Greenhouse gas emissions and irrigation water use in the production of pulse crops in the United States

David I Gustafson

Abstract: Supplying our world’s growing nutrition needs in more sustainable ways has become an urgent global imperative, given the constraints of finite resources and the challenges of accelerating climate change. Pulse crops, which are the dried seeds of legumes such as dry peas, chickpeas, beans, and lentils, play a key role in maintaining affordable, nutritious diets, as they provide high amounts of protein and fiber, and relatively low amounts of fat. As legumes, they are also advantageous from an environmental perspective, because they fix atmospheric nitrogen, thereby reducing the need for added fertilizers. Although some pulse crops are produced in areas that require irrigation, more than 80% of the pulse crop production area in the United States is exclusively rain-fed. In order to quantify eco-efficiency metrics associated with the production of pulse crops in the United States, life cycle assessment techniques were used to calculate “cradle to farm-gate” greenhouse gas emissions and irrigation water use, both on a per unit of production basis. The results demonstrate that pulse crops have low carbon and water footprints relative to most foods, with greenhouse gas emissions of 0.27 kg CO₂/kg and irrigation water use of 0.19 m³/kg, both as national averages across all 2.4 MMT (millions of metric tons) of pulse crops currently produced annually in the United States.

ABOUT THE AUTHOR
David I Gustafson is an independent scientist who uses modeling to help food systems meet human nutrition needs in more sustainable ways. His academic training was in chemical engineering (Stanford, BS, 1980; University of Washington, PhD, 1983). He worked 30 years in private industry (Shell, Rhône-Poulenc, Monsanto), and then served at the ILSI Research Foundation as Director of the Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security (CIMSA) through 2016. Dave’s early career focused on predicting agricultural impacts on water quality. He subsequently developed new modeling approaches to pollen-mediated gene flow and the population genetics of insect and weed resistance. Beginning in 2007, Dave began leading efforts to understand climate adaptation and mitigation imperatives in the global agri-food system. He has served on various national and international teams looking at this issue, including the Executive Secretariat of the US Government’s National Climate Assessment Development & Advisory Committee (2011–2014).

PUBLIC INTEREST STATEMENT
Supplying our world’s growing nutrition needs in more sustainable ways has become an urgent global imperative, given the constraints of finite resources and the challenges of accelerating climate change. Pulse crops, which are the dried seeds of legumes such as dry peas, chickpeas, beans, and lentils, play a key role in maintaining affordable, nutritious diets, as they provide high amounts of protein and fiber, and relatively low amounts of fat. As legumes, they are also advantageous from an environmental perspective, because they fix atmospheric nitrogen, thereby reducing the need for added fertilizers. In order to quantify eco-efficiency metrics associated with the production of pulse crops in the United States, life cycle assessment techniques were used to calculate greenhouse gas emissions and irrigation water use. The results demonstrate that pulse crops have low carbon and water footprints relative to most foods.
1. Introduction

Mankind is trying to prove Malthus wrong, that we can successfully meet our world’s growing nutrition needs despite the intrinsic constraints of finite resources and the challenges of accelerating climate change (IPCC, 2014). To meet the demand expectations for food, feed and fiber production from a growing global population in the 21st century, significant increases in agricultural productivity will be required (Boyd-Orr, 1950; Tilman, Balzer, Hill, & Befort, 2011). In recent years several prominent global organizations have highlighted the magnitude of the challenge facing the world’s agricultural industry to meet the nutritional demands for a growing population in the next 30–50 years (Field to Market, 2009, 2012; Foresight, 2011; Serecon, 2011). Meeting this demand sustainably will require increased productivity from the finite natural resources that exist around the world while balancing demands for environmental protection and social benefit (Beddington et al., 2012; Waddington, Li, Dixon, Hyman, & de Vicente, 2010). Others (Foley et al., 2011; Tomlinson, 2013) have questioned whether productivity advances alone are required to meet future food and nutrition needs, pointing out that tremendous progress could be made by halting agricultural expansion, closing yield gaps on underperforming lands, increasing cropping efficiency, reducing waste, and changing diets.

One particular change in diets that has been suggested by the United Nations (UN) is to increase the consumption of pulse crops: the dried seeds of legumes such as dry peas, chickpeas, beans, and lentils (UN, 2016). Pulse crops provide high amounts of dietary protein and fiber, and relatively low amounts of fat. As legumes, they are also advantageous from an environmental perspective, because they fix atmospheric nitrogen, thereby reducing the need for added fertilizers. Recognition of these benefits caused the UN to name 2016 as the “International Year of Pulses.” In its announcement, the UN noted that pulse crops are a critical source of plant-based proteins and amino acids and that pulses contribute to sustainable food production aimed towards food security and nutrition. The UN further noted that health organizations around the world recommend eating pulses as part of a healthy diet to address obesity, as well as to prevent and help manage chronic diseases such as diabetes, coronary conditions and cancer.

From an agronomic perspective, some pulse crops are produced in regions that require irrigation, but more than 80% of the pulse crop production area in the United States is exclusively rain-fed (USDA, 2016). Pulse crops tend to be rather non-competitive against weeds, so growers are required to employ relatively aggressive methods of weed control in order to maintain yields and facilitate smooth harvest operations. This can include the sequential use of herbicide treatments, which have implications for fuel use and the net greenhouse gas (GHG) emissions associated with production of pulse crops (the so-called “carbon footprint”).

A number of studies have examined the environmental impact associated with individual food items in particular countries (Gephart et al., 2016; Scarborough, Allender, Clarke, