Agricultural Systems 156 (2017) 1–12

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Environmental impact assessment of double- and relay-cropping with winter camelina in the northern Great Plains, USA

Marisol Berti[a,*], Burton Johnson[a], David Ripplinger[b], Russ Gesch[c], Alfredo Aponte[a]

[a] Dept. of Plant Sciences, North Dakota State Univ., Fargo, ND 58105, USA
[b] Dept. of Agribusiness & Applied Sciences, North Dakota State Univ., Fargo, ND 58105, USA
[c] USDA-ARS-NCSCRL, 803 Iowa Ave, Morris, MN 56267, USA

ARTICLE INFO

Keywords:
Winter camelina
Soybean
Sorghum
Environmental impact
LCA
Global warming potential

ABSTRACT

Recent findings indicate that double- or relay-cropping winter camelina (*Camelina sativa* L. Crantz.) with, forage, or food crops can increase yield per area, improve energy balance, and provide several ecosystem services. Double-cropping can help balance food and energy production. The objective of this study was to determine the environmental impact of double- and relay-cropping systems as compared with monocultured maize (*Zea mays* L.) and soybean [*Glycine* max (L.) Merr.] in the Midwest, USA. Ten crop sequences composed of double- and relay-cropped forage sorghum [*Sorghum bicolor* (L.) Moench.] and soybean with winter camelina were evaluated and compared with their monoculture counterparts. The environmental aspects evaluated included global warming potential (GWP), abiotic depletion, acidification, eutrophication, ecotoxicity, and human toxicity. Additionally, provisioning and regulating ecosystem services were estimated, including: primary aboveground productivity, soil erosion, and biodiversity in each crop sequence. The analysis was conducted from 'cradle-to-gate', including only the agricultural phase. Global warming potential estimated by three different methods indicated that winter camelina as a monocrop had a GWP of 579 to 922 kg CO_{2e} ha^{-1}. Maize in monoculture had higher GWP than all other double- and relay-cropping systems studied. The higher emissions of double- and relay-cropping systems and maize can be explained by higher N fertilizer application, which led to greater field N_2O emissions. Also, the additional sowing and harvesting of the double- or relay-crop increased CO_2 emissions due to increased diesel use. Winter camelina as a monocrop had the lowest values in all impact categories, indicating camelina agricultural production phase has low environmental impact compared with maize and soybean in monoculture. Double- and relay- cropping systems increased primary productivity per unit area and biodiversity and reduced soil erosion potential. Increasing productivity with the additional environmental benefits of these systems may encourage more farmers to adopt sustainable agricultural practices.

1. Introduction

Current cropping systems in the US Midwest have low diversity causing negative environmental impacts (Robertson et al., 2014). Most cropping systems that are valued for grain yield and short-term (2–3 years) profitability depend heavily on external inputs. However, several recent studies of US cropping systems suggest that focusing primarily on grain yield and profit, may be neglecting other ecosystem services (Syswerda and Robertson, 2014; Schipanski et al., 2014; Werling et al., 2014).

Double cropping (DC) is defined as two crops grown on the same field within a year (Crabtree et al., 1990; Kyei-Boahen and Zhang, 2006). Also, DC can be defined as the seeding of a second crop once the winter annual crop has been harvested. Double-cropping is suitable for intensive cropping systems and is a way to increase food and feed production per unit area (Schwab et al., 1997). Relay cropping (RC) is a temporal crop intensification system (Heaton et al., 2013). It is defined as a method of multiple cropping, where a crop is planted into an already established crop whereby the life cycles of the two crops overlap each other during a certain period (Kline et al., 2003). Relay cropping allows the production of a second crop in the same field in areas where growing seasons are short (Gesch et al., 2014).

Temporal intensification with double- and relay-cropping systems increases crop diversity, improves soil structure, reduces soil erosion, nitrate leaching, and P run-off, and enhances habitat for wildlife and pollinators (Heaton et al., 2013). Double- and relay-cropping systems can increase crop diversity without reducing the area used to produce food crops (Gesch et al., 2014; Berti et al., 2015).

* Corresponding author.
E-mail address: marisol.berti@ndsu.edu (M. Berti).

http://dx.doi.org/10.1016/j.agsy.2017.05.012
Received 29 August 2016; Received in revised form 3 April 2017; Accepted 22 May 2017

Schipanski et al. (2014) demonstrated that increasing diversity by using cover crops in a 3-year soybean-wheat (*Triticum aestivum* L.)-maize cropping system could increase eight out of eleven ecosystem services without decreasing productivity. In another study that compared ecosystem services along a gradient of management intensity in grain row crops, large differences were observed in soil quality enhancement, climate regulation, groundwater recharge, plant diversity and grain yield among high and low intensity cropping systems, even while achieving similar net productivity (Syswerda and Robertson, 2014).

Life cycle assessment (LCA) and environmental impact assessment of cropping systems has indicated that high input cropping systems have higher GWP, higher risk for acidification, eutrophication, and human toxicity while the opposite is true for low input systems (Nemecek et al., 2011, 2015). Reducing inorganic fertilizer use decreases N-NO_3 leaching, N_2O field emissions, and P run-off (Syswerda and Robertson, 2014). Additionally, if the fertilizer has ammonium ion, a lower fertilization decreases the risk of NH_3 emissions, reducing acidification (Biewinga and Van der Bijl, 1996) Furthermore, increasing the number of crops in rotation has been shown to reduce eutrophication (Tidåker et al., 2014; Nemecek et al., 2011, 2015).

