Regulating Environmental Contamination of Antimicrobials and Antimicrobial Resistance Genes Originating from Agricultural Practices in Canada

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1. Introduction

Antimicrobial resistance (AMR) is increasingly recognized as a major threat to global public health and development. AMR occurs when microorganisms are inherently able to or become capable of surviving in the presence of antimicrobial drugs. In Canada alone, the current estimated level of human infections caused by resistant microorganisms is 26%, and, with projected rise to 40 %, Canada's cumulative GDP could fall by $388 billion, with healthcare costs reaching $120 billion by 2050 (1–3). Although AMR is an expected evolutionary adaptation of bacteria, it is significantly accelerated by the overuse and misuse of antimicrobials, which impose selective pressure favoring the survival and propagation of resistant bacterial populations. This includes both appropriate use against identified target pathogens and inappropriate use where treatment is ineffective. This has been well documented in clinical (4), veterinary (5), and agricultural (6) settings and has been increasingly recognized in the broader environment over the past decade (7,8). The 2025 assessment by the Canadian Academy of Health Sciences states that AMR can be transferred from food-producing animals to humans through food contamination, direct contact, and environmental pathways (9).

In Canada, approximately 82% of all annually sold antimicrobials are used in agriculture and livestock production to prevent or treat disease (10). The impact of antimicrobial use in agriculture and livestock production on the emergence and spread of AMR is widely acknowledged. In food-producing animals, AMU exerts strong selective pressure on both pathogenic and commensal microbial populations, shaping antimicrobial resistance genes (ARGs) composition at the animal, herd, and environmental levels (11–13). Numerous studies across livestock sectors including poultry, swine, beef, dairy, and aquaculture have reported associations between antimicrobial exposure and increased prevalence of ARGs (14–19). For instance, prolonged antibiotic treatments have been associated with increased multidrug resistance and persistence of chronic infection (20).

Many antimicrobials that are used in livestock are water-soluble and poorly absorbed in the gastrointestinal tract, and a large proportion is excreted in urine and feces (up to 90% and 75%, respectively) (21). The use of livestock manure as fertilizer contributes to the spread and emergence of AMR through the direct contamination of soil, as well as the indirect contamination of surface waters through agricultural runoff (6,22). Antimicrobial compounds may be released as active metabolites or unchanged parent molecules, facilitating their dissemination into the environment (23,24). Accumulation of antimicrobials in soil can adversely affect native microbial communities and promote the evolution of resistance (8,25,26). It also affects other organisms across life stages and impairs plant germination and root development, reducing crop yield (27). These residues may also slow down the degradation of pesticides and herbicides, increasing their persistence and exposure risks (28). Together, co-occurring antimicrobials and pollutants can pose compounded risks to ecosystem health.

To address the impacts of agriculture on the spread of AMR, federal legislation has been put into place to restrict the use of medically important antimicrobials, including prescription-only access to medically important antimicrobials and national AMR surveillance initiatives. Since the implementation of this legislation in 2018, a 17% decrease in the total kilograms of antimicrobials sold for use in animals was reported (29). However, current policies remain primarily focused on antimicrobial usage rather than environmental dissemination pathways.

The proposed policy aims to:

1. Reduce environmental dissemination of antibiotics, resistant organisms, and ARGs from agricultural sources.
2. Protect the long-term effectiveness of medically important antimicrobials.
3. Maintain Canadian agricultural competitiveness and food security.
4. Support producers through economically sustainable transition strategies.
5. Align Canadian agricultural policy with a One Health framework integrating human, animal, and environmental health.

The proposed policy recommends a phased, risk-based regulatory framework addressing environmental AMR contamination originating from agricultural operations. It integrates moderate reduction in antimicrobial use with financial and technical support mechanisms to balance public health protection, economic sustainability, and food security, while enabling Canada to reduce AMR-related environmental risk without inducing short-term disruptions to production, producer margins, export competitiveness, or food affordability.

