sustainability

MDPI

Article

Climate Assessment of Vegetable Oil and Biodiesel from Camelina Grown as an Intermediate Crop in Cereal-Based Crop Rotations in Cold Climate Regions

Hanna Karlsson Potter *, Dalia M. M. Yacout and Kajsa Henryson

Department of Energy and Technology, Swedish University of Agricultural Sciences (SLU), P.O. Box 7032, 750 07 Uppsala, Sweden; dalia.abdelfattah@slu.se (D.M.M.Y.)
* Correspondence: hanna.e.karlsson@slu.se

Abstract: The oilseed crop winter camelina (*Camelina sativa*) is attracting increasing interest for biofuel production. This study assessed the climate impacts of growing camelina as an intermediate crop in northern Europe (Sweden) for the production of vegetable oil and biofuel. Climate impacts were analyzed using life cycle assessment (LCA), while impacts on biodiversity and eutrophication were discussed. Three functional units were considered: 1 ha of land use, 1 kg of oil, and 1 MJ biofuel (hydrogenated vegetable oil, HVO). The results showed that dry matter yield over the whole crop rotation was higher in the camelina crop rotation, despite the lower yield of peas due to relay cropping with camelina. In the whole camelina crop rotation, fat production more than doubled, protein and fiber production marginally increased, and the production of carbohydrates decreased. Higher climate impacts related to field operations and fertilizer use in the camelina crop rotation, with associated N_2O emissions, were compensated for by increased soil carbon accumulation due to the increased return of organic matter from the additional crop in the rotation. The total climate impact was around 0.5 kg CO_2 eq/kg camelina oil when macronutrient allocation was used. The global warming potential was 15 g CO_2 eq/MJ HVO, or 27 g CO_2 eq/MJ HVO when soil organic carbon effects were not included, representing an 84% and 71% reduction, respectively, compared with fossil fuels.

Keywords: life cycle assessment; *Camelina sativa*; cover crop; northern Europe; biofuel

check for updates

Citation: Karlsson Potter, H.; Yacout, D.M.M.; Henryson, K. Climate Assessment of Vegetable Oil and Biodiesel from Camelina Grown as an Intermediate Crop in Cereal-Based Crop Rotations in Cold Climate Regions. *Sustainability* **2023**, *15*, 12574. https://doi.org/10.3390/su151612574

Academic Editors: Domenico Licursi and Md. Abul Kalam

Received: 21 June 2023
Revised: 2 August 2023
Accepted: 9 August 2023
Published: 18 August 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The European Union (EU) Renewable Energy Directive (RED) (EU 2018/2001: REDII) established a framework for promoting renewable energy sources in the EU and set a binding target of 32% renewable energy in overall EU energy consumption by 2030. Demand for biofuel is now increasing—by, on average, 4% annually—and is predicted to reach 186 billion L by 2026, with ethanol and biodiesel making up 87% of all biofuel demand [1]. Recent forecasts by the International Energy Agency (IEA) state that "The United States and Europe account for 90% of renewable diesel demand growth and nearly all biojet demand" and that Europe's biofuel demand will expand by 11 billion L due to increasing use in the transportation sector, especially in aviation and shipping [1]. With this increasing demand for renewable energy and materials, the demand for fatty acids is expected to increase [2]. In addition, dietary fat is consumed below recommended levels in many regions of the world and an estimated additional amount of around 45 Mt annually is needed to supply dietary needs [3]. The combined effect of increased demand for renewable energy and materials and increased demand for dietary fats means that fat/oil production needs to increase. Swedish biofuel use is an example of the growing demand for fatty acids, with the use of petrol and diesel in Sweden having decreased by more than 25% in the past 15 years. In 2021, biofuel consumption in the Swedish transportation sector reached 22 TWh, or around 24% of that sector's energy use [4]. Today, the Swedish biofuel market is dominated by hydrogenated vegetable oil (HVO) and fatty acid methyl esters (FAME), both produced from fatty acids using mainly raw materials imported into Sweden. In 2021, only 11% of the sixteen TWh HVO and 4% of the three TWh FAME sold in Sweden were produced from domestic raw materials [4]. Current HVO production is restricted, as resources are limited and there are environmental challenges [5].

Oilseed crops that can be grown as intermediate crops are attracting attention as potential biofuel feedstock, mainly because they can be cultivated with low competition with food and feed crops [6–8]. One such crop is *Camelina sativa* L. Crantz (camelina), an oilseed crop of the Brassicaceae family. It was originally domesticated in Western Asia and later cultivated in other parts of Europe, including Scandinavia [9,10]. It is now being more widely tested as a raw material for biodiesel production, with pilot-scale production established in Europe and North America [11].

Several aspects of camelina make it an interesting oilseed crop, e.g., it is a low-input crop [12], it has high resistance to common and wide-spread Brassicaceae diseases and pests [13], and it is suitable as a spring crop in drier regions of Europe and can be grown on land that is not suitable for food production [14]. In well-designed rotations, camelina can increase fatty acid production without significantly affecting the production of other nutrients. The potential seed yield of camelina when grown as a main crop is 2.5 metric tons/ha, and the seed contains around 42% oil, so it can be used for FAME and HVO production (saturated fatty content 8%, C18:1 17%, C20:1 16%, C18:2 17%, C18:3 38%). Camelina requires low nitrogen (N) inputs per unit of oil produced, so it can make a greater contribution to meeting the RED target on net CO_2 emissions reduction than, e.g., rapeseed [11]. Camelina-derived biofuels are thus considered a sustainable jet fuel or diesel alternative, reducing greenhouse gas (GHG) emissions by 75–80% compared with petroleum-based products based on life cycle assessment (LCA) [15]. Camelina seed meal is considered a valuable feed for poultry and pigs, while the seed hull can be used for electricity production [11].

Several field trials have shown that the production of winter camelina in cold countries with a relatively short growing period is feasible. For example, Gesch and Archer [16] found that winter camelina grown in the northern USA (Minnesota) could be harvested early enough to allow a second crop to be grown in the same year. Gesch and Archer [16] found that such double cropping with winter camelina increased total oil yield in rotations where sunflower or soybean followed winter camelina, despite the yield of the main crop being lower, as sowing had to be postponed for some weeks. In trials in Minnesota and North Dakota, relay cropping (where the main crop is sown in the growing camelina crop) has been shown to give higher energy efficiency in terms of the overall yield of the two crops and upstream inputs [17]. Other cold climate trials have been conducted in Modern, Canada [18].

Growing winter camelina has several potential benefits: (i) increased soil organic carbon (SOC) sequestration, due to higher crop residue inputs compared with crop rotations without an intermediate crop; (ii) decreased soil erosion and nitrate leaching, due to the presence of soil cover in winter [19]; (iii) greater early spring food availability for pollinators [6]; and easier planting of the following crop in wet conditions, through the camelina crop taking up water in late fall and early spring [6].

A few LCA studies have been conducted on winter camelina, especially in North American conditions, mainly using field trial data (e.g., Cecchin, Pourhashem [20], Berti, et al. [21]). Those studies assessed and compared the environmental performance of maize and soybean cropping systems with different winter cover crops, including camelina. Cecchin et al. [20] used an area-based functional unit and considered four impact categories (global warming potential (GWP), eutrophication, soil erosion, and SOC changes). They found that SOC levels were greatly affected by crop residue handling. They also found that camelina had similar eutrophication potential to other crops. Accordingly, they recommended camelina as a winter-hardy intermediate crop to reduce the environmental impacts of maize-soybean crop rotations, while pointing out that field management needs to be optimized for sustainable cropping [20]. The LCA study by Berti et al. [21] examined the environmental impact of double and relay cropping systems, with winter camelina compared with monoculture maize and soybean. They assessed several environmental aspects (GWP, abiotic depletion, acidification, eutrophication, ecotoxicity and human toxicity) and found that monoculture winter camelina gave the lowest values in all impact categories.

Other LCA studies have investigated the potential environmental impacts of camelina-based biofuel compared with fossil fuel. Shonnard et al. [15] found that life cycle GHG emissions of an isoparaffin-rich jet fuel derived from camelina amounted to 22.4 g CO_2 eq/MJ fuel, which was a 75% reduction compared with petroleum jet fuel. In an LCA of the environmental impacts of camelina oil-derived biodiesel and hydroprocessed renewable jet fuel produced on the Canadian prairies, Li and Mupondwa [22] considered four impact categories (GWP, human health, ecosystem quality, energy resource consumption). Dangol et al. [23] conducted an LCA and also assessed the potential for the production of camelina biodiesel in the Pacific Northwest (PNW), USA. They concluded that camelina biodiesel qualifies as an advanced biofuel under the US Energy Independence and Security Act [24] and that camelina could potentially yield 1.6 billion kg seeds per year when grown as a rotational crop in wheat fields in PNW [23]. A recent LCA study by Masella and Galasso [25] compared the environmental impacts of using camelina oil as a raw material for biodiesel production and pure vegetable oil extraction, both in northern Italy.

The aim of the present study was to assess the climate impacts of growing winter camelina as an intermediate crop in northern Europe (Sweden) for the production of vegetable oil for biofuel production (HVO). As camelina is a new crop to modern Swedish agriculture, data collection was based on input requirements (fertilizers, etc.) and agronomic performance reported in previous field trials in climates similar to Sweden. Three functional units were chosen to assess the climate effects from different perspectives: crop rotation effects, vegetable oil production, and biofuel production.

