# WINTER CAMELINA

## ENVIRONMENTAL & AGRONOMIC INSIGHTS

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MBOLD
The GREATER MSP Partnership

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LEIF

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## ABOUT THIS REPORT (METHODS & STAKEHOLDERS)

The MBOLD Coalition commissioned this analysis, with the support of the Builders Initiative, to promote the adoption of soil health practices on agricultural land and to advance sustainability in animal agriculture through the development of alternative feed ingredients such as winter camelina meal. While bringing new crops to market is a long and complex process, MBOLD is committed to building the knowledge base and exploring how crops like winter camelina can become a viable and valuable option for both farmers and supply chain stakeholders. Gaining a better understanding of camelina's environmental performance is central to this effort. This report synthesizes the current state of knowledge on winter camelina's environmental performance, with the aim of informing growers, agronomists, supply chain participants, and policymakers as they evaluate its potential for agricultural diversification and sustainable intensification. MBOLD thanks the Builders Initiative for their funding of this analysis.

LEIF LLC, a science-first sustainability consultancy specializing in life cycle assessment (LCA), product carbon footprints (PCFs), and scenario-based decarbonization modeling, was engaged by MBOLD—under the coordination of the Agricultural Utilization Research Institute (AURI)—to conduct this independent review. The assessment examined peer-reviewed studies and leading technical reports addressing greenhouse gas emissions, soil and water outcomes, biodiversity, agronomics, and economics of integrating winter camelina into Midwestern crop rotations (e.g., corn/soy/wheat). Sources were screened for recency (with emphasis on the past decade), methodological rigor (peer-reviewed and empirically grounded), and geographic relevance to Midwestern production systems. Findings were then synthesized across the literature. To ground the review in current practice and market realities, LEIF also consulted with key stakeholders, including Cargill, the University of Minnesota's Forever Green Initiative, and subject-matter experts at AURI.

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## EXECUTIVE SUMMARY

Winter camelina is an emerging oilseed crop that increases the productivity and sustainability of established crop rotations. This approach, known as temporal intensification, delivers measurable environmental benefits and offers a compelling pathway for sustainable intensification—unlocking climate, economic, and environmental benefits by leveraging bare soil periods for productive gain. Its integration supports the transition toward climate-smart, regenerative agriculture by enhancing output without expanding land use or compromising long-term soil and ecosystem health.

- **Land use efficiency —** Integrating winter camelina into corn–soybean rotations enables a second marketable crop during otherwise idle winter seasons, boosting total output without expanding cropland.
- **Climate-Smart Intensification —** Adding winter camelina to annual rotations can increase total oil production by up to 50% per acre, and can lower total system carbon intensity per unit of total seed output by maximizing seasonal land use efficiency and avoiding land conversion.
- **Water quality, soil health & erosion —** Studies show substantial reductions in nitrate losses (often 50–70%) and sediment/erosion (frequently 40–90%+) when camelina provides living cover from late fall to spring; producers also report improved aggregate stability and infiltration, supporting field resilience.
- **Biodiversity & pollinators —** Early spring bloom supplies nectar/pollen when alternatives are scarce, supporting beneficial insects and on-farm biodiversity.
- **Low-carbon fuel potential —** Winter camelina feedstock enables production of renewable fuels with substantial greenhouse gas reductions compared to conventional fuels: ~40–70% for biodiesel, ~80% for renewable diesel, and ~50–84% for drop-in jet fuel.

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# CLIMATE INSIGHTS

Substantial climate benefits highlight camelina's potential to advance carbon reduction in agriculture and energy

## CARBON INTENSITY

***Crop production carbon intensity (CI) —*** Crop production uses fertilizer and fuel that emit greenhouse gas (GHG) emissions both upstream (manufacture/transport) and on-farm (fuel use and $N_2O$ from fertilizer application). Winter camelina requires significantly lower fertilizer and other inputs (e.g. herbicides) than main-season crops like corn and soybeans, resulting in much lower area-based GHGs. When incorporated into existing Midwest systems as a continuous living cover cash crop, camelina typically contributes only 234–373 kg $CO_2e$/acre[1-7] during its growth cycle—notably lower contribution than the GHG emissions typically associated with corn (590–1,100 kg $CO_2e$/acre)[5,9-13] or soybean (400–800 kg $CO_2e$/acre)[4,5,7,9-12] monocrops.

While camelina seed itself has a higher CI per kilogram (0.40–0.84 kg $CO_2e$/kg) than corn and soy due to currently modest yields[1-7], the combination of these main season crop and camelina yields results in a lower overall CI per unit of total output relative to monoculture.[5] Even in soybean-camelina rotations, where soybean yields now generally decrease 10–30%, the overall CI per unit of total output (camelina+soy) is lower compared to soy monocultures.[5] This means that by using off-season lands, integrating winter camelina into existing rotations delivers more seed at a lower collective CI. Camelina emissions intensities are influenced by nitrogen application levels and resulting yields; a recent study showed that carbon intensity declines as nitrogen rates increase—up to an optimal threshold of 36 lbs N/acre- beyond which additional fertilizer increases emissions more than yields, causing CI to rise.[38]

***Biofuel production carbon intensity —*** Life cycle assessments (LCAs) focused exclusively on camelina's use as a biofuel feedstock show strong GHG-reduction potential compared to fossil fuels. Camelina-based biofuels (biodiesel, renewable diesel, and jet-fuel) typically have a CI around 30 g $CO_2e$/MJ, with fuel-specific ranges spanning 3 to 150 g $CO_2e$/MJ dependent upon the system boundary, N rate, seed yield, and fuel type.[38] When processed into biodiesel, camelina-based fuels reduce lifecycle emissions by 40–70% relative to petroleum diesel.[1,3] When processed into renewable diesel, camelina achieves approximately 80% lifecycle emission reductions compared to petroleum diesel.[42] Camelina is also valued as a feedstock for aviation fuels. When its oil is refined into a drop-in renewable jet fuel, lifecycle emissions are typically 71–84% lower than petroleum jet fuel.[8] Other camelina-derived jet fuels made with more intensive upgrading also cut emissions—often by around 50% compared with petroleum jet fuels.[1,6] These fuels qualify under several national and international low-carbon fuel standards and are actively used in sustainable aviation fuel (SAF) certification trials.[39] The U.S. 45Z guidance currently excludes carbon benefits from soil organic carbon (SOC) increases in CI calculations. However, proposed updates to existing carbon accounting standards and fuel crediting programs (e.g. 45Z, California Low Carbon Fuel Standard, U.S. Renewable Fuel Standard) may allow verified SOC gains, for example, from camelina systems, to count toward emissions reductions.[39]

## SOIL ORGANIC CARBON

**Soil organic carbon (SOC) gains —** While empirical evidence is limited for winter camelina, research suggests continuous living cover cash crops can increase soil organic carbon by approximately 4–8 metric tons carbon per acre over a decade using conventional tillage compared to no cover crops with fields left bare through winter.[41]

**Residue management —** Research shows that SOC outcomes depend critically on how crop residues are handled. Retaining camelina residues after harvest promotes continued SOC accumulation, while consistent residue removal can diminish or even reverse these benefits.[30,31] Pairing continuous living cover cash crops with no-tillage can further enhance SOC in the upper soil layers.

**Impacts on carbon intensity (CI) —** The additional organic matter and carbon stored in soil from incorporating winter camelina into crop rotations can counterbalance the extra fertilizer used, thereby reducing net GHG emissions.[8] While carbon market and regulatory frameworks do not currently account for SOC gains in CI scores, they remain a key environmental benefit that supports soil health and long-term system resilience.

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## LAND USE CHANGE

**No additional cropland needed —** As an intermediate winter oilseed, winter camelina can be sown between main crops, utilizing existing cropland during otherwise bare winter periods, thereby avoiding the significant land use change emissions that directly results from converting new land for production (i.e. direct land use change).[3,30]

**Indirect land use savings —** Camelina meal, a coproduct of oil extraction, can substitute for some soy or other meal in livestock feed, potentially reducing global cropland demand by displacing a portion of soybean cultivation.[6] Recent modeling estimates indicate that these secondary effects of camelina oil production can result in camelina-derived biofuels having indirect land use change (iLUC) GHG emissions of –15.3 g $CO_2e$/MJ, suggesting camelina integration could reduce GHG emissions.[14] By comparison, typical iLUC emissions for conventional biofuels range from 12 g $CO_2e$/MJ for cereal and sugar crops to 55 g $CO_2e$/MJ for oilseeds such as canola, palm, and soybean, which can more than double reported production emissions and substantially reduce their climate mitigation potential.[15]