2. The Economic and Food Security Impacts of Further Regulating the Canadian Agricultural Sector

Canadian agriculture and agri-food generated about $149.2 billion in GDP and supported about 2.3 million jobs in 2024, while 24.0% of Canadians lived in households reporting some level of food insecurity in 2024 (30). Poorly timed or poorly targeted compliance costs could therefore affect farm viability, food prices, and household food access. Similar to human medicine, AMR in livestock is associated with higher infection rates, reduced treatment effectiveness, and decreased productivity, ultimately leading to economic losses and negative impacts on food security (31). Therefore, inaction would threaten the agricultural economy and long-run food security.

The Public Health Agency of Canada, working with federal, provincial, and territorial partners released the Pan-Canadian Action Plan on AMR for 2023 to 2027. The plan is organized around five areas including research and innovation, surveillance, stewardship, infection prevention and control, and leadership. In animal agriculture, earlier federal measures strengthened veterinary oversight by making medically important antimicrobials prescription-only and removing growth-promotion claims from product labels in 2018. Canada also has an important surveillance base through the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS), which brings together antimicrobial use and resistance data across humans, animals, food, and selected environmental sources (32).

2.1. Agricultural Economic Impacts

Evidence from the swine, poultry, and cattle sectors indicates that moderate reductions in antimicrobial use (AMU) can remain economically viable when accompanied by improved management practices, enhanced biosecurity measures, and disease prevention strategies (33–36). Economic analyses suggest that investments in biosecurity can offset reductions in antimicrobial use and, in some production systems, improve overall gross margins (34,37). Furthermore, research demonstrates that the economic benefit derived from antimicrobial use diminishes beyond an optimal threshold, indicating that excessive use may provide limited additional productivity gains while contributing to broader antimicrobial resistance (AMR) risks (35,36). Several studies have also highlighted that reliance on antimicrobials may conceal management deficiencies that could otherwise be addressed through improved husbandry, sanitation, vaccination, and disease monitoring programs (35). Consequently, reducing antimicrobial dependence may encourage more sustainable and efficient production practices over the long term.

Nevertheless, the economic impacts of antimicrobial reduction policies are not distributed equally across the agricultural sector. High-density livestock operations, farms experiencing elevated disease pressure, and small- to medium-sized producers with limited financial reserves may face greater challenges during the transition period (33,38–40). For these reasons, regulatory implementation should prioritize gradual reduction targets, sector-specific flexibility, and transition support programs that allow producers sufficient time and resources to adapt.

2.2. Food Security Considerations

Food security implications must be carefully balanced when considering additional regulations on antimicrobial contamination and resistance dissemination. Excessively restrictive policies may increase production costs, reduce livestock productivity, contribute to higher retail food prices, and diminish the international competitiveness of Canadian agricultural products (38–41). Such outcomes could place additional financial pressure on producers and consumers while potentially affecting domestic food supply stability.

Conversely, insufficient regulation presents its own significant risks. Continued environmental dissemination of antibiotic residues, resistant organisms, and antibiotic resistance genes may accelerate the development and spread of AMR, reducing the effectiveness of both veterinary and human antimicrobial therapies (41–43). The resulting public health consequences could lead to substantially greater future healthcare expenditures, increased disease-control costs, and heightened vulnerability to infectious disease outbreaks in both animal and human populations (39,41). Maintaining long-term food system resilience therefore requires a balanced approach that preserves antimicrobial effectiveness while supporting agricultural productivity and economic sustainability.

3. Regulation of Manure and Pesticide Application in Canada

In Canada, manure application is regulated primarily through provincial nutrient management and environmental protection frameworks aimed at reducing nutrient runoff, groundwater contamination, and other environmental risks. Although regulatory approaches differ among provinces, most systems commonly include manure nutrient content, crop nutrient requirements, restrictions on spreading on frozen or snow-covered ground, and setback requirements from wells, surface waters, and other environmentally sensitive locations when determining land application practices. Several provinces use risk-based approaches that account for nitrogen and phosphorus loading, field slope, and soil conditions to minimize runoffs and subsequent environmental contamination. For example, setback distances may vary depending on proximity to a nearest water source, terrain, or phosphorus overload risk, while some provinces also require manure incorporation within a defined time frame following application. In addition, farms exceeding specified nutrient thresholds may be required to develop nutrient or agro-environmental management plans that align manure application rates with crop nutrient demand.