2. Materials and Methods

2.1. LCA Goal, Scope, System Boundaries, and Functional Units

LCA was performed following the ISO guidelines for LCA (14040/44) and comprised four phases: (1) goal and scope definition, (2) life cycle inventory, (3) life cycle impact assessment, and (4) interpretation [26].

The functional unit of agricultural systems is often connected to crop yield, i.e., 1 kg product, 100 g protein, or similar, and LCA studies often focus on one crop [27]. This approach generally favors maximizing the yield of the target crop. However, considering the whole crop rotation and the combination of products obtained could give new insights into the multifunctionality of land use and crop rotations and possible trade-offs. The three functional units (FU) considered in the present study were the following: 1 hectare of land (in a six-year crop rotation including camelina as an intermediate crop), 1 kg camelina oil, and 1 MJ HVO. The 1 ha of land FU was chosen to show the crop rotation effects of introducing camelina as an intermediate crop, with climate impact expressed per ha of land and per kg macronutrients over the whole crop rotation. Crop rotation effects on biodiversity and eutrophication were also discussed. The system boundary was the cradle (crop production) to the field gate (Figure 1). The 1 kg oil FU was used to allow comparison with other vegetable oils. The system boundary, in that case, was the cradle (crop production) to the factory gate (oil after pressing) (Figure 1). The FU of 1 MJ HVO was used to represent a liquid biofuel product, with the results compared with other diesel-like biofuels and fossil diesel. The system boundary was the cradle (crop production) to the tap station (Figure 1).

The following were included in the analysis: farm inputs (production of seeds, fertilizers, pesticides), field operations, crop outputs (grain yield and biomass), direct farm emissions (e.g., N-related emission), energy and other inputs required for oilseed pressing, energy, hydrogen, other inputs to the HVO production process, and distribution to a tap station. The geographical location for crop cultivation was assumed to be Sweden. For more details, see Section 2.3.1.

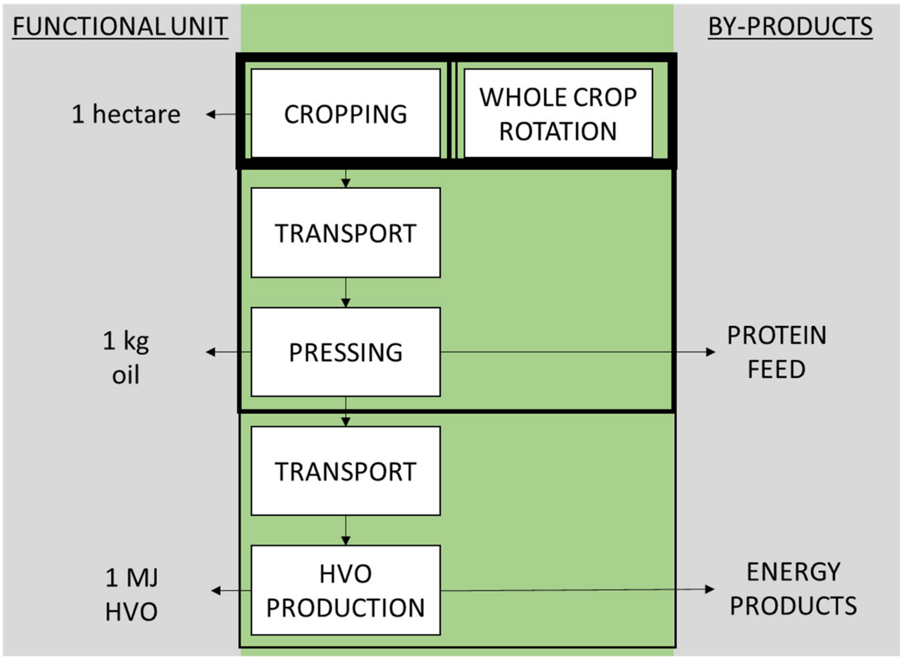

Figure 1. System boundaries for the three different functional units applied. HVO = hydrogenated vegetable oil.

2.2. Allocation

When using 1 kg oil and 1 MH HVO as FU, the allocation was needed for the by-products (protein feed and the energy products from HVO production) and also within the crop rotation, between camelina and the other crops in the rotation. Impacts allocated to camelina were calculated as follows:

$$\text{IMPACTS ALLOCATED TO CAMELINA} = \text{NEW CROP ROTATION} - \text{REFERENCE CROP ROTATION} \quad (1)$$

Thus, the impact on SOC from the introduction of the intermediate crop (camelina) was fully allocated to the camelina. Apart from increased soil carbon accumulation, the introduction of camelina was assumed to lower the yield of the following crop (peas in this case). However, due to higher production over the whole crop rotation, any indirect effects from a lower yield of the pea crop were not considered (see Section 3).

Allocation between camelina oil and the by-product protein feed was made based on energy, mass, and economic allocation as well as on the method for nutrient index-weighted macronutrients presented by Bajželj et al. [3]. For the functional unit 1 MJ HVO, energy allocation was applied to all upstream processes, in accordance with RED requirements [28].

2.3. Life Cycle Inventory Analysis

2.3.1. Camelina Cultivation in Sweden

There is currently very limited information available on the field production of camelina in Sweden. A few field trials have been conducted, but mainly with spring camelina. Camelina has a long history in Swedish agriculture, e.g., it was grown in the Iron Age [10], but today it is scarcely grown at all, and the main oilseed crop is rapeseed [29]. Most field trials with winter camelina in climates similar to Sweden have been conducted in North America [16,17,30–33]. One way to assess the agronomic conditions for crops in a particular geographical region is to calculate growing degree days (GDDs) for the period from sowing to harvest. Walia et al. [18] report GDD values and precipitation data for several locations in which field trials on winter camelina have been conducted. Among these locations, Morris (USA) and Morden (Canada) are most similar to Sweden with regard to mean yearly temperature and have GDDs of 1261–1473 °C and mean annual precipitation of 500–663 mm [18]. Equivalent values for three sites in southern-central Sweden, calculated for the growing period of 1 September–1 July in the cropping seasons of 2018–2019 and 2019–2020, are GDDs of 1031–1366 °C and precipitation of 370–807 mm [18]. This indicates that there is a potential that camelina could be grown as an intermediate crop in southern-central Sweden.

Relay cropping was assumed in this study, meaning that the crop following camelina was sown into the growing camelina, and the camelina was harvested in early July. Relay cropping systems with camelina have been shown to perform better over the whole crop rotation than double cropping, i.e., when the following crop is planted after the camelina is harvested [33]. This is because the sowing of the following crop is delayed until the camelina is harvested in the double cropping system. However, with relay cropping, the establishment of the following crop is affected, and its yield can be reduced [17,31,33]. Thus, we assumed a yield decrease in the following pea crop of 25% (75% of the yield without camelina) in the base case. Figure 2 shows the reference six-year crop rotation compared with a new crop rotation with winter camelina as a relay crop between spring barley and peas. A six-year crop rotation was selected to allow for five years between the occurrence of camelina in the crop rotation, as this is the current recommendation for the related crop rapeseed. The crop rotation was selected to include common crops in the agricultural region 3 in Sweden (Götalands norra slättbygder); more research is needed to identify suitable crop rotations where camelina could be grown.

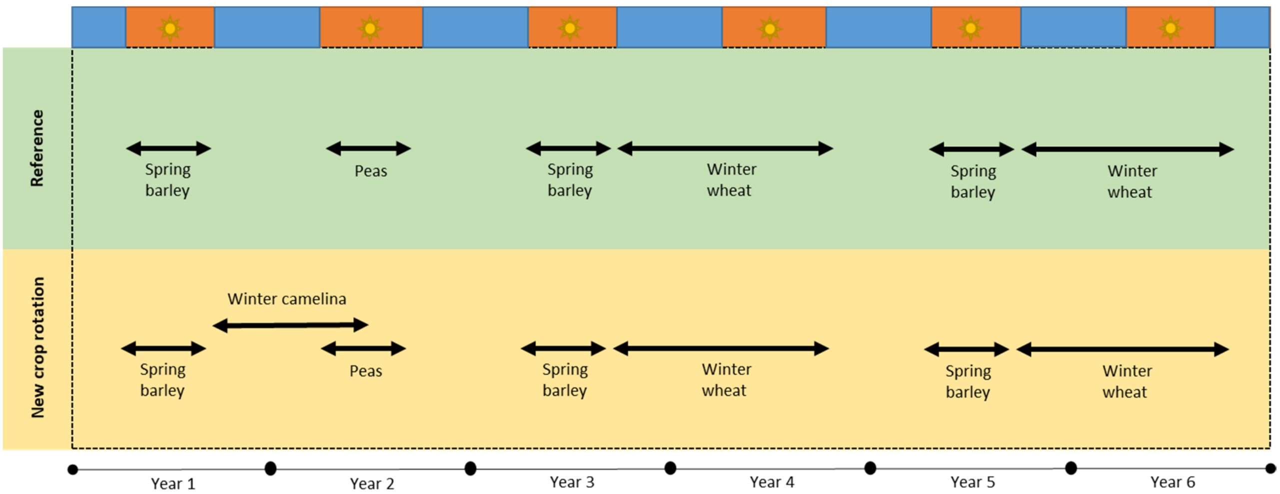

Figure 2. Reference six-year crop rotation (green background) compared with a new crop rotation with winter camelina as a relay crop between spring barley and peas (yellow background).