**Context of iLUC uncertainties —** Modeling iLUC emissions involves large uncertainties, is subject to variable model assumptions, and no harmonized, widely accepted methodology exists. As a result, leading frameworks such as GHG Protocol, SBTi, and ISO do not currently require their inclusion in product carbon footprints.[15]

**Potential yield trade-offs —** The impact of winter camelina on the yields of subsequent main crops remains uncertain. If winter camelina reduces yields, compensatory land expansion elsewhere (i.e. indirect land use change) could offset some climate benefits, highlighting the need for additional field research.[6,30]

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# ECOSYSTEM SERVICES

Better soil structure leads to deeper rooting and water holding, supporting higher productivity and resilience in subsequent crops.

## WATER QUALITY

**Enhanced infiltration and reduced runoff —** Unlike bare ground, camelina cover slows surface water flow and promotes infiltration, reducing runoff and the total export of nitrogen, phosphorus, and other nutrients attached to soil particles, helping safeguard downstream water quality.[17,18] The presence of living cover during high-risk precipitation periods is key to these improvements, as well as proper timing for fertilization.[40]

**Nutrient capture and reduced nitrate leaching —** Winter camelina's vigorous root system scavenges residual soil nutrients, especially nitrogen, preventing leaching into waterways during winter and early spring. Field studies show that including winter camelina in rotations can reduce nitrate concentrations in soil water and runoff by 50–70% compared to bare soil, with 90% reductions possible under optimal management, even with moderate spring fertilizer applications of ~55–65 lb N/acre.[16,17] These benefits occur because camelina maintains active nutrient uptake when no other crop is growing, but benefits can be negated with autumn fertilization.[40]

**Integrated weed management benefits —** Incorporating winter camelina into crop rotations can suppress early-season weed emergence, particularly winter annual and early-spring weeds that thrive in bare field systems. This reduces the soil weed seed bank and may lower the need for herbicide applications.[19] Fewer herbicide passes not only cut input costs but also minimize the risk of herbicide runoff, providing complementary soil and water quality gains.

## SOIL HEALTH

**Erosion protection and improved soil structure —** Camelina's dense root network and persistent surface residue protects soils from erosion by rain, wind, and freeze–thaw cycles that degrade bare fields over winter. Field studies show that soils under winter camelina exhibit higher water infiltration rates and greater aggregate stability than those left bare, allowing precipitation to soak in and significantly reducing loss of topsoil.[16,20]

**Dramatic sediment loss reductions —** Modeling and field trials demonstrate that incorporating winter camelina into crop rotations can reduce sediment loss by 90–95% compared to unprotected soils left bare until spring field operations.[17] Other studies have found a decrease in soil erosion of 39–50%.[31] Such reductions help maintain productive soil depth and prevent nutrient and soil export into waterways.

**Soil organic matter enhancement —** Winter camelina contributes organic matter through leaf litter and dense root biomass, which decompose to feed soil organisms and build stable organic carbon in the soil profile. Repeated use over multiple seasons can significantly increase soil organic matter and cation exchange capacity that improves fertility and moisture-holding capacity.[5,21] These improvements support long-term resilience and productivity of the entire cropping system.

## BIODIVERSITY & POLLINATOR SUPPORT

**Boosts pollinators, insects, and birds —** Winter camelina blooms in late April through May, offering a critical source of nectar and pollen for pollinators and beneficial insects when alternative floral resources are scarce.[22,23] Including camelina in rotations also increases above ground insect diversity, which attracts insect-eating birds and other arthropods that can help control pest populations such as aphids, potentially reducing the need for pesticide applications.[5,24] Although camelina is largely self-pollinating, studies show honey bees and diverse insect pollinators—including bees, flies, butterflies, beetles, and wasps—can enhance pollen transfer, boosting seed yields both in camelina fields and neighboring or subsequent crops.[24,25] While winter camelina provides living cover during the fall-through-spring period when fields would otherwise be bare, specific research on ground-nesting bird benefits is limited and requires further study.