While specific requirements vary regionally, current Canadian manure management regulations primarily focus on nutrient pollution prevention, water-quality protection, and safe manure handling practices; they are not explicitly tailored to regulate AMR dissemination from agricultural settings. Nevertheless, Canadian federal AMR frameworks and government-funded research increasingly recognize livestock manure as an important environmental reservoir and transmission pathway for ARGs (44,45). Existing provincial manure and nutrient management systems provide a practical foundation for integrating AMR-focused environmental regulation into current agricultural frameworks (46,47). Canada should expand these systems to incorporate measures specifically designed to reduce the spread of antibiotic residues and resistance genes.

Recommended interventions include composting requirements, incentives for anaerobic digestion technologies, improved timing of manure applications, establishment of vegetative buffer zones adjacent to waterways, and investment in runoff containment infrastructure. These measures build upon existing agricultural practices while targeting known pathways of environmental contamination.

4. Policy Implementation Approach

The evidence strongly supports a combined approach that integrates targeted regulation with preventive management support. Such a strategy is both economically sustainable and politically feasible, offering a practical pathway to reducing environmental AMR risks while maintaining agricultural productivity (33–35,41). This approach provides multiple benefits. First, it addresses the long-term public health risks associated with antimicrobial resistance by reducing environmental dissemination of antibiotic residues and resistance determinants (42,43). Second, it minimizes abrupt economic shocks by allowing producers time to adapt and by providing financial assistance for required infrastructure and management improvements (34,35). Third, it encourages innovation in animal health management, promoting investments in biosecurity, vaccination, and disease prevention strategies that can improve overall farm resilience (37). Finally, it supports food production stability by avoiding the unintended consequences that may result from sudden or overly restrictive antimicrobial policies (40,41).

In contrast, highly restrictive regulatory approaches implemented without adequate transition support risk generating avoidable economic disruption, reducing producer competitiveness, and potentially compromising food security objectives (38–40). Accordingly, a balanced strategy that combines regulation, surveillance, prevention, and producer assistance represents the most effective policy option.

5. Policy Recommendations

Recommendation 1. Create a Phased 'Environmental AMR Risk Standard' for Agricultural Release Pathways

Canada should regulate environmental contamination from antibiotics, AROs, and ARGs through a phased Environmental AMR Risk Standard. The standard should begin with high-risk pathways such as manure storage and land application from high-density livestock systems, feedlot runoff, aquaculture effluent, and crop settings where antibiotics are used. The first phase should require baseline reporting and risk classification. Farms and sectors would be classified by factors such as production density, manure volume, runoff risk, proximity to surface water, AMU profile, and available waste-management infrastructure. The second phase should implement best management practices for high-risk sites. It includes improved manure storage, runoff controls, drainage management, and effluent handling. The third phase should add monitoring thresholds and corrective action plans when contamination exceeds agreed risk levels.

The Environmental AMR Risk Standard should be supported by a comprehensive national environmental surveillance program designed to monitor antibiotic residues, resistant microorganisms, and ARGs across agricultural environments. Monitoring activities should include agricultural runoff, wastewater systems, soils receiving manure applications, and other environmental pathways associated with antimicrobial dissemination. To maximize effectiveness and ensure efficient allocation of resources, surveillance efforts should initially focus on high-density livestock regions, watersheds with repeated manure application, and operations utilizing medically important antimicrobials. Establishing a robust surveillance system would provide critical baseline data, improve understanding of environmental AMR transmission pathways, support development of scientifically informed risk thresholds, and facilitate evidence-based policy refinement (42,43,48). Ongoing monitoring would also allow governments to evaluate regulatory effectiveness, identify emerging risks, and adapt management strategies as new evidence becomes available.