Camelina was assumed to yield 1560 kg per ha and to receive 80 kg N fertilizer per ha, based on data from field trials in North Dakota, Minnesota [17,33], and Denmark [34]. Phosphorus (P) and potassium (K) fertilizer doses were assumed to be 15 and 35 kg/ha, respectively, based on average Swedish application rates for all crops. The pesticide dose was assumed to be 0.76 kg active ingredient per ha, based on Swedish averages [35]. Fuel consumption was assumed to be around 2261 MJ/ha (64 L/ha) and year [36]. Direct and indirect soil N2O emissions were calculated using the IPCC Tier 1 guidelines with site-generic emission factors [37]. Further details on the inventory analysis of camelina cultivation can be found in Karlsson Potter et al. [38].

2.3.2. Whole Crop Rotation

The climate impact was calculated up to the farm gate for the two crop rotations (Table 1). Energy use for field operations was based on Moberg et al. [39]. Nitrogen leaching from barley and wheat was assumed to be 24% of applied N, while N leaching from the pea crop was assumed to be 24 kg/ha [40]. Yield values used for the different crops were based on official statistics on average yield between 2010 and 2019 [29].

Table 1. Composition of the two crop rotations, crop yield (dry matter, DM), and NPK fertilization rate.

	Yield (kg/ha) (%DM)	NP [a] K (kg/ha)
Reference crop rotation		
Spring barley	4277 (86%)	70-20-10
Pea	2851 (85%)	0-10-20
Spring barley	4277 (86%)	70-20-10
Winter wheat	5617 (86%)	130-25-10
Spring barley	4277 (86%)	70-20-10
Winter wheat	5617 (86%)	130-25-10
Camelina crop rotation		
Spring barley	4277 (86%)	70-20-10
Camelina [b]	1560 (91%)	80-15-35
Pea [b]	2138 (85%)	0-10-20
Spring barley	4277 (86%)	70-20-10
Winter wheat	5617 (86%)	130-25-10
Spring barley	4277 (86%)	70-20-10
Winter wheat	5617 (86%)	130-25-10

[a] Assuming P-AL class III. [b] Base case assumptions (varied in sensitivity analysis); pea yield in the camelina crop rotation assumed to be 75% of that in the reference crop rotation.

2.3.3. Soil Organic Carbon Modeling

The Introductory Carbon Balance Model (ICBM) [41,42] was used to assess SOC changes in the top 25 cm of soil when camelina was introduced into the crop rotation. Parameter values for k_y, k_o, and h were taken from Andrén and Kätterer [42] and for r_e (site-specific) from Andrén et al. [43]. Crop residue amounts for spring barley, winter wheat, and camelina were calculated based on yield (Table 2), according to Andrén et al. [44]. For peas, a value from Hergoualc'h et al. [37] was used. All crop residues were assumed to contain 0.45 kg C/kg dry matter (DM), and all were assumed to be left in the field. Initial SOC content as set by running the ICBM for the reference crop rotation until approximate SOC equilibrium (difference in mean SOC content between two cropping cycles < 0.000001 kg C/ha).

Table 2. Range of yield (kg/ha) of winter camelina and the following crop (values from previous studies).

	Min	Max	Mean	Present Study
Yield of camelina	214	2095	1008 (n = 28)	1560
Yield of following crop [a]	3%	105%	51% (n = 32)	75%

[a] Percentage of that in a crop rotation without winter camelina.

2.3.4. Camelina Transport and Oilseed Pressing

It was assumed that the camelina seeds were transported from the field to the pressing facility (100 km). In the scenarios where HVO was produced, an additional 200 km transport of the oil from the pressing facility to the HVO conversion plant was assumed.

Oil extraction using hexane was assumed, with values for electricity, heat, and hexane use in the process taken from Li and Mupondwa [45].

2.3.5. Conversion to HVO

The percentage conversion of camelina oil to HVO was assumed to be 86.4% *w*/*w* (Katarina Persson, Preem, personal communication 2021). The hydrogen (H) input requirement was assumed to be 37 g/kg of unprocessed oil, with the H assumed to be generated using natural gas. Electricity use (natural gas electricity was assumed) was 0.09 MJ kg/oil. All heat required in the process was assumed to be generated within the production plant, and was therefore not considered. Two byproducts were assumed to be generated: 25 g naphtha and 35 g propane per kg camelina oil converted to HVO. For more details, see Karlsson Potter et al. [38].

2.4. Climate Impact Assessment

Climate impact was assessed as GWP_{100}, with the characterization factors including feedback loops from IPCC AR5 [46]. Climate impact was also assessed as Absolute Global Temperature Change Potential (AGTP), here referred to as the time-dependent temperature response (expressed in degrees K), over a 100-year perspective. Both metrics are based on the radiative forcing of GHG (CO_2, CH_4, and N_2O were considered in the present study), but AGTP better illustrates the climate impact of processes where emissions (or uptake) of GHG vary from year to year. This is common in agricultural systems, especially when there are impacts on SOC.

2.5. Sensitivity Analysis

Since camelina is, in general, a relatively new crop in modern agriculture, and in Swedish conditions in particular, no field data for critical parameters were available. In sensitivity analysis, max and min values for yield of winter camelina in climates relevant for Sweden were taken from the literature and other parameters were varied accordingly (Table 2).

The following studies were identified as relevant for Swedish climate conditions and included yield data for winter camelina and in many cases for the following crop: Zanetti et al. [30]; Ott et al. [31]; Johnson et al. [32]; Berti et al. [17]; Gesch et al. [33]; Gesch and Archer [16]; and Walia et al. [18] (selected locations). Average yield was influenced by lower yields in the study by Berti et al. [17], especially in Morris, Minnesota, where the authors attributed poor crop establishment to low autumn precipitation in the area. The yield of camelina and of the following crop were based on data from double cropping and relay cropping systems. Camelina yield in the present study was set higher than the average value calculated from earlier studies using different experimental designs, based on the assumption that cropping practices will improve and more stable yields of both the camelina and the following crop can be achieved when camelina becomes a more common crop.

3. Results and Discussion

3.1. Crop Rotation Effects

3.1.1. Overall Production from Whole Crop Rotation

Several studies have found that the crop following camelina has a lower yield than when grown as a stand-alone crop due to competition with camelina in early spring, when the crops are grown together, for resources such as water and light [20]. Therefore, the overall gain from using a relay/intermediate crop such as camelina needs to be thoroughly investigated [20]. Further, there is a need to apply a broad perspective, considering the overall yield of the crop rotation as a whole and the functions it can provide. In the present study, DM yield over the whole crop rotation was higher in the camelina crop rotation than in the reference rotation, despite the lower yield of pea crop due to relay cropping with camelina (Figure 3). For the crop rotation as a whole, the production of fat more than doubled and the production of protein and fiber marginally increased when camelina was included, this was because the fat and protein-rich camelina crop was introduced, resulting in a lower yield of the carbohydrate-rich pea crop. This presents a trade-off situation with increased production of fat and protein at the expense of carbohydrates, and care has to be taken to the effects on farmers as well as the indirect environmental effects of this change in production. Macronutrient-weighted results present one way of looking at the results (where fat and protein were weighted higher than carbohydrates based on the allocation method in Bajželj et al. [3]) showing that the introduction of camelina increased the production of valuable micronutrients (Figure 3, Macronutrients*).

