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A meta-analysis approach to examining the greenhouse gas implications of including dry peas (*Pisum sativum* L.) and lentils (*Lens culinaris M.*) in crop rotations in western Canada

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ABSTRACT

This study used a meta-analytic approach to systematically examine changes in greenhouse gas (GHG) emissions intensities (i.e., carbon footprints) between pulse-containing and pulse-free crop rotations in western Canada. A systematic literature review was conducted to identify published literature relevant to the goal of the analysis and meta-analysis was conducted to determine statistically significant differences in GHG emissions between pulse-free and pulse-containing crop rotations. Four pulse-free reference rotations (cereal-cereal [C—C]; oilseed-cereal [O—C]; oilseed-oilseed [O—O]; and cereal-oilseed [C—O]) were compared to rotations where the first crop in each two-year sequence was replaced with either dry pea (*Pisum sativum* L.) or lentil (*Lens culinaris* M.). Two scenarios were considered. The first scenario investigated the effects of dry peas and lentils when synthetic nitrogen (N) applied to cereal and oilseed crops grown after pulses was not reduced (i.e., no change) (N_N). The second scenario (N_{CR}) investigated the effect of dry peas and lentils when synthetic N application rates were reduced to the maximum extent possible (i.e., credit) to maintain subsequent crop yields. Pooled analyses demonstrated that, in general, cereal and oilseed crops grown after a dry pea or lentil crop had similar or reduced GHG emissions compared to those grown after a cereal or oilseed. The GHG emissions from cereal and oilseed crops grown after dry peas and lentils were higher in N_N (888–987 kg CO_2e/ha; 286–598 kg CO_2e/t) than in N_{CR} (311–978 kg CO_2e/ha; 116–598 kg CO_2e/t), suggesting that emissions were reduced to a greater extent when pulse crops offset the N fertilizer requirements of a subsequent crop compared to when they were used to provide N to maximize crop yields. In two-year rotations, the inclusion of pulses reduced GHG emissions compared to all reference rotations in both N_N (savings of 475–719 kg CO_2e/ha over two years [area basis]; 164–496 kg CO_2e/t over two years [yield basis]) and N_{CR} (savings of 489–1185 kg CO_2e/ha over two years [area basis]; 335–610 kg CO_2e/t over two years [yield basis]), mostly as a result of reduced synthetic N requirements of the whole rotation. The results of the analysis are presented by crop for each pulse-free and pulse-containing cropping sequence for each scenario to allow for flexibility in comparing GHG emissions from various rotations.

1. Introduction

Food systems, including preproduction, production, and post-production activities, are estimated to contribute approximately 19–29% of total global anthropogenic greenhouse gas (GHG) emissions (Vermeulen et al., 2012). The agriculture sector is the largest contributor to global anthropogenic nitrous oxide (N_2O) and methane (CH_4) GHG emissions (Smith et al., 2014). In the effort to reduce GHG emissions from food systems while striving to meet current and future global food demands, opportunities to reduce GHG emissions from food systems must be considered throughout the food supply chain. This includes crop production practices. This is particularly important considering climate change is projected to result in increased variability in temperature and precipitation, extreme weather events, water scarcity, and incidence of pest and disease outbreaks (FAO, 2016b), each of which has the potential to affect the ability of cropping systems to meet the requirements of future global food demands.

One of the largest contributors to GHG emissions from the agriculture sector is the production and use of synthetic nitrogen (N) fertilizers. Over the last half century (i.e., 1961–2010), global emissions from synthetic fertilizer have grown at an average rate of almost 4% per year (Smith et al., 2014). Considering current trends, the International

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Panel on Climate Change (IPCC) predicts that synthetic fertilizers will overtake manure deposited on pasture to become the second largest contributor of all agricultural emission categories within the next ten years, following only enteric fermentation (Smith et al., 2014). It is important to recognize however, that the increased use of synthetic fertilizers has helped drive an increase in global grain production.

The most effective way to reduce GHG emissions from cropping systems is to reduce GHG-intensive inputs to the system while maintaining or increasing productivity (MacWilliam et al., 2014). Given its relatively large contribution to the carbon footprint (i.e., total GHG emissions per unit basis) of crop production, it is logical to examine the potential for reducing and/or optimizing the amount of synthetic N applied to cropping systems as a method for reducing the GHG intensity of grain production. However, N is an essential nutrient for crop growth and reducing its application rate may lead to nutrient deficiencies and a decrease in crop yields. This suggests that, rather than simply reducing the application rate of N fertilizer, alternative methods for supplying N to crops may be more effective in decreasing GHG emissions. In western Canada, pulse crops such as dry pea (*Pisum sativum* L.) and lentil (*Lens culinaris* M.) have been shown to reduce the synthetic N requirements of crop rotations and increase the yield and quality of grain grown after the pulses; particularly in cereals (Badaruddin and Meyer, 1994; Lin and Chen, 2014; Miller et al., 2003b). Dry pea and lentil do not typically require synthetic N due to their unique ability to fix N from the atmosphere. Furthermore, these pulse crops have been shown to contribute to meeting the N requirements of subsequent crops, thus reducing the synthetic N requirements of the full two-year cropping sequence (Zentner et al., 2001).

