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Energy balance & greenhouse gas emissions of dryland camelina as influenced by tillage and nitrogen

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Abstract

Despite the great potential of camelina (*Camelina sativa* L. Crantz) as a promising biofuel feedstock, in-farm energy flow of the crop and its associated environmental impacts has not received sufficient attention from researchers. In order to assess net energy gain and to identify energy saving and environmental friendly production operations, a two year study was conducted at central Montana. We investigated the effects of tillage method (CT (conventional tillage) vs. NT (no-tillage)) and N (nitrogen) fertilizer rate (0, 45, 90 kg N ha⁻¹) on energy balance and GHG (greenhouse gas emission) of dryland camelina production. Results indicated that energy input and GHG emission were 5 and 8% lower in NT than in CT. Application of 45 and 90 kg N ha⁻¹ increased camelina energy input by 186 and 365%, while increased energy output by only 21 and 64%, respectively. There was no significant difference in net energy gain in response to N fertilization, but lower energy efficiency in response to higher N inputs. Averaged across tillage systems, the GHG emission was 32.0 kg C eq ha⁻¹ with 0 N applied, and the GHG emission increased by 206 and 389% when 45 and 90 kg N ha⁻¹ was applied. Overall, N fertilizer had the biggest share in total energy input. Averaged over all experimental treatments, 14,945 MJ ha⁻¹ net energy was obtained from camelina crop in this study which shows the potential of this crop as a bioenergy feedstock. Our result showed that implementation of NT is strongly recommendable for camelina production in this region. Moreover, improvement of N use efficiency has the highest priority to improve energy performance and reduce GHG emissions in camelina production.

1. Introduction

Bioenergy crops have great potential to replace the fallow in the predominant fallow-wheat (*Triticum aestivum*) cropping systems in the U.S. NGP (Northern Great Plains) [1]. Only a few bioenergy crops, however, fit the environmental boundaries and restrictions of this region [2]. Camelina is an annual oilseed crop with 32–43% (w/w) oil content [3]. Due to its favorable agronomic features, including short growing season, drought resistant characteristics, and low-input requirements (e.g. fertilizers and pesticides), camelina has become an attractive bio-feedstock for the NGP [4]. It is assumed that camelina, which is not currently approved as an edible oil in the U.S., can be successfully grown for advanced biofuel production on marginal lands of the NGP and/or as a rotation crop on fallow land; while decreasing concern about the “food versus fuel” issue [1].

Exceptional fatty acid profile containing high levels of alpha-linolenic acid, cholesterol, and eicosenoic acid makes camelina an outstanding biofuel feedstock [3]. Several scenarios are now being considered for camelina as an energy crop for advanced biofuel production. In all scenarios camelina biodiesel was found to have lower emissions than diesel fuel. Camelina biodiesel even outperformed the traditional biodiesel crops (soybeans and canola) when land use change emissions were considered [5]. Li and Mupondwa [6] also reported less energy requirement and lower GHG emissions associated with camelina derived fuel production compared to other oilseed derived fuels and petroleum fuel. All these make camelina derived fuel environmentally attractive.

Despite the favorable agronomic features of camelina crop and the environmental attraction of camelina derived fuel, the energy balance and GHG emission of producing this crop have not been evaluated sufficiently. In our previous studies, agronomic [2] and energetic [7] advantages of camelina-winter wheat rotation compared with fallow-winter wheat rotation in central Montana were reported. It has been concluded that optimization of

agronomic practices is necessary to improve energy efficiency of camelina production in this semi-arid environment [7].

