastics, with over 7.2 million tonnes used annually.[118] At the national level, the largest domestic agricultural plastic pollution in China came from Shandong (SD) at 58 kt (10% of national pollution), followed by Xinjiang (XJ) at 49 kt (9%) and Henan (HEN) at 31 kt (6%), with central and eastern provinces contributing over one-third of the country's agricultural plastic pollution due to high population and well-developed agricultural and light industry sectors,[144] Fig. 6.

China has progressively implemented a series of policies and standards, beginning with the 2002 Clean Production Law and reinforced by Soil Pollution Prevention and Control Action Plans in 2016, 2018, and 2019, alongside bans on PE films thinner than 10 μm, requirements for thicker reusable films, promotion of biodegradable alternatives, and recycling targets exceeding 80% by 2020, all aimed at mitigating plastic pollution while sustaining agricultural productivity.

The Chinese government has long promoted the prevention, control, and recycling of agricultural mulch film, setting targets such as the 2015 "one control, two reductions, three bases" policy and 2020 regulations requiring thicker, reusable, or biodegradable films. Despite these measures, rising labor costs and demand for productivity have led farmers to use more mulch film, while low environmental awareness and high collection costs hinder recycling. Informal rural institutions, such as village regulations, play a significant role in encouraging pro-environmental behaviors. Empirical analysis using national micro-survey data confirms that these regulations have both direct and indirect positive effects on mulch film recycling, mediated through film thickness selection and duration of use. Local initiatives, such as voluntary governance in Wuyuan County, further illustrate the effectiveness of village-level interventions in mitigating mulch film pollution,[27,118] Table 5.

8.4 Japan

Japan annually consumes about 120 000 tonnes of agricultural plastics, primarily PVC and PE, of which 40 000 tonnes are agricultural mulch films.[123] Japan's agricultural plastic recycling rate increased from 19% to 61% over the past 20 years mainly due to strict waste management laws, cooperation between local governments and agricultural cooperatives, and the development of efficient collection and recycling systems,[124] Fig. 6.

To mitigate environmental impacts, Japan's policy instruments include the promotion of biodegradable mulch films, the use of biobased non-biodegradable plastics for collection and recycling, and soil-degradable biodegradable plastics for

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Table 5 Overview of agri-plastic use regarding key policy and regulatory measures by country

Country	Main policy and regulatory measures	Source
USA	ACRC collection programs, regulatory limits for specific contaminants by local governments, EPR, state-by-state policy, pilot recycling	112–115 and 140–143
Canada	Cleanfarms-led stewardship, provincial EPR pilots, federal Zero Plastic Waste Strategy	1, 5, 18, 87 and 89
China	Clean production law since 2002, control action plans (2016, 2018, 2019), "one control, two reductions, three bases" policy, standards for biodegradable and thicker mulch films (2017, 2018), agricultural film management measures (2020), five-year plan to ban single-use plastics, village regulations, circular economy promotion law (2008), national standards mandating thicker ($\geq$0.010 mm) and biodegradable mulch films (2017 onwards), and soil pollution prevention and control action plans (2016–2019), recycling and reuse requirements, and the national green agriculture development plan (2021), rural subsidies and mandatory recycling plans, pilot collection in 10 provinces, voluntary cropLife program (EPR)	1 and 116–121
Japan	Pay-As-You-Throw municipal programs, recycling subsidies, biodegradable plastic innovation, local co-ops	123 and 124
EU	Green deal roadmap, national collection schemes as some EPR legislations, bans on PVC in agriculture, landfill tax, certified soil-biodegradable plastics, EU fertilizing products regulation 2019/1009, common agricultural policy, GLOBALG.A.P. standards	1 and 125–131
Australia	CropLife Australia programs, Ag Stewardship framework, DrumMuster & ChemClear schemes, national container stewardship expansion, plastic packaging tax, EPR schemes, community groups	132–135
Latin America	EPR laws (Brazil, Chile), single-use plastic bans, biodegradable standards (Colombia), harmonization in food-contact plastics (MERCOSUR), regional environmental treaties (Escazú)	1 and 136–139
South Africa	African circular economy action plan, voluntary cropLife program (EPR), industry-led initiatives and certification schemes (EPR)	1, 77, 80 and 122

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plowing into farmland. For controlled-release fertilizer coatings, the use of plastics biodegradable in both soil and marine environments is encouraged to reduce leakage risks. In fisheries, non-biodegradable biobased plastics are recommended where recycling is feasible, while marine-biodegradable plastics are promoted where high durability is not required. The strategy further emphasizes R&D into innovative biodegradable materials and stakeholder awareness and education to ensure proper use and disposal, preventing environmental leakage,[123] Table 5.