**Enhances plant and soil biodiversity through crop diversity —** Crop sequences that include winter camelina score higher on biodiversity indices than monocultures like corn. In addition to adding another crop phase, camelina's relatively modest stature and slower spring growth can allow cool-season grasses and broadleaf plants to coexist in the understory, contributing to greater plant diversity. These coexisting species may be viewed as weeds agronomically, but ecologically, they enhance habitat and functional diversity without necessarily compromising yields or requiring additional control measures. This diversity supports a wider range of above- and below-ground organisms including insects, arachnids, earthworms, and microbes.[5]

**Avoids biodiversity loss from land use change —** Unlike conventional oilseed crops such as soybeans or corn, which can drive significant land use change (LUC) and indirect LUC (iLUC) impacts, winter camelina is grown on existing cropland without expanding agricultural land. This avoids one of the main global drivers of biodiversity loss, as agricultural LUC leads to habitat destruction, fragmentation, and declines in species abundance and richness across biomes.[26]

**Supports soil biodiversity with conservation practices —** Studies show that no-till systems with continuous living cover cash crops like camelina greatly enhance soil macropores and earthworm biomass, compared to deeply-plowed conventional tillage, supporting richer soil microbial and invertebrate communities.[5] This interaction between no-till and camelina further strengthens positive effects on soil health and biodiversity.

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# AGRONOMIC INSIGHTS

Winter camelina offers **agronomic advantages** that can enhance whole-farm productivity

## PRODUCTIVITY

**Seed Yields & Trade-offs —** Despite its short growing season, winter camelina can produce respectable seed yields, adding significant output on land that would otherwise lie bare, with on-farm yields typically ranging from 600–1,500 lb /acre depending on conditions.[1-7, 27]

**Relay-cropping with soybeans —** Integrating camelina into rotations via relay-cropping (overlapping camelina and soybean growth) can substantially boost total farm productivity relative to single-crop systems. Additional peer-reviewed studies are underway to confirm variability across soils and climates. Camelina can also serve as a "nurse crop," shielding emerging soybean seedlings from wind and pest damage.

**Double-cropping feasibility —** Sequential double-cropping of camelina followed by soybeans is possible in longer-season regions, though soybean yields in this system are typically 50–70% of full-season soy.[30] Site-specific research and local growing degree-days should guide adoption.

**Optimal planting windows —** In northern climates (e.g., Minnesota and Upper Midwest), best results are achieved when winter camelina is sown from mid-September to early October. Sowing earlier may cause excessive vegetative growth before winter, increasing the risk of winterkill. In milder regions, such as the Mid-South, successful establishment can occur with planting dates extending into late September or October.[33,36]

**Fertility management** — Depending on soil conditions, spring-applied nitrogen at 55–65 lbs N/acre can be the agronomic optimum for maximizing seed yield under Minnesota conditions, typically doubling yields over unfertilized controls.[32] However, recent research shows that 36 lbs N/acre optimizes carbon intensity, minimizing carbon output per unit of total production.[38] Fertilizer should be applied in early spring (late April) to coincide with rapid vegetative growth. Fall nitrogen is discouraged, as uptake before dormancy is limited and loss risk is high.[30,32] Over-fertilization may reduce oil content, and further research is needed to clarify the effects of other nutrient amendments on yield and seed quality.[32]

## WEED SUPPRESSION

**Weed suppression benefits —** By covering the soil surface and competing for resources in fall and early spring, winter camelina can suppress winter and early-spring weeds by up to 90% compared to bare fields.[19] This effect often allows growers in relay systems to skip a post-emergence herbicide in soybeans, though results vary by site and management. Other studies report no effect, indicating a need for more research.[19,21]

**Low risk of volunteer issues —** Volunteer camelina seedlings after harvest are easily managed with shallow tillage or low-rate herbicides and seldom become problem weeds in subsequent crops, making camelina a practical tool for weed control without downstream challenges.[19]

## SEED CHARACTERISTICS

**Oil value —** Camelina seeds typically contain 30–34% oil but can range between 22–50%, and are high in omega-3 and 6 fatty acids.[34,36]

**Meal value —** After oil extraction, the camelina meal remaining after crush contains 35–40% protein, serving as a valuable, FDA-approved livestock feed ingredient, usable at up to 10% inclusion in beef cattle and poultry (broiler and layers) diets.[35]

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