Optimization of the production practices, including tillage and fertilization could enhance the energy and economic performance of camelina thus improves the sustainability of camelina bio-feedstock production. Although camelina is known as a crop with low input requirements [3], nitrogen fertilization plays a vital role in camelina growth and seed formation [8] whereas the optimal N input level for best net energy gain and minimal environmental impact have not been established. Since production of nitrogen fertilizer requires large quantities of non-renewable energy, nitrogen represents the largest component of energy consumption among all inputs used in most agricultural systems [9]. The share of nitrogen fertilizer in total energy input has been reported in a range of 40–55% in most cropping systems of the developed countries [10]. McLaughlin et al. [9] reported that the indirect energy requirement for the manufacture of inorganic fertilizers and their application in the field represented the single largest energy input (40–50% of the total energy input) in NT grain-corn in Canada. Rathke and Diepenbrock [11] found 21–51% share of nitrogen fertilizer in total energy input of oilseed rape production when 80 and 240 kg N ha⁻¹ was applied, respectively. Keshavarz-Afshar and Chen [7] reported 70% share of nitrogen fertilizer in total energy input of camelina in central Montana. Optimization of nitrogen fertilization, therefore, will highly influence the energy balance of camelina.

Soil preparation and tillage is another high energy-demanding operation in crop production systems [12]. Borin et al. [13] estimated that 30% of energy used in the field is attributed to tillage. Thus, implementation of conservation tillage practices, such as MT (minimum tillage) and NT, is expected to reduce the consumption of non-renewable energy inputs, which in turn will improve the overall energy use efficiency [14]. Šarauskiis et al. [15] reported 12–58% and Bonari et al. [16] reported 55% less fuel consumption in conservation tillage practices compared to CT (conventional tillage) without any negative influence on crop yield. Hernanz et al. [12] reported that adoption of MT and NT in monoculture cereal and cereal-fallow rotation in central Spain resulted in 11 and 14% energy saving, respectively. They also reported 15 and 19% higher energy productivity in NT and MT compared with CT in each crop rotation. Most long-term field experiments demonstrated that NT and CT produced comparable yields (thus energy outputs). Cantero-Martínez et al. [17] reported that in two locations out of three in semiarid regions of Spain, NT barley produced 4 and 13% greater yield than MT and 9 and 14% greater yield than CT. López-Bellido et al. [18] evaluated the effect of NT and CT on wheat yield in a wheat–chickpea rotation under rain-fed Mediterranean conditions. They found no significant influence of the tillage system on wheat yield in three years of the study. In another study, López-Bellido et al. [19] concluded that continuous NT may represent an economically and environmentally viable alternative to conventional tillage for sunflower production under rain-fed Mediterranean conditions.

Optimization of the agronomic practices will not only improve energy efficiency, but also affect GHG emissions of the bio-feedstock production, thereby affecting the sustainability of the farming system [20]. The current policies within agriculture seek to develop crop production systems that minimize fossil energy consumption and minimize GHG emissions without deleterious effects on energy output [21]. Understanding the GHG emissions associated with different agronomic practices, such as tillage and fertilization, is helpful to identify C-efficient alternatives [22].

Since camelina is a relatively new crop to the United States, energy performance of this crop and its associated GHG emissions under different production practices has not been well studied. The

objective of this study was to determine how tillage method and N fertilizer rate influence energy balance and GHG emissions of camelina in a dryland farming system of central Montana.

2. Materials and methods

To evaluate the effects of tillage method (CT and NT) and N fertilizer rate (0, 45, 90 kg N ha⁻¹) on energy balance and GHG emissions of camelina production, a two-year field study (2013–2014) was conducted at the Central Agricultural Research Center (47° 03' N, 109° 57' W; 1400 m elevation) near Moccasin, Montana. The soil at the site is classified as a Judith clay loam (fine-loamy, carbonatic, frigid Typic Calcicustolls) and its water holding capacity is limited by gravel content and shallow soil profile. Long term (1909–2013) average crop year (September to August) precipitation in this area is about 390 mm with mean air temperature of about 5.8 °C. Table 1 presents the monthly precipitation and average temperature during the study and the 20-yr long-term averages.

2.1. Experimental design and treatments

The experiment layout was split-plot based on a randomized complete block design with four replicates. Tillage was assigned to the main plots and nitrogen treatments were allocated to the subplots. Individual subplots were 15.2 m long and 3.7 m wide. In both years, camelina was planted following wheat. Conventional tillage consisted of two passes of a sweep cultivator, while in NT system seeds were sown directly into wheat stubble.