8.5 Europe

In Europe, approximately 720 000 tonnes of agricultural plastics are used annually, with only 24% recycled Fig. 6; the majority ends up in landfills, around 34 000 tonnes are burned in fields, and nearly 950 000 hectares of soil are contaminated with plastic residues. Mulch films, threads, and clips are the most difficult to collect due to entanglement with soil and green waste, with mulch films alone accounting for 83 000 tonnes per year. The main polymers used are PP, PE, and PVC, with southern European countries being the largest consumers.

Certified soil-biodegradable plastics, including PHAs, PBAT, PBS, PCL, PLA, and starch, represent about 8% of global bioplastics production in 2022, projected to reach 9% by 2027. Europe's production capacity for biodegradable materials grew from 200 000 tonnes in 2011 to 390 000 tonnes in 2022, expected to exceed 610 000 tonnes by 2027. In Germany, certified biodegradable mulch films account for 129 tonnes per year, compared to 1691 tonnes of conventional mulch films, while Spain and Italy already use 1.5 kt year^{-1} and 2 kt year^{-1}, respectively.[125]

To promote circularity, several countries implement National Collection Schemes (NCS) based on EPR. France, Germany, Ireland, and Finland have fully operational NCS, while the UK and Spain are in early stages.[131] For example, France's A.D.I. VALOR system, established voluntarily *via* collaboration between government and industry in 2018, manages both packaging and non-packaging agricultural plastic waste. Converters committed to increase recycled content in new products from 19% to 25% by 2025, with many agricultural plastics, such as silage sheets, stretch films, and irrigation pipes, already containing 10–40% recycled material,[145,146] Table 5.

Regulatory measures also include the EU Fertilising Products Regulation 2019/1009, which bans non-biodegradable polymer-coated fertilizers from 2026 to reduce soil microplastic pollution.[117] Oxo-degradable plastics are banned in the EU due to microplastic risks.[1]

Environmental taxes and incentives, such as the UK Plastic Packaging Tax (2022), initially GBP 200 per ton for products with <30% recycled content and Denmark's PVC tax (2000–2018), encourage the use of recycled materials and alternatives,[117,128,129] Table 5.

At the policy level, the European Green Deal (2019) sets a roadmap for carbon neutrality by 2 050 ,[126] and the Common Agricultural Policy supports Italian farmers in three regions to use biodegradable mulch films.[130] In addition, GLOBALG.A.P. standards for crop, livestock, and aquaculture production

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include waste management requirements, particularly for empty pesticide containers in Germany,[127] Table 5.

8.6 Australia

CropLife Australia urges federal, state, and territory governments to support industry-led solutions advancing a circular economy for agricultural plastics during National Recycling Week. Australian agriculture consumes about 82 300 tonnes of plastic annually, but only 12% is recycled Fig. 6, with CropLife Australia driving change through expanded collection programs and its drumMuster initiative, which accounts for nearly half of agricultural hard plastic recycling. drumMuster has recycled over 43.5 million containers in 26 years, diverting 45 000 tonnes of plastic from landfill through 840+ collection points.[133] The main plastics are flexible films, twines, ropes, and irrigation pipes, predominantly PE (81%) and PP (8%).[135]

As an example of an EPR scheme, drumMuster in Australia is a voluntary program where agricultural chemical producers pay fees that fund the collection, inspection, and recycling of containers, reimbursing local councils, community groups, and processors,[134] Table 5.

8.7 Latin America

In Latin America, the agricultural sector consumes approximately 240 000 tonnes of plastic film annually Fig. 6, primarily for mulching and tunneling, covering nearly 200 000 hectares, with Brazil holding the largest share. The remaining plastic film use is dominated by silage film, amounting to around 60 000 tonnes.[136] Despite this widespread use, the average recycling rate in the region remains low, at around 4%.[137] Several policy and regulatory measures have been implemented across Latin America to address plastic pollution and promote sustainable agricultural practices. Single-use plastic bans were first introduced in Chile (2018), making it the first South American country to implement a nationwide ban on plastic bags. Colombia and Mexico followed by introducing taxes and regulations that limit plastic bag use and gradually phase out other single-use plastics. In the Caribbean, nations such as Costa Rica, Panama, and Ecuador have also passed bans on plastic bags and other disposable item,[139] Table 5.

To encourage biodegradable and compostable alternatives, Colombia enacted Law 2232 in 2022, mandating that such products comply with ASTM and ISO quality standards.[138]

A key example of an EPR scheme in the region is Brazil's legally mandated inpEV program, which collects empty pesticide containers. Established under regulations in 2000 and 2002, the scheme requires manufacturers and distributors to set up collection and recycling programs and obligates farmers to participate. inpEV is recognized as the most effective EPR scheme for pesticide containers, achieving a 94% recycling rate. Its success is reinforced by Brazil's record system for pesticide purchases and container returns, which provides the enforcement mechanism ensuring high compliance and recycling performance,[1] Table 5.