This approach gives producers time to adapt and reduces the risk of sudden food supply disruption. It also fits the economic evidence. OECD reviews find that the benefits of antimicrobials in modern production systems are often modest when good biosecurity, housing, hygiene, and management are already in place, while poorly prepared systems may face higher adjustment costs (41,49). Therefore, this recommendation protects public and environmental health while limiting avoidable pressure on producer margins and food affordability.

Recommendation 2. Protect Therapeutic Veterinary Use While Reducing Routine Preventive Dependence

Rather than implementing immediate blanket restrictions on antimicrobial use, Canada should adopt a phased and risk-based reduction strategy. Such an approach would prioritize reducing routine prophylactic and metaphylactic antimicrobial use while maintaining access to necessary treatments for animal health and welfare. Enhanced veterinary oversight should be incorporated to ensure responsible prescribing practices and to promote alternative disease prevention measures. At the same time, regulation should reduce routine preventive dependence where antibiotics are used to compensate for avoidable disease pressure linked to crowding, poor housing, weak biosecurity, or inadequate management.

Reduction targets should also prioritize medically important antimicrobials and recognize the differing disease pressures and production realities faced by poultry, swine, dairy, beef, and feedlot sectors. Research consistently demonstrates that moderate antimicrobial reductions paired with preventive management practices are more economically sustainable and operationally feasible than abrupt restrictions or outright bans (33,34,36,39).

As an example, Chicken Farmers of Canada reports that its Responsible AMU Strategy removed preventive use of Category I antimicrobials in 2014 and Category II preventive use at the end of 2018, while still allowing treatment and disease control when needed (50)**.** The sector also states that complete "raised without antibiotics" production is not sustainable for the whole industry because treatment remains needed for animal welfare and food safety. Therefore, it is recommended to reduce avoidable environmental AMR pressure, but do not remove necessary veterinary tools.

The route of antimicrobial administration has a considerable impact on the temporal ARGs dynamic in animals and their ability to shed AMR determinants in excreta. Studies have demonstrated that direct gut microbiota exposure to orally administered antimicrobials resulted in much higher and prolonged occurrence of ARGs compared to localized administration. Moreover, the occurrence of resistant pathogens due to in-feed exposure to antimicrobials correlates with each additional animal daily dose (ADD) (17,51). Thus, localized administration should be prioritized before in-feed antimicrobial additives. Additionally, antimicrobials with shorter depletion times should be prioritized when oral administration is necessary.

Alternative therapeutic and prevention strategies should include vaccination, nutritional supplements and interventions that replace growth-promoting antimicrobials, the use of pre-, pro-, and synbiotics, and selective breeding for more resilient animals (52). These measures aim to protect animal welfare and production stability while reducing avoidable AMR pressure.

Recommendation 3. Regulating Antibiotic Residue Concentrations in Manure

Similar to the recommendations proposed by WHO for reducing antimicrobial pollution resulting from the production of antimicrobials (53), we propose implementing concentration limits on antimicrobials and antimicrobial residues present in manure. Predicted no-effect concentrations (PNECs) have already been established for numerous antimicrobials (54–56), including many used in the agricultural sector for veterinary care (e.g., oxytetracycline) as well as medicating feed ingredients (e.g., avilamycin) (56,57). In the case of antimicrobials for which a PNEC has yet to be established, a default PNEC of 0.05 ug/L has been proposed based on a statistical evaluation of currently available data (58).

To implement this policy, antimicrobial concentrations could be measured at appropriate time points prior to land application based on existing provincial regulations for soil and manure chemical analysis. Ground and surface water samples within a defined proximity to agricultural operations may also be assessed for their antimicrobial content. Analysis of the chemical composition of agricultural soils could be integrated into ongoing monitoring activities, which are currently in place to monitor various environmental conditions, risks, and changes resulting from agriculture and associated management activities. These indicators, termed Agri-environmental indicators, currently monitor agricultural land use and biodiversity, air quality, soil health, and water quality (59). In Canada, ground and surface waters are also monitored by Agriculture and Agrifood Canada (AAFC) for their pesticide content. Site selection for these water samples is based upon several risk factors, including pesticide application, slope and associated runoff potential, precipitation, soil characteristics, as well as crops and management practices in use by agricultural operations (60). This provides evidence that such an approach is feasible and could be implemented for antimicrobial pollution resulting from agriculture activities.