In both tillage systems, camelina was planted in late March to early April using a NT air-seeder at the rate of 3.4 kg seed ha⁻¹ with 30-cm row spacing. Based on our previous experiences, no P (phosphorus), K (potassium), and S (sulfur) fertilizers were applied since P, K, and S carried over from the previous crop supplied camelina requirements. Respective plots received 0, 45, and 90 kg N ha⁻¹ which was broadcasted in the form of urea (46% N) at the end of rosette stage.

Weed management differed between tillage systems. In NT system, glyphosate (N-[phosphonomethyl] glycine) was sprayed once in the fall. In CT system, however, no herbicide was used in the fall and weeds were controlled by tillage (sweep cultivator). Both NT and CT systems received a glyphosate (N-[phosphonomethyl] glycine) application in the spring prior to seeding camelina (both at the rate of 1.12 L active ingredient ha⁻¹).

Table 1

Monthly precipitation and average air temperature during the study and long term average at Moccasin, Montana.

Month	Rainfall (mm)			Air temperature (°C)		
	2013	2014	Long-term AVG	2013	2014	Long-term AVG
Jan	5.6	28.2	14.0	25	28	22
Feb	6.6	9.4	11.4	28	15	25
Mar	2.5	28.4	18.0	32	28	25
Apr	17.3	16.3	30.5	37	38	41
May	80.5	41.7	65.5	52	48	50
Jun	96.3	62.2	79.2	58	55	58
Jul	42.9	34.5	42.4	68	68	66
Aug	24.6	159.3	41.7	59	65	65
Sep	96.5	59.4	35.8	60	55	55
Oct	39.9	16.5	23.1	46	50	45
Nov	3.8	11.4	14.5	33	27	33
Dec	12.4	8.9	13.7	21	25	25

2.2. Grain yield data collection

Plants were harvested when grains were completely matured (in early- to mid-July) using a Wintersteiger plot combine (Wintersteiger Inc., Salt Lake City, UT). After harvesting, grains were weighed. Grain yield was reported based on 6% (w/w) moisture content.

2.3. Energy balance

Energy balance was evaluated according to the Process Analysis Methodology [23], accounting for energy input of machinery (manufacturer and operation, fuel, and lubricants), fertilizer, and pesticides. Inputs of machines, fertilizers, and pesticides were converted to energy equivalents using standard coefficients (Table 2). Among the available coefficients, we selected the most up-to-date values that have been used by other researchers in similar environments. Seed for planting was not included as energy input; instead, it was subtracted from the harvested grain yield. Neither environmental inputs (e.g. solar radiation, precipitation, soil nutrients) nor labor inputs were considered in the energy input calculation, because labor usually has an insignificant share in the total energy inputs of the mechanized farming systems [14]. Since this study only considers in-farm energy flow, energy costs for delivering the product to off-farm location and storage were not considered (the energy costs for delivery and storage are usually included in biorefinery logistics). The total energy input per hectare was calculated by summing up the energy equivalents of all inputs.

Energy output was determined by multiplying grain yield with grain high heating value (26.5 MJ kg^{-1}) which was measured using a bomb calorimeter. Crop residue did not get an allowance as energy output since it was returned to the soil. Based on the energy inputs and outputs, the following energy balance indices were calculated:

- Energy efficiency = Energy Output (MJ ha^{-1})/Energy Input (MJ ha^{-1})
- Net energy (MJ ha^{-1}) = Energy Output (MJ ha^{-1}) – Energy Input (MJ ha^{-1})
- Energy intensity (MJ kg^{-1}) = Energy Input (MJ ha^{-1})/Grain Yield (kg ha^{-1})

2.4. CO₂ emission

Proper emission factors (which refers to a typical quantity of GHGs released to the atmosphere per unit of the activity) for each input and farm operation was used to determine GHG emissions

Table 2
Energy coefficients and GHG emissions factor used in this study.