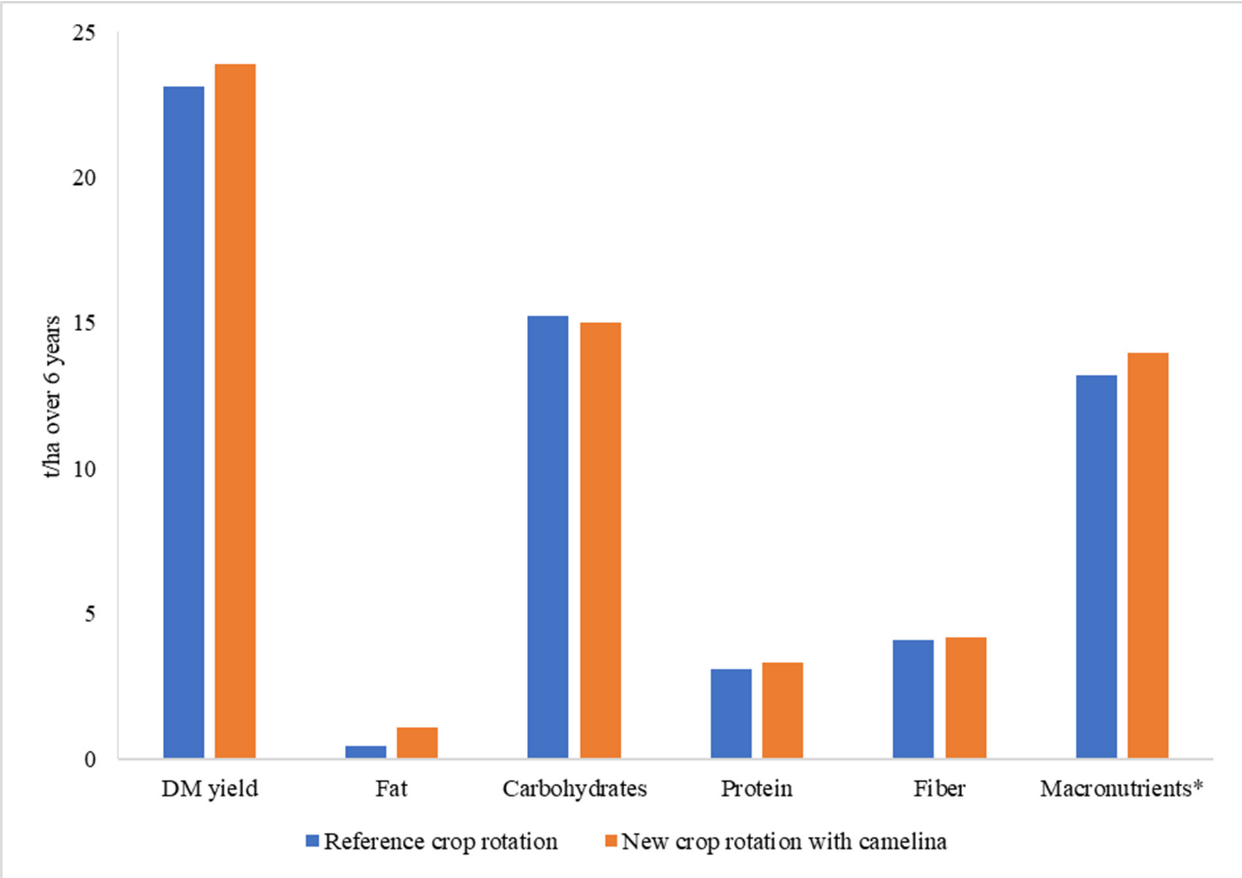

Figure 3. Total production over six years in the reference and camelina crop rotations, presented as dry matter (DM) yield and fat, carbohydrate, protein, and fiber yield. Macronutrients* were weighted using a nutrition index (Bajželj et al. [3]), so the pairs of bars cannot be compared with other pairs in the diagram, i.e., macronutrient production can only be compared between the two crop rotations.

3.1.2. Climate Impact on the Whole Crop Rotation

The overall climate impact over 100 years was similar for the reference and camelina crop rotations. Figure 4 shows the time-dependent temperature response over 100 years, assessed per hectare, where "Total new crop rotation" represents the climate impact of the intermediate camelina crop, including SOC effects. The crop rotation with winter camelina had higher climate impacts related to field operations and fertilizer use, with associated N_2O emissions, but this was compensated for by increased SOC accumulation due to increased return of organic matter when an additional crop was included in the rotation. Soil organic carbon content increased despite the 25% decrease in the yield of the pea crop after winter camelina.

The climate impact per kg macronutrients produced (macronutrients weighted according to Bajželj et al. [3]) was higher for the reference crop rotation, due to overall lower production in that rotation (Figure 3). However, the difference between the two rotations was small, and the yield of both camelina and the following crop was important for the outcome.

3.2. Climate Impact of Camelina Oil Production

The total climate impact of oil production was around 0.5 kg CO_2 eq/kg camelina oil when macronutrient allocation was used, which is low compared with the climate impact of other oilseed crops (range 2.5–7 kg CO_2 eq/kg fat, based on Bajželj et al. [3]). Without considering SOC effects, the climate impact was assessed to be around 1 kg CO_2 eq/kg fat.

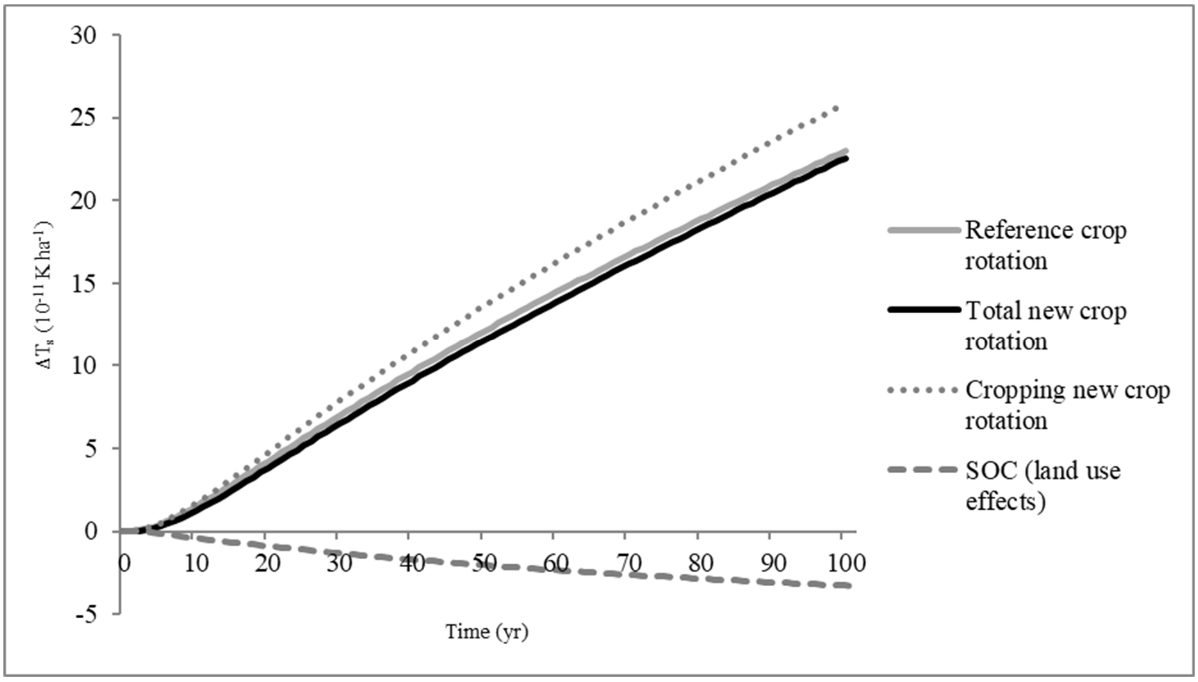

Figure 4. Time-dependent temperature response over 100 years assessed per hectare for the reference crop and new crop rotation including winter camelina. "Total new crop rotation" represents the climate impact including soil organic carbon (SOC) effects.

Depending on the allocation method (energy, mass, or economic allocation), the total climate impact, including SOC effects of camelina oil production, varied between around 0.5 and 1 kg CO_2 eq/g camelina oil (Figure 5). The cropping system had the highest impact in the different allocations, which indicates the importance of good crop management to maintain yield in the following crop and optimization of cropping systems with respect to, for example, nitrogen use efficiency and yield to achieve sustainable crop production in practice [20]. In the case of camelina grown in Sweden, field trials are needed to establish agronomic practices. Further, in the cropping phase, nitrogen fertilizer-related emissions are dominating. It is important to highlight that the nitrogen fertilization rates for camelina grown in Swedish crop rotations are unknown, and the rate in the present study was based on earlier studies. To lower climate impact from cropping, it would be beneficial to, for example, grow camelina after a crop that tends to leave available nitrogen in the soil; in that way, camelina could utilize that nitrogen and potentially decrease nitrogen leaching while fertilization rates could be kept lower.

3.3. Climate Impact of HVO Production

The climate impact (as GWP) of HVO production was 15 g CO_2 eq/MJ HVO with SOC effects included, or 27 g CO_2 eq/MJ with SOC effects excluded, representing an 84% and 71% reduction, respectively, compared with fossil fuel [28]. This indicates that camelina HVO meets the current reduction targets in the EU Renewable Energy Directive [28]. The reduction values can also be compared with, for example, rapeseed HVO, which has a typical reduction of 51% in the Directive [28]. Similar results to the current study were found by Shonnard et al. [15] and Dangol et al. [23] in previous studies of GHG emissions from fuel-based camelina. Shonnard et al. (2010) reported estimated GHG emissions of 22.4 g CO_2 eq/MJ, representing a 75% reduction compared with fossil fuel, while Dangol et al. [23] reported a 69% reduction compared with fossil fuel. Li and Mupondwa [22] reported GHG emissions of 7.6–24.7 g CO_2 eq/MJ for camelina-derived biodiesel and 3.06–31.0 kg CO_2 eq/MJ for camelina-derived jet fuel. Masella and Galasso [25] compared the environmental impacts of using camelina oil as a raw material for biodiesel production and pure vegetable oil extraction and found that both scenarios gave markedly lower GWP values than fossil fuel (67% lower for PVO and >50% lower for biodiesel).