8.8 South Africa

In 2019, South Africa's agricultural sector used 152 000 tonnes of plastics Fig. 6 (10% of national consumption) primarily PE (52%) and PP (34%), and accounted for 11% of all plastic recycled, mainly HDPE and PVC, used for irrigation equipment and fencing poles.

In 2020, rigid plastic packaging (HDPE) used for agricultural chemicals (<25 l containers, drums, totes, and IBCs) by CropLife South Africa members had a 76% output recycling rate, with recycled plastics making up 25% of total agricultural consumption, making agriculture the third-largest consumer of recycled plastics after construction and textiles, though significant potential remains for increased use of recycled HDPE, PP, and LD/LLDPE.[1,80,122]

In South Africa, circularity for agricultural plastics is driven primarily through industry-led initiatives and certification schemes. The key program is CropLife South Africa's container management system, which recovers and recycles HDPE chemical containers, irrigation pipes, water tanks, cattle troughs, and plastic droppers *via* a network of over 117 certified recyclers, achieving high recycling rates. The Global G.A.P. food safety certification also supports better waste management and partial recovery of plastics, particularly for export-oriented farms. Policy and regulatory levers include promoting material substitution (*e.g.*, replacing problematic mulch films, plastic ties, and bags), developing product standards to increase the use of post-consumer recycled plastics in agricultural products, expanding local manufacturing using recycled content, and advocating for EPR regulations to finance end-of-life processing. Additionally, the emerging African Circular Economy Action Plan under the African Union proposes enabling cross-border return of agricultural plastics to South Africa for recycling, ensuring proper governance and reducing environmental leakage,[80] Table 5.

The Fig. 6 highlights the contrasting dynamics of agricultural plastic use and recycling performance across major regions. China is by far the largest consumer, exceeding 7.2 million tonnes annually, yet its recycling rate remains below 10%, reflecting a significant gap between production and sustainable waste management. In contrast, Japan demonstrates the most effective governance, achieving a 61% recycling rate despite relatively modest consumption, largely due to strict waste management laws and cooperative recycling systems. The European Union also shows a relatively balanced profile, with high consumption (720 000 tonnes annually) coupled with moderate recycling rates (24%), driven by EPR schemes and regulatory incentives. The United States and Canada consume substantial volumes but recycle less than 10%, indicating reliance on landfilling and limited collection infrastructure. Latin America and South Africa stand out with very low recycling rates (∼4%), underlining policy and infrastructural weaknesses. Overall, the figure demonstrates that higher consumption does not necessarily correlate with effective recycling, emphasizing the importance of robust regulatory frameworks, producer responsibility schemes, and farmer participation in closing the plastic loop.

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9 Discussion and conclusion

This study presents a comprehensive and integrated review of agricultural plastic usage and waste generation in Canada and other regions, examining their socio-economic and environmental implications through provincial-level data, national policies, and international comparisons. The findings demonstrate that agricultural plastics are both an enabler of productivity and a source of persistent environmental and socio-economic challenges. On one hand, they significantly enhance agricultural performance by improving water-use efficiency, increasing yields, extending growing seasons, reducing post-harvest losses, and contributing to food security. On the other hand, their widespread and often unregulated use has resulted in mounting environmental risks, financial burdens, and social inequities, as well as potential threats to consumer health and long-term stability in the food supply chain.

Canada generates over 61 000 tonnes of agricultural plastic waste annually, with the Prairie provinces contributing more than half of the total. Despite localized success stories and the expansion of Cleanfarms' stewardship programs and provincial pilot projects (notably in Saskatchewan, Quebec, and Manitoba), only about 10% of this waste is currently diverted from landfills or on-farm disposal through national recovery systems. Agricultural plastics are particularly concentrated in a few high-impact sectors, such as LLDPE bale wraps, LDPE grain bags, and PS trays, suggesting clear intervention points for targeted policies and recycling infrastructure. However, rising rural collection costs, the lack of formal waste management infrastructure in some provinces, and limited extension services exacerbate the challenge. As a result, farmers in under-resourced or remote regions often face disproportionate waste management burdens, which raises issues of environmental injustice and social equity.

From a policy perspective, Canada's approach remains fragmented, with uneven implementation of EPR frameworks across provinces and insufficient integration of circular economy principles. Provinces such as Saskatchewan and Quebec have introduced structured recovery systems, but others lag behind, creating uneven outcomes. This stands in contrast to some EU countries such as Germany and Spain, where integrated policies ensure consistent farmer participation, or China, which has introduced technical standards (*e.g.*, minimum mulch film thickness) to facilitate waste removal. The European Union provides another instructive example, where harmonized EPR schemes, regulatory enforcement, and bioplastic innovations have led to higher recovery outcomes. Canada's relatively low recycling rates not only heighten risks of soil degradation, microplastic accumulation, greenhouse gas emissions, and biodiversity loss, but also lag far behind international benchmarks.