Input	Energy coefficient (MJ input^{-1})	Reference	GHG emission factor ($\text{kg C eq input}^{-1}$)	Reference
<i>Input</i>				
Glyphosate (L a.i. ^a)	356	[23]	9.1	[22]
Nitrogen (kg N)	56.7	[23]	1.3	[22]
<i>Operation (ha)^b</i>				
Tillage	244.7	[14]	7.9	[22]
Air seeder	408.0	[23]	3.8	[22]
Pesticide sprayer	126.0	[23]	1.4	[22]
Fertilizer spreader	91.0	[23]	7.6	[22]
Combine harvester	350.0	[23]	10.0	[24]

^a Active ingredient.

^b Including energy for manufacturing, operating, maintenance, fuel and lubrication.

per hectare (kg C eq ha^{-1}) (Table 2). In these emission factors, emissions of important GHG associated with agricultural activities (i.e., carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4)) are converted to C eq using the GWP (global warming potential) of each gas, which refers to the relative contribution of a gas to the greenhouse effect with a time span of 100 years [25]. This approach helped us to assess the real C cost of production system by converting the diverse units into kg C eq emission.

2.5. Data analysis

Data of energy output and energy balance indices (averaged over two years) as influenced by tillage system and nitrogen fertilization were subject to ANOVA using PROC GLM of SAS. Fisher's least significant difference test (LSD) at $P < 0.05$ was employed to separate the means.

3. Results

3.1. Energy input

The influence of tillage system and nitrogen fertilizer on camelina energy input is shown in Fig. 1. No considerable differences were found between tillage systems. Averaged across nitrogen treatments, 4138 and 3927 MJ ha^{-1} non-renewable energy was used for camelina production in CT and NT, respectively Fig. 1.

Nitrogen fertilizer greatly influenced total energy used for production of camelina. With the N input level increased from control treatment (0 kg N ha^{-1}) to 45 and 90 kg N ha^{-1} , energy input for camelina production increased by 186 and 365% compared to 1420 MJ ha^{-1} in the control treatment (Fig. 1). Nitrogen fertilizer had the biggest share in total energy input of camelina followed by machinery (Fig. 1). Nitrogen input accounts for 61–76% of the total energy used for camelina production at 45 and 90 kg N ha^{-1} input rates, respectively.

3.2. Energy output

Analysis of variance showed that energy output of camelina was significantly affected by nitrogen fertilizer, but not by tillage system (Table 3). Irrespective to the tillage method, total energy output of camelina in 0 N treatment was 14,805 MJ ha^{-1} (Fig. 2). When camelina received 45 and 90 kg N ha^{-1} , its energy output increased by 21 and 64%, respectively.

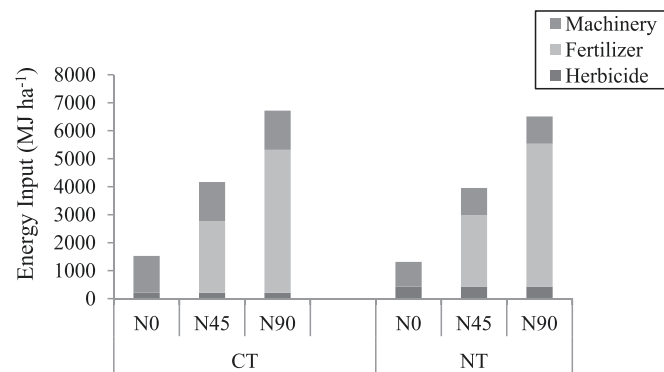


Fig. 1. Camelina energy input and its constituents as influenced by tillage method and nitrogen fertilizer rate. CT: conventional tillage; NT: no tillage. N0: 0 kg N ha^{-1} ; N45: 45 kg N ha^{-1} ; N90: 90 kg N ha^{-1}