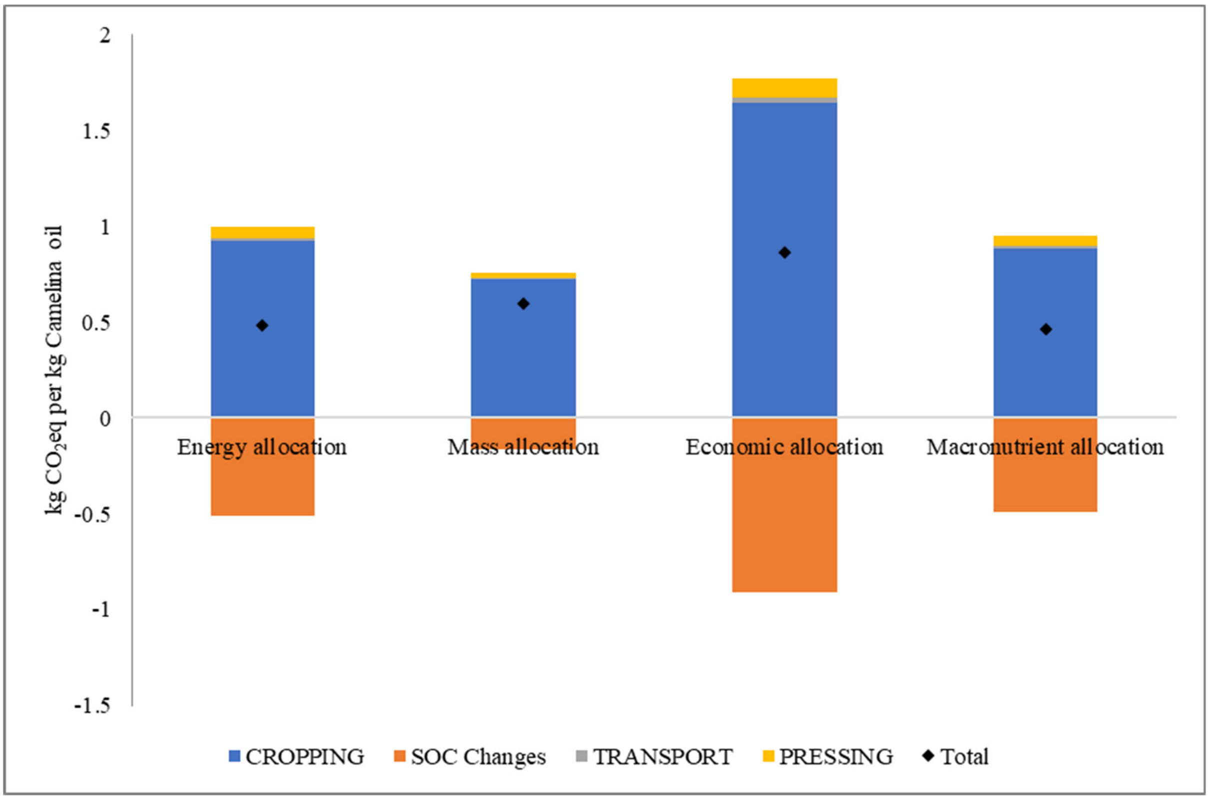

Figure 5. Climate impact (as GWP, kg CO_2 eq per kg camelina oil) when using energy, mass, economic allocation, and allocation based on macronutrient content (macronutrient weighting using a nutrition index from Bajželj et al. [3]).

The time-dependent temperature response for camelina HVO compared with a fossil fuel reference was strongly affected by the SOC accumulation rate (Figure 6). Accumulation of SOC over time is uncertain and likely to decline once the soil reaches a new equilibrium (Figure 6). However, the temperature response over 100 years from producing camelina HVO (emissions from cropping, transport, pressing, and HVO conversion; dotted line in Figure 6) was about one-third of that from the reference fossil fuel.

3.4. Sensitivity Analysis

3.4.1. Crop Rotation Overall Production

Climate impacts from the production of 1 kg camelina oil at different yield levels and allocation methods tested in sensitivity analysis are presented in Table 3. The effects on winter camelina and the following pea crop compared with the reference crop rotation are shown in Figure 7. Dry matter yield and production of all macronutrients except carbohydrates were higher in the camelina crop rotation than in the reference rotation, except when minimum yield values for camelina and pea were applied.

3.4.2. Climate Impact of Oil and HVO

In general, the climate impact of camelina oil with different allocation methods applied and at different yield levels was lower than literature values (2.5–7 kg CO_2 eq; Bajželj et al. [3]) (Table 3). However, at the lowest yield reported in the literature, the climate impact was relatively high (>4 kg CO_2 eq/kg oil).

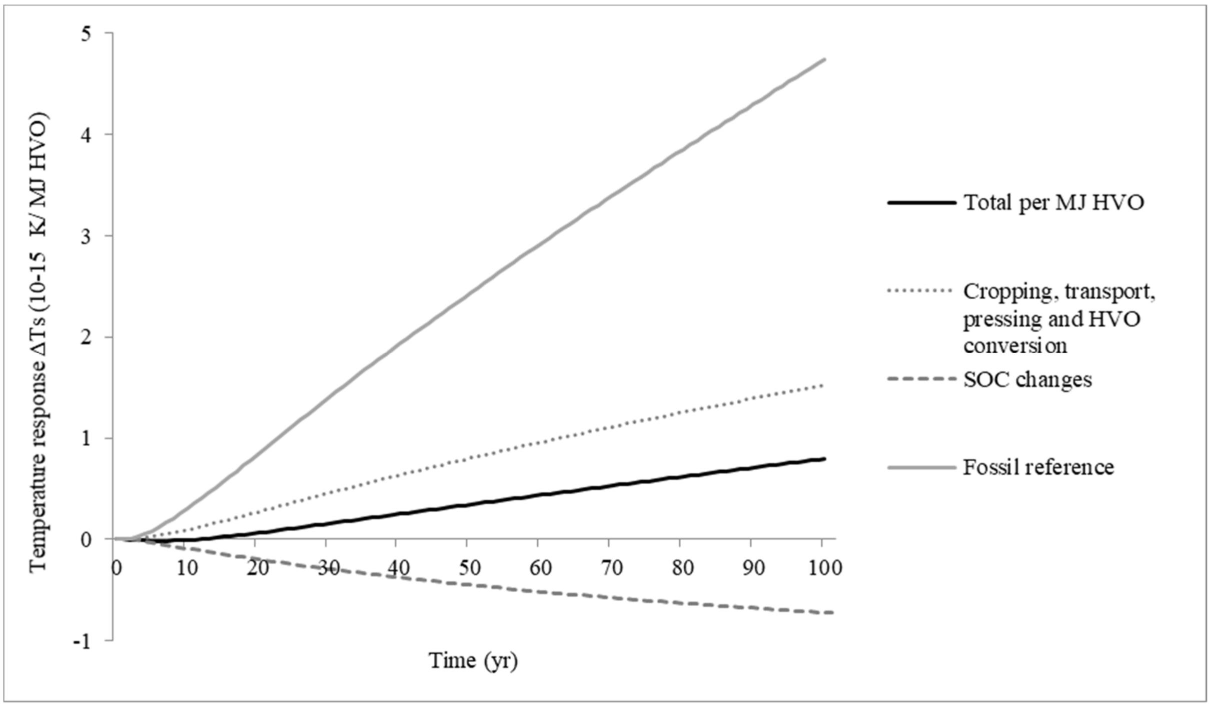

Figure 6. Time-dependent temperature response from production and use of 1 MJ hydrogenated vegetable oil (HVO) from camelina oil compared with fossil diesel. "Total per MJ HVO" represents the climate impact of HVO including soil organic carbon (SOC effects).

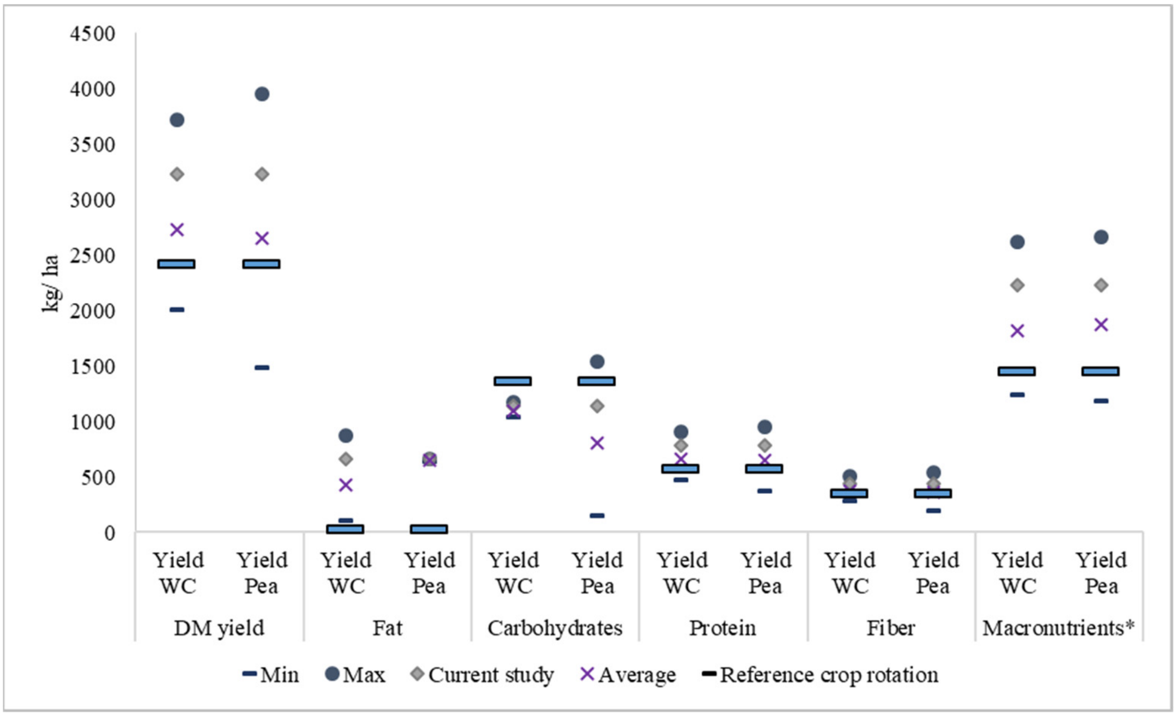

Figure 7. Sensitivity analysis where yield of winter camelina (WC) and the following pea crop were varied separately based on literature values. Only combined yield of camelina and peas is shown, since these were the only crops affected by introduction of camelina in the crop rotation. Macronutrients* were weighted using a nutrition index (Bajželj et al. [3]), so the results cannot be compared with other results in the diagram, i.e., macronutrient production can only be compared between the two crop rotations.

