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Energy balance and 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 became 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 biofueld 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 cemelina 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

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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]. Šarauskis 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 Calciustolls) and its water holding capacity is limited by gravel content and shallow soil profile. Long term (l909–2013) 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