Damage assessment of environmental contaminants in apiary honey bee (Apis mellifera) colonies

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Abstract. The article addresses the assessment of harm from pollutants to honey bees in apiaries under escalating pesticide pressure associated with the cultivation of entomophilous crops. The stated objective is pursued by investigating the consequences of pesticide exposure for the health of pollinator bees. Methodologically, the study combines general scientific and domain-specific approaches, including analysis and synthesis, systems and logical methods, interpretation of legal norms, and comparative-legal and structural–functional analyses of international and Russian sources. The research finds that improper field treatments against agricultural pests frequently lead to mass mortality of honey bee colonies, while in practice no unified approach exists for quantifying damage caused to colonies by pesticide applications to crops. Accordingly, the study formulates recommendations: to codify, at the regulatory level, a standard methodology with an explicit reference to the "3-D" framework; to standardize the inspection report format (including colony strength metrics and brood photogrammetry); to regulate chain-of-custody procedures for sampling; and to establish a federal electronic registry of pesticide applications with advance notification to beekeepers. In the authors' view, these measures will protect pollinator bees from harmful pollutant exposures and ensure the normal functioning of beekeeping operations, ultimately supporting the development of apiculture in the Russian Federation.

1 Introduction

Mass mortality of the Western honey bee (Apis mellifera) and wild pollinators amid the intensification of agriculture remains one of the most acute challenges to agroecology and food security. The international literature consistently describes the risk as multifactorial: direct and sublethal effects of pesticides, mixtures ("cocktails") of active substances, synergies with pathogens, deficits in floral resources, and climatic stressors. The application of plant protection products during the flowering of entomophilous crops creates short-lived but extreme exposure peaks that translate into colony losses and economic damage for

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beekeepers and, downstream, into diminished agronomic benefits from pollination. The updated EFSA guidance on the risk assessment of plant protection products for bees underscores the need for colony-level endpoints and more realistic exposure scenarios, which is likewise important for legal practice in damage compensation and enforcement [1].

The use of insecticides in crop production is, given the precarious status of pollinators, an especially urgent global issue; under contemporary production systems, some entomophilous crops require extensive pesticide use. Rapeseed/canola (Brassica napus) is one such crop: the biodiesel yield from one metric ton of rapeseed oil can reach ~96% under optimized transesterification. However, successful cultivation entails technological risks, including repeated applications of insecticides, fungicides, and herbicides. In many countries, the resulting pesticide burden on the environment is regarded as a constraint on acreage expansion, whereas in the Russian Federation both acreage and output of rapeseed have steadily increased over the past decade, heightening the importance of poisoning prevention and of adequate valuation of damages to beekeepers.

Empirical findings for rapeseed show that:

- dozens of active substances, including systemic insecticides, are detectable in nectar and pollen at concentrations relevant to sublethal effects;
- insect pollination contributes substantially to rapeseed yield, and under certain conditions this contribution exceeds the predictive benefit of pesticide treatments;
- exposure is associated with behavioral and physiological impairments in bees, which are amplified by interactions with other stressors.

Taken together, these results explain the high vulnerability of apiaries in zones of intensive rapeseed cultivation and delineate a set of verifiable variables for judicial assessment of the causal chain “treatment → colony mortality/weakening” [2].

From a legal standpoint, the Russian system of damage compensation rests on the general tort provisions of civil law [3] and on specific duties imposed on agricultural producers; however, there is no unified economic–legal methodology for quantifying losses when bee colonies die. Judicial practice exhibits heterogeneous approaches (e.g., replacement value per colony, recalculation by occupied inter-frame “streets,” lost profits). An integrated methodology is therefore needed—one that combines scientifically valid indicators of exposure and injury (colony-level and production metrics) with legally reproducible evidence (inspection reports, laboratory protocols, price series)—to ensure predictable adjudication and fair compensation under the growing pesticide burden from entomophilous crops, foremost rapeseed.

2 Methodology

The study employs general scientific and specialized methods traditionally used to investigate economic and legal phenomena. Specifically, it applies analysis and synthesis, a systems approach, interpretation of legal norms, and logical reasoning in examining normative legal acts, federal and regional guidance on the prevention and documentation of pesticide poisonings, and judicial practice (2019–2025)—including compensation cases involving poisonings (Bryansk Oblast, Altai Krai, Tatarstan) and the disclosed formulas for recalculating occupied inter-frame “streets” (bee spaces) and brood.