The dual nature of agricultural plastics underscores the need for systemic, multi-instrumental solutions. Regulatory bans on open burning, combined with economic instruments such as subsidies, tax credits, or reduced tipping fees, could alleviate financial burdens on farmers and improve compliance. Informational tools, including extension services, farmer education, and behavior-change programs, remain underdeveloped in Canada, yet are essential for shifting cultural practices surrounding plastic use and disposal. Voluntary stewardship programs, while valuable, are insufficient without strong regulatory and financial support. Effective strategies will require hybrid policy models that combine regulatory mandates, economic incentives, voluntary initiatives, and educational outreach.

At the same time, investments in rural infrastructure, decentralized recycling facilities, and bioplastic research are critical to advancing Canada's transition toward a circular agricultural economy. Canada's current efforts to invest in bioplastics and circular solutions are important first steps, but stronger integration of policy, innovation, and farmer engagement is needed. Equally important is addressing knowledge and data gaps: secondary datasets, while valuable, remain inconsistent across provinces, and informal or unreported disposal practices (such as on-farm burning or burial) are underrepresented in official statistics, leading to potential underestimation of environmental risks. Moreover, certain specific datasets are unavailable for all regions, and both empirical field-based studies and systematic data collection remain limited. These gaps underscore the need for harmonized, nationwide data systems and more rigorous scientific research.

In summary, Canada's experience reflects both progress and persistent gaps. The challenges posed by agricultural plastics are not only technical, but also institutional, behavioral, and socio-economic. By learning from global best practices and integrating regulatory, economic, informational, and voluntary instruments, Canada can accelerate its transition toward sustainable agricultural plastic management. Such a transition requires coordinated, cross-sectoral collaboration among governments, farmers, industry, waste managers, and scientific communities. Only through national harmonization, investment in social and physical infrastructure, and long-term behavioral change initiatives can Canada ensure environmental protection, economic resilience, and social equity within its rural and agricultural communities.

10 Recommendations

- Farmer engagement and behavior change through locally tailored education, outreach, and peer-led initiatives to highlight risks of improper disposal and benefits of recycling.
- Economic incentives such as subsidies, tax credits, or reduced tipping fees to motivate participation.
- Improved data collection and transparency *via* a national digital platform to track plastic use, recovery, and infrastructure, enabling evidence-based policies and research.
- Circular economy in product design by promoting recyclable, biodegradable, or compostable inputs, supported by regulatory standards and clear labelling.
- Multi-stakeholder collaboration through interprovincial and cross-sectoral task forces uniting farmers, industry, policymakers, NGOs, and researchers.

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- Strengthened regulatory frameworks with a harmonized national EPR system, using successful provincial models such as Saskatchewan and Quebec as templates.
- Expanded rural infrastructure through investment in compaction sites, mobile collection units, and storage hubs, prioritizing underserved regions.
- Looking forward, emerging technologies such as blockchain could revolutionize agri-plastic management by providing end-to-end traceability and utilizing smart contracts for environmental compliance. Additionally, tokenized incentives could motivate farmer participation in recycling programs. Future research should explore these decentralized frameworks to foster a more transparent and efficient circular economy.
- Innovation in recycling technologies supported by research and public–private partnerships to process mixed or contaminated agri-plastics efficiently.

11 Limitations

This study relies primarily on secondary data, which are often inconsistent and uneven in coverage across provinces and countries. In addition, certain specific datasets are not available for all regions, making cross-regional comparisons more challenging. Informal and unreported waste disposal practices (*e.g.*, on-farm burning or burial) are also underrepresented in official statistics, which likely leads to an underestimation of the actual environmental risks. Moreover, in this topic, both the availability of reliable datasets and the number of field-based empirical studies are still very limited. These limitations underscore the need for more harmonized data collection systems and for conducting systematic, field-based research in the future.

Author contributions

Dr Saeedeh Nazari Nooghabi: conceptualization, methodology, investigation, data analysis, visualization, writing – original draft. Prof. Amar K. Mohanty: conceptualization, methodology, validation, project administration. Prof. Manjusri Misra: conceptualization, methodology, validation, supervision. Dr Michael R. Snowdon: methodology, validation, writing – review & editing.

Conflicts of interest

There are no conflicts to declare.

Data availability

The underlying raw data supporting the analyses in this study are derived from publicly available sources as described in the Methodology section. These sources, including annual reports from Cleanfarms and other cited literature and organizational reports, are fully referenced within the article's reference list. The processed datasets generated and/or analysed during the current study (*e.g.*, data files used for creating Fig. 1, 3 and 4–6) are available from the corresponding author upon reasonable request.

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