3.3. Energy indices

Tillage method did not influence camelina energetic indices (Table 3). Averaged over all experimental treatments, 14,945 MJ ha⁻¹ net energy was obtained from camelina in this study (Fig. 3). Net energy followed a progressive increasing trend in response to the application of N fertilizer; however, no significant differences were found between the N treatments in this regard (Fig. 3). The positive impact of nitrogen in enhancing the energy output was completely offset by greater energy input associated with N fertilization. An opposite trend was observed for energy efficiency, where the highest energy efficiency (10.4) was obtained at 0 kg N ha⁻¹ (Fig. 4). Energy efficiency declined from 10.4 to 4.4 when 45 kg N ha⁻¹ was applied, and further declined to 3.7 when 90 kg N ha⁻¹ was added. It clearly shows the more external nitrogen was applied the less efficiency of input energy was obtained. Energy intensity, the amount of non-renewable energy used to produce one unit (kg) of grain, also responded significantly to the application of nitrogen (Table 3; Fig. 5). When no nitrogen was applied, 2.7 MJ non-renewable energy was required to produce one kg camelina grain. This value reached 6.3 and 7.7 MJ when 45 and 90 kg N ha⁻¹ were consumed.

3.4. GHG emissions

Data of GHG emissions are shown in Figs. 6 and 7. Averaged over tillage and fertilizer treatments, 95.6 kg C eq ha⁻¹ was emitted due to camelina biofuel feedstock production. Implementation of NT resulted in 8% lower GHG emissions compared with CT (Fig. 6). Unlike the effect of tillage method, nitrogen fertilization greatly influenced GHG emissions. When no external nitrogen was applied, GHG emissions were 32.1 kg C eq ha⁻¹ (averaged over two tillage systems). With the application of 45 and 90 kg N ha⁻¹, GHG emissions increased 206 and 389% compared to the control treatment, respectively. Fig. 7 shows the changes in GHG emission based on net energy gained under the influence of tillage method and nitrogen fertilizer. When 0 and 45 kg N ha⁻¹ was applied, GHG emissions in CT plots were greater than those in NT plots. However, when 90 kg N ha⁻¹ was used, GHG emission per each unit of net energy (MJ) was higher in NT than in CT.

4. Discussion

Under the condition of this study, camelina production required 4032 MJ ha⁻¹ energy input and emitted 95.6 kg C eq ha⁻¹ GHG (averaged over tillage and N treatments). One of the most important factors determining the suitability of a bioenergy crop is the amount of input energy [26] and the quantity of GHG emitted during the production process of the crop [27]. Compared with the energy input used for production of other biofuel crops such as rapeseed, camelina required less energy input in this dryland

Table 3

Analysis of variance for the effect of tillage method and nitrogen fertilizer rate on energy output and energy balance indicators of camelina (combined data of 2013 and 2014 were subject to analysis).

SOV	Energy output	Net energy	Energy efficiency	Energy intensity
Tillage system	NS	NS	NS	NS
Nitrogen	**	NS	**	**
Tillage × Nitrogen	NS	NS	NS	NS
CV	18.9	19.8	21.9	11.2

**Significant at P < 0.01.

NS non-significant.

CV: coefficient of variation.

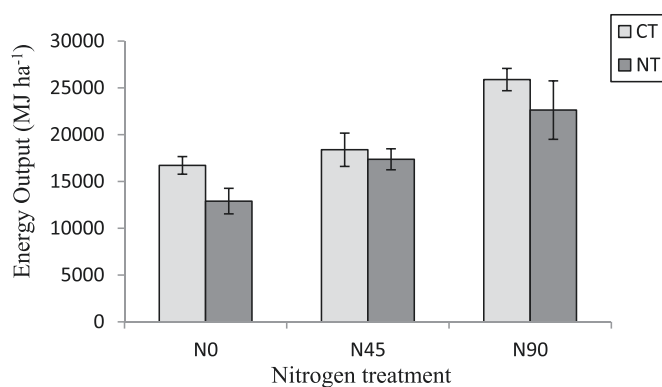


Fig. 2. Camelina energy output as influenced by tillage method and nitrogen fertilizer rate. Vertical bars are standard error (n = 4). CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