Comparative-legal and structural–functional methods are used to analyze the EFSA guidance on bee risk assessment, peer-reviewed studies on toxicity and residue levels, and colony-level loss metrics.

A synthetic methodology is further employed through the development of a computational model comprising three modules: (i) direct damage (biomass of adult bees, brood, queens); (ii) product losses (honey, bee bread, wax); and (iii) lost profits (seasonal potential and colony recovery).

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3 Results

At present, the Russian Federation is expanding the cultivation of various agricultural crops, including rapeseed, that require treatment with insecticides, fungicides, and herbicides. This practice imposes additional pressure on the environment and poses a threat to the survival of bees and other pollinators [4]. The use in practice of pesticide application rates prescribed by current regulations, without accounting for the actual ecology of the agroecosystem, destabilizes "population oscillations" [5] and may result in harm to pollinators through poisoning by various agrochemicals.

At the same time, conserving bee populations as pollinators is a key objective of state policy aimed at environmental protection and ensuring the ecological safety of the population. The expansion of rapeseed acreage in the Russian Federation is confirmed by statistics: both planted area and production have reached record levels (see Figure 1), increasing the likelihood of bee contact with residues of plant protection products and raising the evidentiary burden for establishing the causal link "treatment → colony impairment." Moreover, many studies indicate that pesticide applications may lead not only to direct bee mortality but also to diverse adverse effects on bee health [6–9].

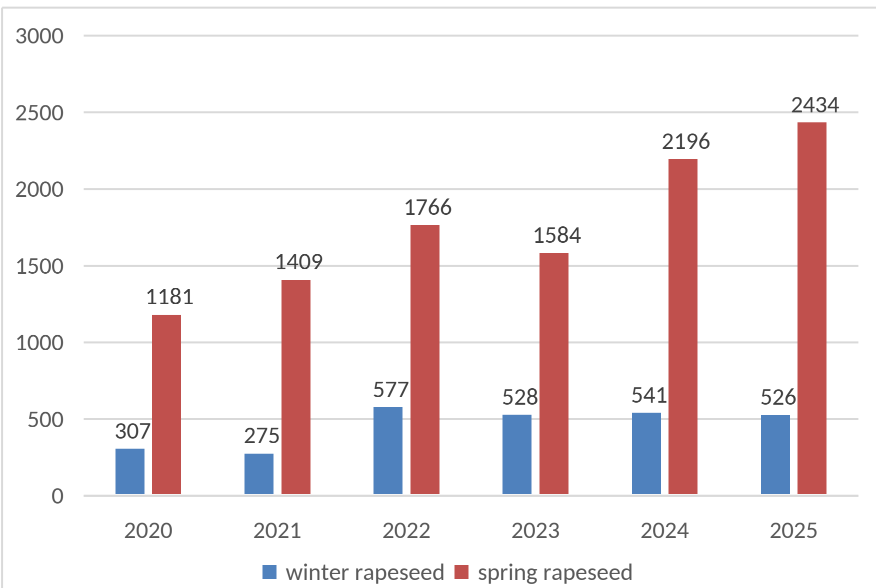

Fig. 1. Sown area of rapeseed in the Russian Federation, thousand hectares (authors' compilation based on data from the Federal State Statistics Service of the Russian Federation,https://rosstat.gov.ru/storage/mediabank/posev_pl.xls)

Against this backdrop, industry and official data on honey indicate a stable yet non-growing level of output: according to Rosstat, approximately 64.5 thousand tonnes were produced in 2023, and the Ministry of Agriculture together with industry organizations projected that volumes would remain in the 64–65 thousand-tonne range in 2024–2025; in agricultural organizations, the number of bee colonies in 2024 amounted to 49.7 thousand (+4.2% y/y) (A Drop of Tar in a Barrel of Fakes: What's Wrong with Honey Production in Russia. URL: https://www.forbes.ru/prodovolstvennaya-bezopasnost/527810-lozka-degta-v-bocke-fal-sivki-cto-ne-tak-s-proizvodstvom-meda-v-rossii?utm_source=chatgpt.com), illustrating a structural shift toward small producers and the sector's vulnerability to localized poisoning events.