Previous LCA or energy balance analysis including camelina as a biodiesel or jet fuel feedstock, out-performed other common biodiesel-feedstocks, reducing greenhouse gases (GHG) emissions (Krohn and Fripp, 2012; Miller and Kumar, 2013; Li and Mupondwa, 2014). Life cycle emissions in the agricultural phase of crops are greatly influenced by N_2O field emissions. Krohn and Fripp (2012) reported that double cropping camelina with soybean resulted in increased N_2O emission compared with single-season crops because of the addition of N fertilizer for camelina cultivation. However, camelina-based jet fuel had lower impact on human health and ecosystem toxicity than conventional fuels.

Winter camelina dual-cropped with soybean or forage sorghum can sequester excess N and P while protecting soil from wind and water erosion between autumn and spring (Ott et al., 2015), provides food to pollinators early in the spring (Eberle et al., 2015), and it is economically feasible (Gesch et al., 2014; Berti et al., 2015).

However, few studies have addressed the environmental impact of dual cropping systems, especially those involving new or alternative crops such as camelina. The study conducted by Berti et al. (2015) concluded that relay and double cropping with camelina has potential for biofuel and energy feedstock production in the northern Great Plains. But this study did not evaluate the environmental impact of dual cropping systems. Therefore, the objective of this study was to assess the environmental impact of double- and relay-cropping systems with winter camelina in the North Central US.

2. Methodology and assumptions

Ten cropping sequences were evaluated in Prosper, Carrington, ND and Morris, MN, in 2012 and 2013. Experimental methods, sowing dates, design, seed yield, biomass yield, and energy balance were reported in Berti et al., (2015). The mean value of biomass and seed yield, and energy input, output and efficiency from five environments, three locations in two years, were used to calculate the environmental impact of the ten cropping sequences. The ten cropping systems scenarios evaluated are described in Table 1. Normal sowing dates (NSD) were defined as sowing the crop on a date when farmers normally sow the crops at that location. Dates varied greatly with years and locations; for soybean and maize, 24 April-28 May, and for forage sorghum, 30 April and 28 May. Double sowing date (DSD), or date when sowing the second crop, also varied among locations and years between 3 and 11 July for both soybean and forage sorghum (Berti et al., 2015).

The system boundary was set from cradle (crop planting) to the farm gate (harvesting) (Fig. 1). The system included inputs and processes needed to produce seed or forage at the farm gate and the direct and indirect emissions produced by inputs and processes. All inputs for each scenario of the analysis are described in detail in Table 2.

The functional unit was 1 ha yr^{-1}. In rain-fed environments, LCA by unit of product seed or biomass would vary greatly depending soil water availability and temperature. It is for this, that the LCA was conducted based on 1 ha yr^{-1}. This way, the results of the impact analysis would not depend on crop yield but inputs. Most farmers decide the inputs to use before the season starts according to the yield potential to achieve. For example, if in a particular season rainfall is below normal, the crop yield potential might not be achieved, although the inputs remain the same. Therefore, the environmental impacts are driven mainly by inputs, rather than yield, in the agricultural phase. This is only valid when comparing systems from 'cradle to gate' because processing after the field gate will depend on yield and volume of seed or biomass produced by unit area. Crop residues were assumed to stay on the field, and all systems analyzed were on no-till dryland production.

The life cycle inventories are described in Tables 3 and 4. Fertilizer rates used in the analysis were those used in the field experiments conducted in 2012 and 2013 (Berti et al., 2015). Rates were not necessarily optimized for double- and relay-crop yields in this particular study. For instance, for winter camelina, the optimum fertility rate, or even if fertility is needed, especially when following a crop such as wheat is not known. Also, previous research indicates that double- and relay-cropping are likely to be less effective the further North they are practiced in the US Midwest (Gesch et al., 2014; Berti et al., 2015). This mainly because of the shorter season to grow two crops. Moreover, for relay cropping, factors such as row spacing and plant populations may significantly impact yields of both crops (Gesch et al., 2014). For crop combinations, double- or relay-cropping sequences, the inputs needed in each scenario were used to calculate the crop's-combined LCA's. For the impact assessment the CLM–IA-baseline V3.02/World 2000 method, originally developed by Biewinga and Van der Bijl (1996) was used and calculations were done in SimaPro 8.04.30, Educational. Eighteen impact categories were analyzed but only the eight most relevant categories are presented (Tables 5–7). Categories that did have insignificant or very similar results among cropping systems evaluated are not presented.

Since the impact categories analyzed by the CLM method do not asses diversity of provisioning services (food, forage, and energy), timing of the crop in the field (soil cover), soil health, wind–driven soil erosion (particularly important in the northern Great Plains), and biodiversity. Thus, different methods to estimate additional ecosystem services such as aboveground primary productivity (food, feed, forage, and energy), biodiversity, and soil quality were calculated for each cropping system.

Global warming potential for the agricultural phase of double- and relay-cropping was calculated and compared among three different methods. The first method was arithmetic calculation of the estimated CO_2 emissions for inputs, labor, and services in each cropping system. Conversion factors and references used for the calculations are shown in Tables 3 and 4. Also, GWP was estimated by SimaPro 8.04.30, Educational impact method, CLM-IA-baseline V3.02/World 2000, and GREET software. The models assembled in SimaPro were based on the inputs and services indicated in Table 2, using a 1-ha yr^{-1} functional unit. The model built in GREET was based on the mean biomass or seed yield of each crop in each cropping sequence (Berti et al., 2015). Built-in simulations for crops and their combinations in the GREET database were used. For double- and relay-cropping systems the emissions of both crops in the sequence were added to the model. Calculated emission values were divided by the average seed or biomass yield of