Table 3. Climate impact (GWP_{100} in kg CO_2 e) of production of 1 kg camelina oil at different yield levels and with different allocation methods, with and without soil organic carbon (SOC) effects.

	Allocation Method			
	Energy	**Mass**	**Economic**	**Macronutrient**
With SOC effects				
Present study	0.49	0.60	0.87	0.47
Min yield	5.62	4.63	10.03	5.38
Average yield	0.92	0.94	1.64	0.88
Max yield	0.28	0.44	0.51	0.27
Without SOC effects				
Present study	1.00	0.76	1.78	0.95
Min yield	6.16	4.81	10.99	5.90
Average yield	1.43	1.10	2.56	1.37
Max yield	0.79	0.60	1.41	0.76

The time-dependent temperature response of camelina HVO was strongly affected by camelina yield (Figure 8), and also the yield of the following pea crop (Figure 9). Pea yield had an effect through SOC accumulation, which varied with yield due to differences in the amount of crop residues. No indirect effects due to lower production of the pea crop were considered. On varying camelina crop yield over the range reported in field trials, the climate impact over time was well below that of fossil diesel (Figure 8). When the yield of the following crop (pea) remained at a similar level as in the reference crop rotation or slightly higher (the highest following crop yield in the literature was 5% higher than in the reference without winter camelina), the climate impact of camelina HVO was below zero for the first 60 years, indicating slightly avoided warming. This was due to increased SOC accumulation through the introduction of camelina as a relay crop, combined with the maintained yield of the pea crop, compensating for GHG emissions from cultivation and HVO production. However, the rate of SOC accumulation decreased over time (Figure 9).

3.5. Other Environmental Impacts

Apart from climate impacts, several other environmental impact categories were of interest in this study, especially biodiversity impacts and eutrophication. Due to a lack of data on camelina cultivation under Swedish conditions as regards, e.g., fertilizer use, leaching, and water use, we were only able to assess these two environmental impact categories briefly based on earlier studies on camelina as an intermediate crop in cold-climate regions.

3.5.1. Biodiversity Impacts

Introducing a new crop into a crop rotation can have several effects on biodiversity, e.g., increasing crop biodiversity and implementing a more varied crop rotation are known to increase yield in the following crop and decrease disease pressure [47]. Early flowering crops such as camelina can provide forage for pollinating insects early in the season, when floral resources are scarce [48]. Pollinating insects are an important part of the ecosystem, not least for pollinating agricultural crops [49]. Introducing an early flowering intermediate crop could therefore potentially improve pollination and increase yield in crops requiring cross-pollination. Adding more biological material to the soil as crop residues and roots from the camelina crop can benefit soil organism growth and diversity [50]. Soil organisms are essential for organic matter turnover and for creating good soil structure [50]. Further, increased soil organic matter content is associated with enhanced soil productivity, thereby increasing crop yields, at least under certain conditions [51,52]. The indirect effects of increased production due to the introduction of the intermediate crop and possible consequences for land use elsewhere, and thereby biodiversity, were not considered here.

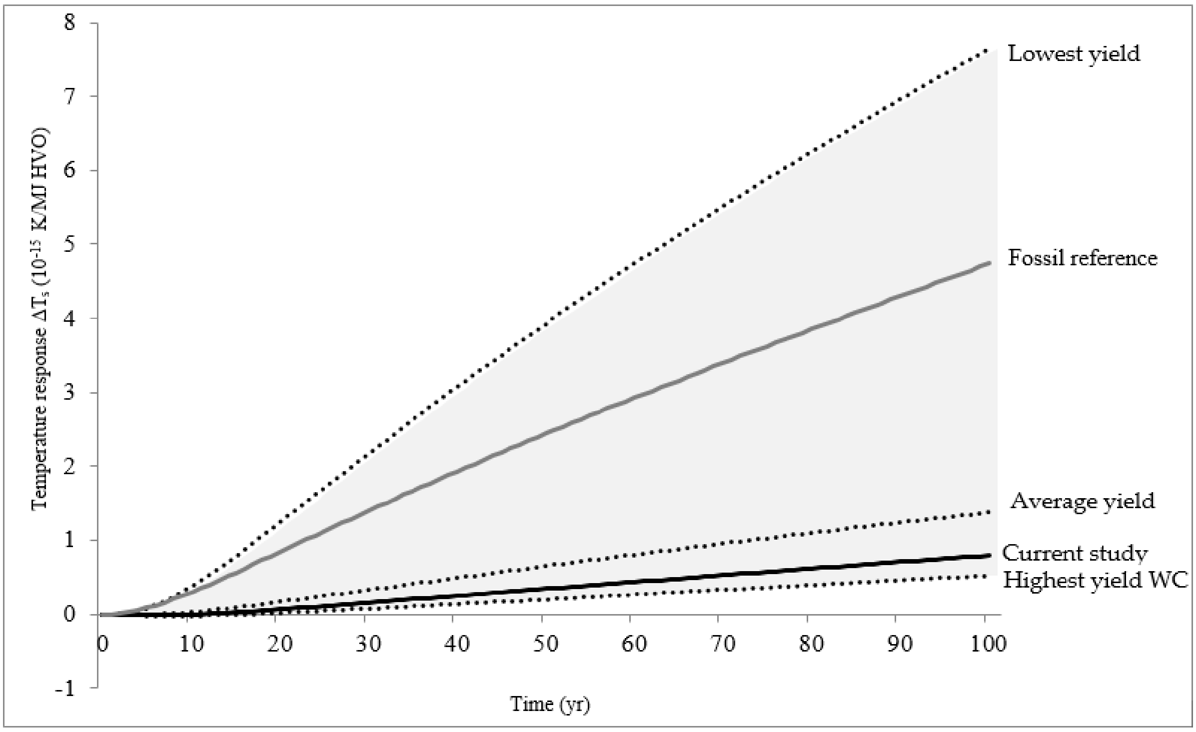

Figure 8. Time-dependent temperature response from production and use of 1 MJ hydrogenated vegetable oil (HVO) from camelina oil compared with fossil diesel in sensitivity analysis where yield of winter camelina (WC) was varied based on field trial data from earlier studies.

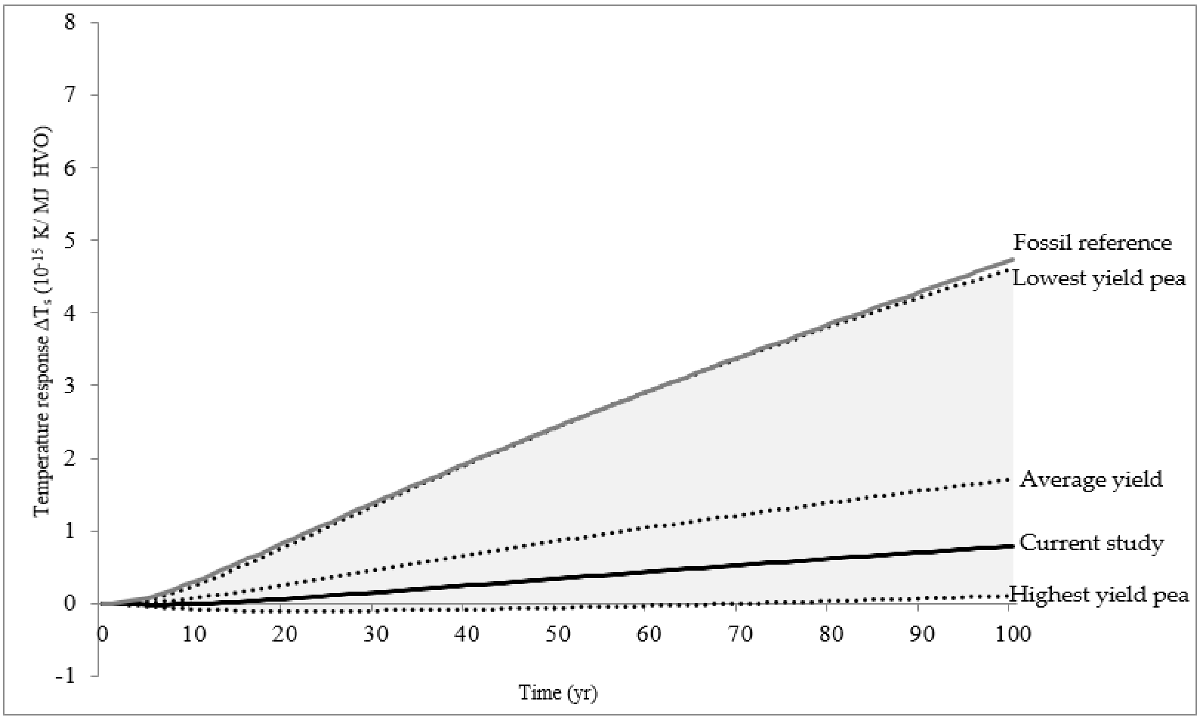

Figure 9. Time-dependent temperature response from production and use of 1 MJ hydrogenated vegetable oil (HVO) from camelina oil compared with fossil diesel in sensitivity analysis where yield of the following crop (pea) was varied based on field trial data from earlier studies.