The Civil Code of the Russian Federation provides for tort liability of the party causing harm (Art. 1064) and establishes a special regime for "sources of heightened danger" (Art. 1079); agricultural spraying by tractor units and the use of plant protection products are, in the logic of law enforcement, classified as activities of heightened danger, which elevates the standard of due care.

Federal Law No. 490-FZ of 30 December 2020 "On Beekeeping in the Russian Federation" (Art. 16) expressly requires agricultural producers to notify beekeepers of treatments to prevent bee poisoning. Non-compliance with notification procedures, application techniques, and regulatory requirements for pesticides and agrochemicals gives rise to a presumption of fault. In practice, however, agricultural producers often fail to discharge this duty properly, leading to mass bee die-offs. This necessitates more detailed regulation of this obligation for agribusinesses and the creation of a federal electronic registry of plant protection product applications with mandatory beekeeper notification.

Pursuant to Article 25 of Federal Law No. 109-FZ of 19 July 1997 (as amended on 28 December 2024) "On the Safe Handling of Pesticides and Agrochemicals," persons responsible for violations of Russian legislation governing the safe handling of pesticides and agrochemicals are liable in accordance with Russian law. These provisions also extend to bee mortality resulting from chemical treatment of fields.

Under Article 15 of the Civil Code of the Russian Federation, losses incurred as a result of an unlawful act are subject to full compensation, including actual damage and lost profits. To obtain full compensation, the injured party must file a claim in court, and the prerequisites for imposing tort liability must be present. As clarified by the Plenum of the Supreme Court of the Russian Federation in Resolution No. 25 of 23 June 2015 "On the Application by Courts of Certain Provisions of Section I of Part One of the Civil Code of the Russian Federation," in actions for damages the claimant must prove that the defendant is the person whose actions (or omissions) caused the harm, as well as the facts of breach or tortious conduct and the existence of losses. The amount of recoverable losses must be established with a reasonable degree of certainty.

In practice, the most challenging task is to establish a causal nexus between agrochemical crop treatments and bee mortality. To minimize disputes over causation, it is advisable to: (i) promptly document the incident (photo/video evidence, meteorological data, distance/radius from the apiary to the fields, notifications/warning signage); (ii) collect samples of bees/pollen/plants for residue analysis; (iii) convene a commission with participation of the veterinary service and local authorities; (iv) request farm treatment logs (date, product, application rate, phenological stage, spraying/flight hours); and (v) assemble corroborating economic evidence (price lists, contracts, harvest/production statistics). These steps are consistent with regional recommendations and judicial practice.

A persistent difficulty in recovering damages for bee die-offs is quantifying the losses suffered by the apicultural enterprise, as no unified methodology currently exists. In conducting expert evaluations and damage assessments, experts typically rely on Federal Law No. 135-FZ of 29 July 1998 (as amended on 14 February 2024) "On Valuation Activity in the Russian Federation" and applicable appraisal standards, which envisage cost, income, and comparative (market) approaches. However, calculating losses arising from bee mortality requires a specialized methodology that accounts for the specific features of apiculture. Such a methodology was developed in the USSR - the Instruction on the Prevention of Bee Poisoning by Pesticides of 14 June 1989 - which, while no longer formally in force as a normative legal act, is still frequently applied in practice when determining damages.

We present a comparative analysis of the methodologies used in the Russian Federation to calculate damages arising from bee mortality due to agrochemical poisoning, taking into account the Instruction on the Prevention of Bee Poisoning by Pesticides of 14 June 1989 and current judicial–appraisal practice.

The 1989 Instruction defines conversion units termed "conditional honey units" (UME). The Instruction contains not only preventive and procedural provisions (commission procedures, sampling, laboratory verification), but also a full section on the economic valuation of damage. The key technique is to convert apiary components into UME and then multiply by the price of 1 kg of honey: 1 kg of bees = 10 UME; a mated queen = 2 UME; brood recalculated per standard 435×300 mm frame = 10 UME; a brood comb = 0.5 UME; bee bread (perga) = 6.5 UME; etc. In cases of complete colony loss, losses of marketable honey are taken from planned/average productivity over the preceding three years; in partial-loss scenarios, the mass of bees "before" and "after" is compared using veterinary passports and official reports. These coefficients and the underlying logic are set out explicitly in the Instruction.