farming system. For instance, Fore et al. [28] estimated that production of rapeseed in the U.S. upper Midwest requires 9506 MJ ha⁻¹ energy input. Jankowski et al. [29] found that production of winter rapeseed in Poland requires of 26,290 MJ ha⁻¹ and Unakitan et al. [30] reported 18,297 MJ ha⁻¹ as energy input requirement of rapeseed in Turkey. Moreover, GHG emissions from camelina field seems lower compared with other suitable biofuel crops for this region such as canola. The GHG emissions for production of canola has been reported in the range of 207–389 kg C eq ha⁻¹ [31], 442–469 kg C eq ha⁻¹ [27], and 278 ± 35 kg C eq ha⁻¹ [32]. A lower estimation of GHG emissions from camelina in the current study could mainly be attributed to low energy input used for camelina production in this region as well as the exclusion of irrigation which possess a great portion in total GHG emissions in irrigated farms.

On the other hand, camelina energy output, net energy, energy efficiency and energy intensity were 18,987 MJ ha⁻¹, 14,945 MJ ha⁻¹, 6.1, and 5.6 MJ kg⁻¹, respectively (averaged over tillage and N treatments). In an earlier effort, we estimated energy output, net energy, and energy efficiency of camelina in dryland farming system of central Montana as 24,022 MJ ha⁻¹, 18,283 MJ ha⁻¹, and 4.2, respectively (averaged over three experimental years) [7]. Compared with other biofuel crops such as canola [28–30], energy output of camelina was lower due to low yield of the crop in this dryland system. Lewandowski and Schmidt

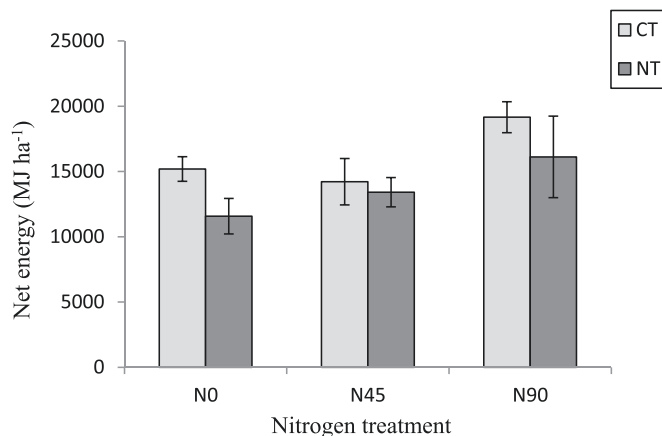


Fig. 3. Camelina net energy output as influenced by tillage method and nitrogen fertilizer rate. Vertical bars are standard error (n = 4). CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

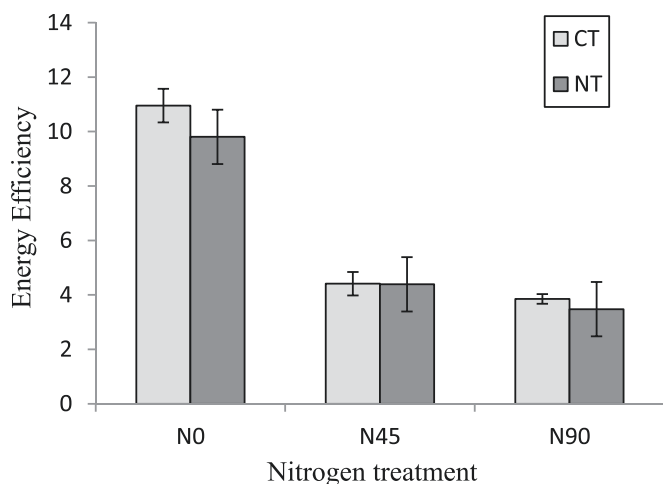


Fig. 4. Camelina energy efficiency as influenced by tillage method and nitrogen fertilizer rate. Vertical bars are standard error ($n = 4$). CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

[26] stated that suitable energy crops yield significantly more energy than that used to grow them. In this study, camelina net energy output was 14,945 MJ ha⁻¹, reflecting the potential of this crop for energy farming.

It should be noticed that many other biofuel crops such as corn or soybean has low chance to grow in this semi-arid northern environment and our field studies show that canola usually yields less than camelina in this environment. Thus, it seems that camelina has higher potential for biofuel feedstock production in the NPG dryland farming systems when compared to other biofuel crops.