Recommendation 4. Regulating ARG Concentrations in Agricultural Soil

ARGs may be disseminated as a result of agricultural activities via runoff, which may subsequently contaminate ground water and/or nearby surface waters, or through crops that have been fertilized with ARG-containing manure (61). Regulating the concentration of ARGs present in agricultural soil would therefore be aimed at reducing the transfer of resistance genes within and between non-pathogens and pathogens to ultimately minimize the spread of AMR.

Prior to implementing a policy regulating ARG concentrations in agricultural soils, baseline data on the presence of ARGs in manure and soils must be established. This will inform the development of appropriate maximum acceptable ARG limits to be implemented in the next phase of the policy. Following the determination of baseline levels of ARGs in various soil and manure types, the monitoring phase of the policy could be implemented. To begin, annual pre-application testing of soil for ARG abundance would provide baseline data and help guide manure application decisions. The ARG content of agricultural soils may be measured at determined appropriate time intervals to monitor deviations from established baselines and to subsequently implement risk management measures, if necessary.

Regulatory frameworks should incorporate soil-specific risk assessments when determining manure application rates and timing. Soil characteristics including texture, initial organic matter content, pH, and drainage strongly influence ARGs persistence and mobility. For example, clay-rich soils may retain ARGs for prolonged periods of time, while sandy soils may facilitate leaching into groundwater. Additionally, the presence of ARGs in various types of soil and their mobility potential (i.e., ability to be transferred between bacteria) is dependent upon the viability of ARG-harboring bacteria within the given type of soil (62), which should be considered when conducting a risk assessment. Soil analysis could be incorporated with ongoing one-time soil texture analyses that are currently required in certain provinces (63), or with soil nutrient testing regulations which require sampling at regular intervals (64).

Recommendation 5. Optimization of Manure Treatment Strategies

When properly managed, manure serves as a valuable nutrient source and supports plant growth. Various manure treatment and processing methods are applied to mitigate environmental and public health risks; however, their effectiveness in reducing ARGs varies (65). Research has demonstrated that composting and manure treatment technologies can significantly reduce the abundance and dissemination of antibiotic resistance genes, thereby limiting environmental exposure risks (42,48,66).

Selection of manure treatment technologies should balance economic feasibility and environmental effectiveness. The most cost-effective method depends primarily on the scale of livestock operation and available capital. For small and medium-sized farms, composting is generally more cost-effective due to low initial capital investment, simple technology, and lower operating costs. While composting can substantially remove antimicrobial residues, it could lead to accumulation of more stable drugs in compost and thereby, manure-treated soil (67). Currently, anaerobic digestion (AD) of manure is widely implemented in intensive farming systems. However, the efficiency of AD may depend on the initial microbial community composition, abundance of ARB and ARGs, and operating conditions (43). AD is more cost-effective for large-scale operations due to the economic value of produced biogas and nutrient-rich digestate, which can double the economic return compared to composting. The effectiveness of both composting and AD in terms of ARGs removal can be improved by extending the thermophilic phase. The thermophilic phase requires operational conditions above 55 ℃ during manure composting and can be extended by maintaining high microbial activity through adequate aeration, optimal moisture levels (50-60%), and sufficient insulating volume. Key strategies include adding high-carbon materials like straw, using batch-fed composting to extend feeding, or adding thermophilic microbial inoculants.

Increasing temperature of composting and AD may correlate with an increased greenhouse gas emission. While extended thermophilic phase requires higher initial investment, it accelerates the decomposition of organic matter, leading to roughly 15% to 50% more methane production compared to mesophilic digestion, which offsets the added energy costs.