Advantages: standardization; familiarity to commissions and courts; linkage to field-observable measures (frame, inter-frame "streets").

Limitations: the economic base is tied to the price of honey and may lead to "double counting" when both biomass/brood and honey-related lost profits are included; coefficients and examples were developed under different price regimes; modern heads of loss (pollination contracts, reputational/logistical losses) are not captured.

Nevertheless, courts still frequently apply this logic and its coefficients. For example, in a case before the Pochep District Court (Bryansk Oblast), the court accepted recalculation by occupied inter-frame "streets" (≈200–250 g per street) with subsequent conversion into "conditional units" via the price of 1 kg of honey, and it also accounted for rejected bee bread and expert costs (Decision in case No. 2-131/2023 of 17 October 2023 — recovery of damages caused by chemical treatment of fields, Pochep District Court, Bryansk Oblast).

"Street-based" (mass) assessment of colony biomass with subsequent conversion. A common field technique estimates bee mass as the number of occupied "streets" × 0.20–0.25 kg; the resulting mass is then converted into UME (typically ×10) and multiplied by the honey price. Brood is handled analogously using counts of "squares" on the frame (1 square ≈ 10 g/≈100 bees). This method features prominently in judicial decisions and methodological memoranda (e.g., Decision No. 2-263/2021, 22 November 2021, Shipunovsky District Court, Altai Krai).

Advantages: rapid, low-cost instrumentation at the incident site; traces of normative verification via GOST 20728-75/2014 (colony composition/strength).

Limitations: sensitivity to commission subjectivity in visual assessments; variation by breed/season; risk of improper aggregation with marketable products.

Market replacement cost plus documented lost profits. In appraisal and court practice, a "market replacement" model is often used: the value of the deceased/lost units (colonies, packages, queens) at current regional market prices + actual expenses (feed, veterinary services, laboratory work, representation) + lost profits (shortfalls in honey/bee bread/wax, canceled deliveries, pollination services) based on the enterprise's multi-year time series and market price indicators (e.g., "Assessment of damage caused by poisoning or death of bees (bee colonies)," https://www.ceae-ocenka.ru/okazyvaemye-uslugi/uslugi-ocenki/uslugi-oczenki-ushherba/ushherb-pri-gibeli-pchyol.html?utm_source=chatgpt.com).

Advantages: anchoring in real prices and contracts; flexibility to accommodate apiary- and season-specific circumstances.

Limitations: high evidentiary demands (contracts, invoices, honey-harvest statistics); the need to avoid "double counting" when combined with UME-based approaches.

A number of regions/agencies publish memoranda and recommendations specifying procedures for convening commissions, standardized act forms (requiring mandatory documentation of colony strength in inter-frame "streets" before/after, the list of affected frames, and the type/mass of products), rules for sampling/transport of specimens, and document checklists to substantiate loss estimates. These materials do not replace a federal methodology, but they improve the reproducibility of evidence and "stitch together" the calculation with laboratory verification of plant-protection product residues.

International instruments—most notably the 2023 EFSA Guidance—recommend colony-level assessment of effects and exposure; current research documents mixtures of insecticides/fungicides/herbicides in pollen and bees, sublethal effects (cognitive, microbiome), and heightened viral loads under combined stressors. These findings are essential for judicial verification of the causal chain (exposure → effect) and for estimating the horizon of lost profits (colony recovery time) [1].

Historically, the 1989 Instruction and its derivative UME-coefficients have operated as a de facto standard often accepted by courts (e.g., detailed formulas converting bees, brood, and queens into UMEs with multiplication by the market price of honey). However, tying the economic base to honey prices without a clear separation of damage blocks creates risks of double counting and fails to capture all modern heads of loss.