3.5.2. Eutrophication

A previous study on the eutrophication impact of camelina biodiesel found that it was dominated by emissions from fertilizer production and nutrient leaching from the field [53]. The eutrophication potential per MJ camelina biodiesel can therefore be expected to heavily depend on the amount of fertilizer required per unit of camelina seed produced. Under some conditions, intermediate crops can reduce nutrient losses at the field level [54]. However, this applies mainly to cover crops grown with very low or no additional fertilizer input and instead relying on residual nutrients from the preceding crop, which was not the case for the camelina in this study. In unfertilized field trials with winter camelina, Johnson et al. [32] found a lower risk of N leaching compared with the reference with no winter camelina.

In this study, camelina yield per kg N fertilizer was similar to that of Swedish rapeseed [55], indicating that N losses, and thereby the eutrophication impact from N leaching, may also be similar. However, fertilizer rate and camelina yield vary significantly between field experiments reported in the literature [21,30,34,56], and it is uncertain how the crop would perform in northern European conditions. Further, it is important to note that camelina is in a relatively early stage of plant breeding, so yield and nutrient use could improve substantially in the future [57].

4. Conclusions

The study showed that introducing winter camelina in a cereal-based crop rotation can increase the overall yield of fat, fiber, and protein, while the yield of carbohydrates may decrease. From a whole crop rotation perspective, the climate impact of rotations with and without camelina was similar. Emissions were higher when camelina was introduced, but this was compensated for by greater SOC accumulation in the rotation with winter camelina. Climate impact per kg oil, including SOC effects, was estimated to range between 0.5 and 1.0 kg CO_2 eq, depending on the allocation method applied. Camelina HVO was estimated to give a 71% reduction in climate impact compared with fossil fuel when SOC effects were not included, and an 84% reduction when SOC effects were included, although the impact of SOC effects decreased over time. Even when SOC effects were excluded, however, the temperature response from camelina HVO was still only around one-third of that from the reference fossil fuel. The yield was important for the climate impact assessment, including the yield of the following crop, as this affected SOC accumulation. However, the way in which environmental performance was measured affected the outcomes and results. Using multiple functional units provided a more comprehensive assessment of cropping system performance.

The results obtained show that, from an environmental perspective, winter camelina could be an interesting intermediate crop for food, feed, or biofuel production in Sweden. However, further field studies are needed to determine, e.g., the crop rotation effects in a northern European climate (Sweden) and the economic effects of changes in overall production in crop rotation.

Author Contributions: Conceptualization, H.K.P.; Methodology, K.H. and H.K.P.; Validation, D.M.M.Y.; Data curation, K.H.; Writing—original draft, H.K.P.; Writing—review & editing, H.K.P., D.M.M.Y. and K.H.; Project administration, H.K.P.; Funding acquisition, H.K.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Swedish Energy Agency (46980-1), Swedish Research Council for Environment Agricultural Sciences and Spatial Planning (2020-00879).

Data Availability Statement: Not applicable.

Acknowledgments: Thanks to Giulia Vico for the data and for answering questions on how to calculate GDD for sites around Sweden; the F3 center and Formas 2020-00879 for funding the project; and to the project members, master student, and reference group to the project on “Sustainable HVO production”.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IEA International Energy Agency. Renewables 2021 Analysis and Forecast to 2026. 2021. Available online: https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026,pdf (accessed on 15 May 2023).
2. Panoutsou, C. *Sustainable Biomass Availability in the EU, to 2050*; Imperial Collage London Consultants: London, UK, 2021.
3. Bajželj, B.; Laguzzi, F.; Röös, E. The role of fats in the transition to sustainable diets. *Lancet Planet. Health* **2021**, *5*, e644–e653. [CrossRef] [PubMed]
4. Swedish Energy Agency. Drivmedel 2021. ISSN 1403-1892. 2022. Available online: https://www.energimyndigheten.se (accessed on 15 May 2023).
5. Karlsson Potter, H.; Poulikidou, S.; Henryson, K.; Hammar, T.; Hansson, J. HVO Produced from Swedish Raw Materials—Current and Future Potentials. Report No. FDOS 07:2020. 2020. Available online: https://f3centre.se/en/renewable-transportationfuels-and-systems/ (accessed on 1 January 2023).
6. Sindelar, A.J.; Schmer, M.R.; Gesch, R.W.; Forcella, F.; Eberle, C.A.; Thom, M.D.; Archer, D.W. Winter oilseed production for biofuel in the US Corn Belt: Opportunities and limitations. *GCB Bioenergy* **2017**, *9*, 508–524. [CrossRef]
7. Chammoun, N.; Geller, D.P.; Das, K. Fuel properties, performance testing and economic feasibility of Raphanus sativus (oilseed radish) biodiesel. *Ind. Crops Prod.* **2013**, *45*, 155–159. [CrossRef]
8. Krohn, B.J.; Fripp, M. A life cycle assessment of biodiesel derived from the "niche filling" energy crop camelina in the USA. *Appl. Energy* **2012**, *92*, 92–98. [CrossRef]
9. Dönmez, E.O.; Belli, O. Urartian plant cultivation at Yoncatepe (Van), eastern Turkey. *Econ. Bot.* **2007**, *61*, 290–298. [CrossRef]
10. Larsson, M. Cultivation and processing of Linum usitatissimum and Camelina sativa in southern Scandinavia during the Roman Iron Age. *Veg. Hist. Archaeobotany* **2013**, *22*, 509–520. [CrossRef]
11. EU (2016) European Commission. Improving the Sustainability of Fatty Acid Methyl Esters (FAME—Biodiesel) Tender No. ENER/C2/2013/628. Available online: https://energy.ec.europa.eu/system/files/2016-07/Technical%2520report_0.pdf (accessed on 15 May 2023).
12. Putnam, D.H.; Budin, J.T.; Field, L.A.; Breene, W.M. Camelina: A promising low-input oilseed. *New Crops* **1993**, *314*, 322.
13. Li, H.; Barbetti, M.; Sivasithamparam, K. Hazard from reliance on cruciferous hosts as sources of major gene-based resistance for managing blackleg (*Leptosphaeria maculans*) disease. *Field Crops Res.* **2005**, *91*, 185–198. [CrossRef]
14. Kakani, R.; Fowler, J.; Haq, A.-U.; Murphy, E.J.; Rosenberger, T.A.; Berhow, M.; Bailey, C.A. Camelina meal increases egg n-3 fatty acid content without altering quality or production in laying hens. *Lipids* **2012**, *47*, 519–526. [CrossRef]
15. Shonnard, D.R.; Williams, L.; Kalnes, T.N. Camelina-derived jet fuel and diesel: Sustainable advanced biofuels. *Environ. Prog. Sustain. Energy* **2010**, *29*, 382–392. [CrossRef]
16. Gesch, R.; Archer, D. Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. *Ind. Crops Prod.* **2013**, *44*, 718–725. [CrossRef]
17. Berti, M.; Gesch, R.; Johnson, B.; Ji, Y.; Seames, W.; Aponte, A. Double-and relay-cropping of energy crops in the northern Great Plains, USA. *Ind. Crops Prod.* **2015**, *75*, 26–34. [CrossRef]
18. Walia, M.K.; Zanetti, F.; Gesch, R.W.; Krzyżaniak, M.; Eynck, C.; Puttick, D.; Alexopoulou, E.; Royo-Esnal, A.; Stolarski, M.J.; Isbell, T.; et al. Winter camelina seed quality in different growing environments across Northern America and Europe. *Ind. Crops Prod.* **2021**, *169*, 113639. [CrossRef]
19. Weyers, S.; Thom, M.; Forcella, F.; Eberle, C.; Matthees, H.; Gesch, R.; Ott, M.; Feyereisen, G.; Strock, J.; Wyse, D. Reduced potential for nitrogen loss in cover crop–soybean relay systems in a cold climate. *J. Environ. Qual.* **2019**, *48*, 660–669. [CrossRef] [PubMed]
20. Cecchin, A.; Pourhashem, G.; Gesch, R.W.; Lenssen, A.W.; Mohammed, Y.A.; Patel, S.; Berti, M.T. Environmental trade-offs of relay-cropping winter cover crops with soybean in a maize-soybean cropping system. *Agric. Syst.* **2021**, *189*, 103062. [CrossRef]
21. Berti, M.; Johnson, B.; Ripplinger, D.; Gesch, R.; Aponte, A. Environmental impact assessment of double-and relay-cropping with winter camelina in the northern Great Plains, USA. *Agric. Syst.* **2017**, *156*, 1–12. [CrossRef]
22. Li, X.; Mupondwa, E. Life cycle assessment of camelina oil derived biodiesel and jet fuel in the Canadian Prairies. *Sci. Total Environ.* **2014**, *481*, 17–26. [CrossRef]
23. Dangol, N.; Shrestha, D.S.; Duffield, J.A. Life cycle analysis and production potential of camelina biodiesel in the Pacific Northwest. *Trans. ASABE* **2015**, *58*, 465–475.
24. EISA. *Energy Independence and Security Act of 2007 (Public Law 110-140)*; U.S. Government Printing Office: Washington, DC, USA, 2007. Available online: www.gpo.gov/fdsys/pkg (accessed on 15 May 2023).
25. Masella, P.; Galasso, I. A comparative cradle-to-gate life cycle study of bio-energy feedstock from Camelina sativa, an Italian case study. *Sustainability* **2020**, *12*, 9590. [CrossRef]
26. ISO. *ISO 14040: Environmental Management—Life Cycle Assessment—Principles and Framework*; International Organization for Standardization: Geneva, Switzerland, 2006; p. 20.
27. Goglio, P.; Brankatschk, G.; Knudsen, M.T.; Williams, A.G.; Nemecek, T. Addressing crop interactions within cropping systems in LCA. *Int. J. Life Cycle Assess.* **2018**, *23*, 1735–1743. [CrossRef]