Recommendation 6. Pair Regulation with a Producer Transition Package

Any AMR regulation should include financial and technical support. The transition package should include cost-sharing for manure treatment, runoff control, covered storage, drainage changes, composting or anaerobic digestion where suitable, and monitoring costs. It should also fund veterinary extension, farm health planning, vaccination, biosecurity, animal density management, ventilation, bedding, water quality, and training.

To encourage adoption and minimize economic disruption, the transition package should also include infrastructure grants, tax incentives, veterinary advisory services, biosecurity modernization support, and targeted funding mechanisms for environmental AMR mitigation measures. Evidence consistently demonstrates that regulatory approaches are considerably more effective when paired with financial and technical assistance (33,34,41,46,47). By reducing the financial burden associated with infrastructure upgrades, monitoring requirements, and management changes, government support programs can improve adoption rates, strengthen producer engagement, and facilitate a smoother transition toward sustainable antimicrobial stewardship practices. Such support is particularly important for small- and medium-sized producers, high-density livestock operations, and farms facing elevated disease pressures, which may encounter greater challenges adapting to new regulatory requirements (33,38–40).

The costs should be shared between governments, producers, and industry. Federal, provincial, and territorial governments should fund public-good components such as baseline monitoring, data systems, technical guidance, and extension services, using existing cost-shared agriculture programs as a model. For example, the Sustainable Canadian Agricultural Partnership is a five-year, $3.5 billion federal, provincial, and territorial agreement, including $2.5 billion in cost-shared programs, with the federal government contributing 60% and provincial or territorial governments contributing 40% (68). It also includes the Resilient Agricultural Landscape Program, a $250 million cost-shared program to support on-farm adoption of beneficial practices. This type of structure could be adapted for AMR risk reduction.

Producers should contribute to farm-level upgrades that also improve productivity, such as manure storage, runoff control, water management, ventilation, biosecurity, and animal health planning, with contribution rates scaled by farm size, risk level, and financial capability. Industry groups, processors, integrators, and producer boards should support sector-wide tools such as training, benchmarking, and audit systems because these protect market access and public trust. After an initial transition period, farms that repeatedly exceed agreed thresholds or fail to follow required practices should bear the cost of corrective actions. This cost-sharing approach supports fair transition while keeping accountability for ongoing non-compliance.

This support is not a subsidy for pollution. It is a risk-reduction investment. Pig and poultry evidence shows that withdrawing prophylactic antibiotics can be feasible but may cause short-run performance or health effects if farms do not have strong husbandry and disease prevention in place. For example, a commercial pig study found early growth and feed-intake reductions after removing in-feed prophylactic antibiotics, but health and finisher performance effects were limited when sick animals could still be treated, and management was maintained (69)**.** This recommendation helps to avoid pushing producers into losses while still lowering environmental AMR risk.

6. Implementation Strategy

Implementation should occur through a phased, evidence-based process that allows regulators and producers to adapt gradually while generating the data required for future policy refinement.

During Phase I (Years 1–3): Governments should establish national monitoring infrastructure, expand environmental surveillance programs, develop scientifically informed AMR thresholds, and introduce voluntary incentive programs to encourage early adoption of best management practices. This initial phase would focus primarily on data collection, stakeholder engagement, and capacity building.

During Phase II (Years 3–6): Moderate antimicrobial reduction targets should be implemented alongside expanded manure management requirements and mandatory reporting systems. This phase would represent the transition from voluntary participation toward a more structured regulatory framework while maintaining flexibility for sector-specific circumstances.

During Phase III (Years 6–10): Policymakers should conduct comprehensive evaluations of program outcomes, assess environmental and economic impacts, and determine whether additional regulatory measures are warranted. AMR indicators should also be integrated into broader national environmental assessment frameworks to ensure continued monitoring and accountability.

This phased implementation strategy balances the need for meaningful action on environmental AMR with the practical realities of agricultural production. By emphasizing gradual change, continuous evaluation, and producer support, Canada can reduce environmental contamination associated with antimicrobial use while protecting farm viability, food security, and public health.