It's worth mentioning that there was a gap between camelina yield in this study and average yield reported for this crop in other regions of Montana [4]. Development of new and high yielding cultivars along with the improvement of the agronomic practices will likely improve camelina yields which in turn will also enhance its energy performance in this dryland farming system.

Energy input and GHG emissions of camelina were slightly lower in NT than that in CT which is consistent with reports by other researchers [11,33]. Arvidsson [34] reported that implementation of NT in wheat production resulted in 1000–2200 MJ ha⁻¹ (depending on the soil texture) savings of

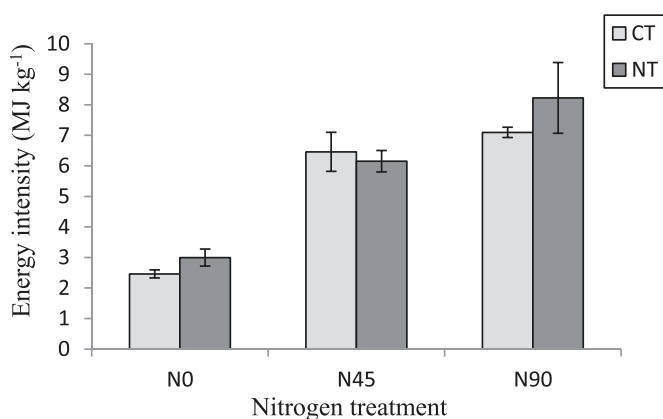


Fig. 5. Camelina energy intensity as influenced by tillage method and nitrogen fertilizer rate. Vertical bars are standard error ($n = 4$). CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

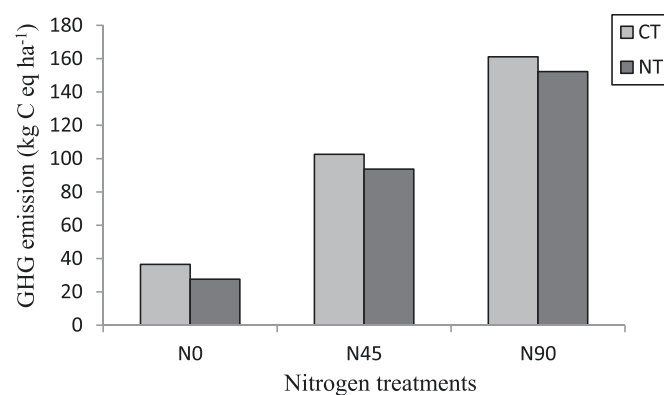


Fig. 6. GHG emission (kg C eq ha⁻¹) from camelina field as influenced by tillage method and nitrogen fertilizer rate. CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

energy input compared with CT in Sweden. Similarly, Rathke et al. [35] reported 1380 MJ ha⁻¹ energy savings when moldboard plowing was replaced with NT in a maize–soybean production system of eastern Nebraska.

Not a significant difference between NT and CT in terms of energy input and GHG emissions in the current study is primarily due to small contribution of machinery in total energy input of camelina in such low-input dryland farming system. Generally, in dryland farming system tillage intensity is minimized even when CT is practiced in order to reduce the risk of soil erosion and loss of soil stored moisture. Consequently, adoption of NT system did not considerably influence energy input and GHG emissions compared to CT. Furthermore, lower energy input and GHG emissions attributed to machinery and fossil fuel spent in NT was compromised with additional herbicide used in this system for weed control. The comparable and similar performance of camelina in NT and CT systems is positive. This result reveals that in addition to the agronomic and economic benefits of NT in this dryland ecosystem such as soil protection and soil water conservation [36], no unfavorable impacts on camelina energy balance and GHG emissions was associated with this type of tillage. Therefore, implementation of NT could be strongly recommended for camelina production in this region.