28. EU. *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources (Recast)*; The European Parliament and of the Council: Brussels, Belgium, 2018.
29. SBA. *Skörd av Spannmål, Trindsäd och Oljeväxter 2020, JO 19 SM 2001*; Swedish Board of Agriculture: Jönköping, Sweden, 2020.
30. Zanetti, F.; Gesch, R.W.; Walia, M.K.; Johnson, J.M.; Monti, A. Winter camelina root characteristics and yield performance under contrasting environmental conditions. *Field Crops Res.* **2020**, *252*, 107794. [CrossRef]
31. Ott, M.A.; Eberle, C.A.; Thom, M.D.; Archer, D.W.; Forcella, F.; Gesch, R.W.; Wyse, D.L. Economics and agronomics of relay-cropping pennycress and camelina with soybean in Minnesota. *Agron. J.* **2019**, *111*, 1281–1292. [CrossRef]
32. Johnson, G.A.; Wells, M.S.; Anderson, K.; Gesch, R.W.; Forcella, F.; Wyse, D.L. Yield tradeoffs and nitrogen between pennycress, camelina, and soybean in relay-and double-crop systems. *Agron. J.* **2017**, *109*, 2128–2135. [CrossRef]
33. Gesch, R.; Archer, D.; Berti, M. Dual cropping winter camelina with soybean in the northern corn belt. *Agron. J.* **2014**, *106*, 1735–1745. [CrossRef]
34. Zubr, J. Oil-seed crop: Camelina sativa. *Ind. Crops Prod.* **1997**, *6*, 113–119. [CrossRef]
35. Statistics Sweden. *Växtskyddsmedel i Jord-Och Trädgårdsbruket 2010, Användning i Grödor*; Statistics Sweden: Örebro, Sweden, 2011.
36. Lindgren, M.; Pettersson, O.; Hansson, P.-A.; Norén, O. Engine load pattern and engine exhaust gas emissions from off-road vehicles and methods to reduce fuel-consumption and engine exhaust gas emissions. *Animal Husbandry* **2002**, *61*, 89–97.
37. Hergoualc'h, K.; Akiyama, H.; Bernoux, M.; Chirinda, N.; del Prado, A.; Kasimir, Å.; MacDonald, J.D.; Ogle, S.M.; Regina, K.; Weerden, T. *N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application*; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2019.
38. Karlsson Potter, H.; Hammar, T.; Henryson, K.; Nyberg, T.; Nojponya, P.; Poulikidou, S.; Hansson, J. *Environmental and Techno-Economic Assessment of Alternative Production Pathways for Swedish Domestic HVO Production*; Publ. No. FDOS 20:2021; Swedish Energy Agency: Eskilstuna, Sweden, 2021.
39. Moberg, E.; Andersson, M.W.; Säll, S.; Hansson, P.-A.; Röös, E. Determining the climate impact of food for use in a climate tax—Design of a consistent and transparent model. *Int. J. Life Cycle Assess.* **2019**, *24*, 1715–1728. [CrossRef]
40. Krüger Persson, S. *Livscykelanalys av Svenskproducerad Trindsäd*; Department of Energy and Technology, SLU: Uppsala, Sweden, 2019.
41. Kätterer, T.; Andrén, O.; Persson, J. The impact of altered management on long-term agricultural soil carbon stocks—A Swedish case study. *Nutr. Cycl. Agroecosyst.* **2004**, *70*, 179–188. [CrossRef]
42. Andrén, O.; Kätterer, T. ICBM: The introductory carbon balance model for exploration of soil carbon balances. *Ecol. Appl.* **1997**, *7*, 1226–1236. [CrossRef]
43. Andrén, O.; Kätterer, T.; Karlsson, T.; Eriksson, J. Soil C balances in Swedish agricultural soils 1990–2004, with preliminary projections. *Nutr. Cycl. Agroecosyst.* **2008**, *81*, 129–144. [CrossRef]
44. Andrén, O.; Kätterer, T.; Karlsson, T. ICBM regional model for estimations of dynamics of agricultural soil carbon pools. *Nutr. Cycl. Agroecosyst.* **2004**, *70*, 231–239. [CrossRef]
45. Mupondwa, E.; Li, X.; Tabil, L.; Falk, K.; Gugel, R. Technoeconomic analysis of camelina oil extraction as feedstock for biojet fuel in the Canadian Prairies. *Biomass Bioenergy* **2016**, *95*, 221–234. [CrossRef]
46. Bréon, F.-M.; Collins, W.; Fuglestvedt, J.; Huang, J.; Koch, D.; Lamarque, J.-F.; Lee, D.; Mendoza, B.; Nakajima, T.; Robock, A.; et al. Anthropogenic and natural radiative forcing. In *Climate Change 2013*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
47. Kirkegaard, J.; Christen, O.; Krupinsky, J.; Layzell, D. Break crop benefits in temperate wheat production. *Field Crops Res.* **2008**, *107*, 185–195. [CrossRef]
48. Eberle, C.A.; Thom, M.D.; Nemec, K.T.; Forcella, F.; Lundgren, J.G.; Gesch, R.W.; Riedell, W.E.; Papiernik, S.K.; Wagner, A.; Peterson, D.H.; et al. Using pennycress, camelina, and canola cash cover crops to provision pollinators. *Ind. Crops Prod.* **2015**, *75*, 20–25. [CrossRef]
49. Klein, A.-M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. B Biol. Sci.* **2007**, *274*, 303–313. [CrossRef] [PubMed]
50. Van der Putten, W.H.; Mudgal, S.; Turbé, A.; de Toni, A.; Lavelle, P.; Benito, P. *Ruiz Soil Biodiversity: Functions, Threats and Tools for Policy Makers*; Bio Intelligence Service: Paris, France, 2010.
51. Henryson, K.; Hansson, P.-A.; Sundberg, C. Spatially differentiated midpoint indicator for marine eutrophication of waterborne emissions in Sweden. *Int. J. Life Cycle Assess.* **2018**, *23*, 70–81. [CrossRef]
52. Lal, R. Beyond Copenhagen: Mitigating climate change and achieving food security through soil carbon sequestration. *Food Secur.* **2010**, *2*, 169–177. [CrossRef]
53. Bacenetti, J.; Restuccia, A.; Schillaci, G.; Failla, S. Biodiesel production from unconventional oilseed crops (*Linum usitatissimum* L. and *Camelina sativa* L.) in Mediterranean conditions: Environmental sustainability assessment. *Renew. Energy* **2017**, *112*, 444–456. [CrossRef]
54. Aronsson, H.; Hansen, E.M.; Thomsen, I.K.; Liu, J.; Ogaard, A.F.; Kankanen, H.; Ulen, B. The ability of cover crops to reduce nitrogen and phosphorus losses from arable land in southern Scandinavia and Finland. *J. Soil Water Conserv.* **2016**, *71*, 41–55. [CrossRef]

55. Ahlgren, S.; Hansson, P.-A.; Kimming, M.; Aronsson, P.; Lundkvist, H. *Utsläpp av Växthusgaser vid Odling av Grödor för Biodrivmedel Samt Produktion av Biogas Från Gödsel—Tillämpning av Europaparlamentets och Rådets Direktiv om Främjandet av Användningen av Energi Från Förnybara Energikällor in Dnr SLU ua 12-4067/08*; Sveriges Lantbruksuniversitet: Uppsala, Sweden, 2009.
56. Gesch, R.W.; Matthees, H.L.; Alvarez, A.L.; Gardner, R.D. Winter camelina: Crop growth, seed yield, and quality response to cultivar and seeding rate. *Crop Sci.* **2018**, *58*, 2089–2098. [CrossRef]
57. Vollmann, J.; Eynck, C. Camelina as a sustainable oilseed crop: Contributions of plant breeding and genetic engineering. *Biotechnol. J.* **2015**, *10*, 525–535. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.