7. Strengths and Limitations

The main strength of this policy is that it balances public health protection with agricultural feasibility. It does not ask Canada to remove antibiotics from farms. It asks Canada to manage environmental release in a way that preserves veterinary treatment, reduces avoidable contamination, and supports producers through the transition. The policy also responds to long-run food security. Food security is not only the current production volume. It also means stable, safe, and affordable production over time. AMR threatens that stability because it can raise health care costs, reduce workforce productivity, harm animal health, and affect agriculture itself. CARSS 2025 notes that AMR could cost Canadian agriculture CAD 11 billion annually by 2050 (29). It makes AMR prevention an agricultural resilience issue, not only a medical issue.

The policy may face limitations associated with cost. Producers may face new monitoring, infrastructure, and management costs, and these costs will not be equal across sectors. Pork, beef, poultry, dairy, aquaculture, and orchards differ in disease risks, production cycles, margins, and environmental pathways. A second limitation is measurement. Antibiotic residues, AROs, and ARGs are not equally easy to monitor, and setting thresholds for ARGs is harder than setting thresholds for conventional chemical pollutants. A third limitation is jurisdiction. Agriculture, water, environment, veterinary oversight, and food safety are divided across federal, provincial, and territorial systems. This does not mean the policy is unworkable, but it means implementation must be phased and coordinated.

In addition to cost-related limitations, regulating antimicrobial and ARG concentrations in agricultural soils presents its own challenges despite the potential for reducing AMR spread and protecting human and environmental health. Although there are defined PNECs for many antimicrobial compounds, further research is required to understand the selective pressure of long-term exposure to subinhibitory concentrations of antimicrobials. Further research is also required to understand the complex dynamics of ARGs in agricultural soils, including their persistence and cumulative effects on microbial communities over time, as well as the co-selection of ARGs by other environmental stressors present in agricultural settings (e.g., pesticides and herbicides, metals). Setting a conservative cutoff for antimicrobial concentrations in soil, however, will serve to reduce the selective pressure exerted on soil microbial communities favoring the development of resistance, and can be updated as novel evidence emerges.

8. Communication Strategy

The proposed policy aims to address AMR pollution originating from agricultural operations that is disseminated into the environment via wastewater, agricultural waste, and runoff. The policy considers the economic and food security impacts of implementing additional regulations within the Canadian agricultural sector, and how current regulations focused on the spread of manure and pesticides may be adapted for antimicrobial pollution. If Canadian legislation required the regulation of environmental pollution of antimicrobials and ARGs, the agricultural producers within Canada's agricultural and agri-food sectors would be significantly impacted. Thus, is it imperative that regulation changes are clearly communicated to those within these sectors, and support with both actionable training and financial aspects are provided to ensure maximal effective cooperation within the agricultural workforce. Our proposed communication strategies are directed at workers in the agricultural sector using methods that are easily digestible and frequently encountered in the average daily routines of impacted individuals. The communication methods include a website dedicated to policy related information and resources, a radio broadcast, a televised public service announcement (PSA), social media posts, and targeted unionist representative outreach.

An official Government of Canada sanctioned website managed by AAFC will be the main communication method for publicly accessible information related to the proposed policies. The website will contain all policy details and legislation; policy implementation timelines and status reports; financial and informational resources for agricultural workers and agri-food business; and updated answers for frequently asked questions. The website will also contain a means to provide feedback related to updated policy structures and contact relevant human resource officials when needed. More concretely, the website will be organized into seven tabs: a Homepage, an Overview of AMR and Agriculture, Policy Recommendations, a Policy Regulatory Framework, a Phased Policy Implementation Strategy, Food Security Implications, and a Contact page.