In 2016, pulse crop production in western Canada accounted for approximately 98% of the total Canadian pulse production; however, only 10% in Alberta, 18% in Saskatchewan, and 1% in Manitoba of total principle field crop area was dedicated to dry pea and lentil (Statistics Canada, 2017). Despite the relatively low area dedicated to pulse production, Canada was the world's largest producer of dry pea and lentil, contributing 35% and 48% of the total supply, respectively (STAT Communications Ltd., 2017). Given the scale of total crop production in western Canada, the potential for increasing pulse production, and the prospective N-related benefits of dry pea and lentil to crop rotations, opportunities may exist for developing crop production strategies that better utilize pulses as a method for decreasing GHG emissions from cropping systems. A number of studies have examined the effects of pulses in cereal and oilseed crop rotations on the N fertilizer requirements and the N cycle of crop rotations in western Canada (e.g., Khakbazan et al., 2016; Dusenbury et al., 2008; Badaruddin and Meyer, 1994). However, differences in location, growing conditions, management practices, and results across studies present challenges for ascertaining definite conclusions about the effects of including pulse crops in cropping systems. In the case that the combined results of these studies clearly indicate a reduction in required synthetic N fertilizer and an associated reduction in GHG emissions from the use of pulse crops in cropping systems, an opportunity exists to increase and/or modify the use of pulse crops to improve the environmental performance of crop production, and food systems.

The goal of this work was to use a meta-analytic approach to determine the statistically significant effects of either dry pea or lentil in annual cropping systems in western Canada on the GHG emissions intensities of crop production systems. Meta-analysis was selected as the approach for the analysis as its primary purpose is "to combine the results of a number of different reports into one report to create a single, more precise estimate of an effect" (Ferrer, 1998). The benefits of meta-analysis include: 1) The provision of better estimates of relationships in a population compared to single studies; 2) An increase in the amount of data and statistical power, leading to improved precision in estimates; 3) Allowance for the examination of hypothesis testing and biases; and 4) Helps to resolve inconsistencies in research (Stone and Rosopa, 2017).

The objectives of this study were to: 1) Systematically review the literature and compile agronomic and emissions data corresponding to yield, protein levels, N fertilizer application, soil organic carbon (SOC), energy input, and GHG emissions from studies that compared western Canadian cereal and oilseed cropping systems with and without peas and lentils; 2) Use meta-analysis to statistically determine the effects of dry peas and lentils on agronomic and emissions outcomes of subsequently grown cereals and oilseeds in western Canada; and 3) Apply data derived from objectives 1 and 2 to develop improved carbon footprints of pulse-free and pulse-containing cropping systems. The results of this study are intended to support and inform the development of strategies for improving the environmental performance of cropping systems in western Canada. For this study, the term "pulses" refers to dry peas and lentils.

2. Materials and methods

2.1. Overview

A systematic literature review was conducted to identify published literature reporting agronomic or emissions data with comparisons between pulse-free and pulse-containing crop rotations in western Canada. All data points of potential significance to the GHG emissions of cropping systems reported in the literature were extracted for further analysis and a series of plots were generated to examine the relationships between data points. Relationships were identified and maintained through statistical analysis. Statistically significant differences between pulse-free and pulse-containing crop rotations were identified using meta-analysis for each set of data points where the data were sufficient in number and either consistent in format or able to be standardized into comparable formats. The results of the meta-analysis were supported by literature from the systematic review to estimate the effects on GHG emission intensities (i.e., carbon footprints) from the production of pulse-containing and pulse-free crop rotations. Additional information on the methodology for each stage of the project are provided in Sub-Sections 2.2-2.5.

2.2. Systematic literature review

A systematic review of English-language, peer-reviewed literature using EBSCO*host* (EBSCO Information Services, 2016a), EBSCO Discovery Service (EBSCO Information Services, 2016b), AGRIS (FAO, 2016a), and PubAg (USDA, 2016) databases was conducted to identify literature relevant to the goal of this analysis. Literature selected for inclusion in the meta-analysis met the following criteria: 1) Studies were conducted in the field (i.e., studies conducted exclusively in a lab or greenhouse were excluded); 2) Studies reported data on principal field crops grown in crop rotation and for grain (i.e., intercropping, green manure, and forage crops were excluded); 3) Studies were reporting on dry pea, lentil, or both; 4) Direct comparisons between pulse-containing and pulse-free rotations were made; 5) New data were reported (i.e., review studies were excluded unless they reported previously unpublished data); and 6) Studies were conducted in western Canada (Manitoba, Saskatchewan, Alberta).

For comparison to pulse-containing rotations, the following four pulse-free rotations were identified based on the data from the systematic review and used as reference sequences: cereal-cereal (C—C), oilseed-cereal (O—C), cereal-oilseed (C—O), and oilseed-oilseed (O—O). Each of these reference sequences was compared to a sequence where the first crop in the sequence was replaced by either dry pea or lentil. Data relevant to the goal and scope of the analysis were extracted on a trial-by-trial basis from each paper during the systematic review. The extracted data included: crop yield; grain protein content; N fertilization rates; cropping sequence; study specifications including location (s), number of trials, and years of study; GHG emissions; fossil energy requirements; any information pertaining to the N cycle of the cropping