Unlike tillage system, nitrogen fertilizer greatly influenced energy balance and GHG emissions for camelina production. When nitrogen fertilizer was used, energy input and GHG emissions

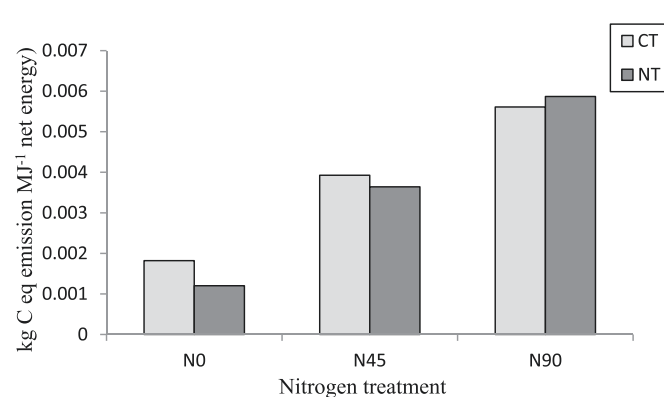


Fig. 7. GHG emission per MJ of net energy (kg C eq MJ⁻¹ net energy) produced in camelina field under the influence of tillage method and nitrogen fertilizer rate. CT: conventional tillage; NT: no tillage. N0: 0 kg N ha⁻¹; N45: 45 kg N ha⁻¹; N90: 90 kg N ha⁻¹

increased considerably. The production of nitrogen fertilizer is a very energy-demanding process, and thus generates considerable GHG emissions [37]. Results showed that when 45 and 90 kg N ha⁻¹ was used, 61–76% of the total energy used for camelina production was attributed to the application of this input (irrespective to tillage method). Our results agreed with most previous studies which showed considerable constitution of nitrogen fertilizer in total energy input for production of different agronomic crops [9–11,14].

Application of nitrogen fertilizer also significantly influenced energy indices of camelina. Applications of 45 and 90 kg N ha⁻¹ increased camelina gross output energy by 21 and 64%, whereas net energy remained stable in response to nitrogen fertilization. In fact, the positive effect of nitrogen to increase energy output was completely offset by greater energy input associated with this input. Nitrogen fertilization also adversely affected energy efficiency and energy intensity (Fig. 5). These results show that nitrogen is not used effectively in the camelina production system and not sufficient outcome was gained per unit of used fertilizer. In this region, urea, the main source of N fertilizer, is top-dressed in the spring. This practice resulted in considerable nitrogen losses through volatilization and denitrification. Engel et al. [38] reported that ammonia volatilization can exceed 40% of the applied N in this region. Being a very C-intensive input, optimization of nitrogen fertilization and minimizing losses are prudent to enhance the ecological sustainability of the farming system in this region. Inclusion of pulse crops in the cropping system, integration of crop-livestock production system, refinement of the nitrogen fertilization strategies (type of fertilizer, timing and placement method) are among the useful approaches to improve NUE (Nitrogen Use Efficiency) in this region. Enhancement of NUE will improve energy efficiency, reduce the environmental emissions, and curb economic costs, which ultimately will increase the sustainability of the farming system.

5. Conclusion

Camelina production in dryland farming system at central Montana resulted in 14,945 MJ net energy ha⁻¹ and 95.6 kg C eq ha⁻¹ GHG emissions (averaged over tillage and N treatments). Due to similar energetic performance and gas emissions of camelina in NT and CT practices, adoption of NT is desirable for camelina production in this region. According to the results of this study, nitrogen plays a crucial role in determining energy efficiency and GHG emissions of camelina. Application of nitrogen fertilizer did not influence net energy, but lowered energy efficiency and considerably increased GHG emissions. Potentially, it is possible to improve energy efficiency and reduce GHG emissions of camelina through the optimization of agronomic practices and utilization of modern high yielding cultivars. Our results showed that improvement of nitrogen use efficiency is crucial to improve energy balance and ecological sustainability of camelina and has the highest priority to achieve the above mentioned goals. The results of this study help us toward identifying and modifying the high energy-demanding and C-intensive inputs and operations for the camelina biofeedstock production in this dryland environment. It is expected the information obtained from this study is applicable to camelina producers in other regions to improve energy balance in camelina production.

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