A PSA relating to the policy will be broadcast through both radio and television channels to increase awareness among the public and provide direction to the website resources. It is important to consider aspects of the target demographic to ensure effective communication. Radio communication is a primary method of information dissemination among agricultural workers in North America, with 79% of farmers reporting listening to radio every day and 93% tuning in at least once per week (70,71). The 2021 Canadian Census of Population found that the median age of Canadian farmers was 41.6 years, and three in five (60.5%) farm operators were ages 55 years or older (72,73). Television is another effective method of communication for the agricultural workforce as 87% of Canadians over the age of 50, and 83% between the ages of 35 and 49, consume traditional broadcasted television regularly (74). The proposed radio and television broadcasts will have the same script and audio recording, with the televised broadcast containing additional video clips corresponding to the spoken material and content related to Canadian agricultural environments. The content of the broadcasts will include an overview of AMR, its agricultural origins, the associated public health risks, the upcoming regulatory changes, and a referral to the official government website for compliance support. The proposed agency responsible for governing this broadcasting will be the Canadian Radio-television and Telecommunications Commission, and the networks providing the broadcasting service will include Canadian channels such as the Canadian Broadcasting Corporation (CBC) and local municipal channels across agriculturally dominated areas. The funding for this broadcasting will be allocated from the AAFC budget. Often, radio and television channels, including the CBC, will permit "on-air" broadcasting for a predetermined amount of time at no cost to the organization for PSA's which provide information that can contribute to the broader well-being of a community. Thus, the allocated budget will primarily fund the recording and construction of the broadcasts, along with potential costs associated with smaller channel distribution, which can be highly variable (75).

To increase awareness among those impacted by the proposed policies who do not regularly engage in radio or television consumption, our proposal also includes the promotion of policy-related information on social media. The social media platform we believe would be most effective in communicating to the Canadian agricultural population is Facebook, as 83% of North American farmers who regularly use social media rely on Facebook as their primary source of content (71). These social media posts will be created and managed by the official AAFC Facebook account (https://www.facebook.com/CanadianAgriculture/) using their predisposed resources and budget. Examples of social media post topics include awareness of new policy changes, timelines of future policy implementation, promotion of the website, links to resources to help agricultural workers with policy conformance, information about AMR, and other relevant policy-related announcements.

The final proposed method of communication to help with policy implementation and awareness will be outreach to the major national farmer's unions of Canada including the National Farmers Union (NFU), the United Food and Commercial Workers (UFCW): Union for Agricultural Workers Canada, and the Syndicat Agriculture Union (76–78). Unions at the provincial and commodity-specific levels will also be contacted on an as-needed basis, determined by how specific policy regulations will impact different farm types. Outreach will include a two-step process for efficient understanding and discussion between all implicated parties. First, a formal letter with the policy brief will be sent to the national and commodity-specific union groups to examine the novel policy. In the weeks following letter circulation, a meeting can be arranged between AAFC and union heads to ensure correct understanding of the content of the brief and to answer any questions regarding the policy. Union groups have existing information dissemination pathways for the agricultural force such as "e-news" that can provide updates on upcoming changes in legislation from a trusted source. The unions will also provide an avenue for the workforce to freely communicate any concerns or difficulties with policy implementation that can be relayed back to official governing and decision-making bodies.

Overall, we believe communication avenues including a dedicated website, radio broadcasts, televised PSAs, social media posts, and targeted unionist representative outreach will provide ample means to the agricultural workforce of Canada to ensure the proposed policies are effectively communicated and implemented. Additionally, these methods will provide access to support with implementation of new regulations, practical training resources, and opportunities for feedback from the workforce.

9. Conclusion

Canada should regulate environmental contamination originating from agricultural antimicrobial use through a phased, evidence-based framework grounded in One Health principles.

The literature indicates that moderate antimicrobial reduction combined with improved management and prevention strategies can achieve meaningful environmental and public health benefits while preserving agricultural productivity and food security (33,34,36,37,39). Abrupt restrictions without adequate support, however, risk creating unnecessary economic disruption and production instability (38–40).

Accordingly, Canada should adopt a balanced regulatory model emphasizing:

- Environmental monitoring
- Risk-based AMU reduction
- Improved manure management
- Producer incentives and transition support
- Long-term antimicrobial stewardship

Such a framework would position Canada as a leader in sustainable agricultural production while protecting both public health and the long-term viability of the agricultural sector.

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