In practice, a hybrid is advisable: (i) direct damage - valued at market replacement cost (colonies/packages/queens), anchored in GOST-based colony-strength metrics; (ii) production losses - rejected products valued using laboratory results and market prices; (iii) lost profits - estimated from the enterprise's multi-year time series and regional price indices, kept analytically separate from UME conversions. This "3-D" approach aligns with the evidentiary logic of commissions and contemporary judicial practice, reduces disputability, and prevents double counting.

For legal certainty, the coefficients and calculation algorithms should be formally confirmed (updated) in a subordinate act of the Government of the Russian Federation.

The proposed optimal damage-calculation methodology - the "3-D" (Direct–Derived–Deferred) model - structures the components and eliminates double counting.

Table 1. Structure and formulas for calculating losses incurred by an apicultural enterprise.

Component	**Calculation formula (core concept)**	**Rationale / data source**
Direct damage: adult bees	∑colonies(occupied inter-frame "streets"×0.20–0.25 kg)×Ccol (market price per colony)	Inspection report; "street" method; regional price lists for colonies/bee packages
Direct damage: brood	Brood area (grid "squares")×mass per square×Ccol	Court-adopted formulas; laboratory photos/measurements of brood
Direct damage: queens	Nqueens×Cqueen	Market price lists for queens/strains
Rejected product	(Honey+bee bread+wax)unfit×realized prices	Laboratory findings on contamination; sales invoices
Lost profits	(Planned honey harvest−actual)×price+foregone revenue from packages/pollination	Average yields over 2–4 years in the locality; pollination contracts
Apiary recovery	Cost of replenishing colonies to the pre-incident baseline + feed/medical expenses	Market prices for packages/syrup/veterina

		ry preparations

Notes: Ccol - market price of a colony (or bee package);
C queen - market price of a queen.

Example calculation (schema):

Apiary: 70 colonies; average strength = 10 inter-frame “streets”; 30 colonies lost completely, 20 weakened by 50%.

— Adult bees (total loss): 30 col × 10 streets × 0.22 kg ≈ 66 kg × C col (biomass/colony price).

— Brood: frame photo-planimetry × mass × price.

— Lost profits: (three-year average honey yield for the district − actual) × price (Rosstat/market).

— Recovery: purchase of packages to rebuild to 70 colonies + feed/veterinary expenses.

This approach yields a more transparent and verifiable calculation than a “universal conversion into kilograms of honey.”

4 Conclusion/recommendations

Thus, the analysis demonstrates that the rising pesticide burden associated with the expansion of entomophilous (insect-pollinated) crops - above all rapeseed - coincides with legal uncertainty both in establishing causation and in quantifying losses incurred by apicultural enterprises. The proposed unified “3-D” model (Direct–Derived–Deferred) provides a separate and verifiable accounting of direct damage (biomass of adult bees, brood, queens), production/commodity losses (honey, bee bread, wax), and deferred consequences (lost profits, apiary recovery costs). Its application enhances the reproducibility of expert assessments and the predictability of judicial decisions while minimizing the risk of “double counting” inherent in blanket conversions of all losses into “kilograms of honey.”

It is recommended to codify a standard damage-calculation methodology at the level of a subordinate act of the Government of the Russian Federation, with explicit reference to the 3-D structure, a list of admissible data sources (commission reports, frame photogrammetry, veterinary passports, laboratory residue protocols, multi-year series on honey yields and prices), and standards for proving causation (treatment time window, crop phenology, weather conditions, sample matrices). The inspection-act form should be standardized and include mandatory fields (number of occupied inter-frame “streets,” brood area by frame, queen status, accounting of rejected product, inventory of co-stressors), and the chain of custody for samples destined for chemico-toxicological analysis should be regulated.

To prevent incidents, a federal electronic registry of plant-protection product applications should be established with mandatory beekeeper notification (SMS/email/push via a mobile application) no later than three days prior to treatment, specifying the product, application rate, phenophase, and flight restrictions. At the regional level, “biologically grounded application windows” should be formalized (night/pre-dawn treatments; prohibitions on flowering stands and where melliferous wild flora is present), along with buffer zones and limits on tank mixtures that heighten pollinator toxicity. Product labelling should include a standardized “Bee-safe use” panel: safe-use window, brood risk, and requirements to close hive entrances and remove waterers.

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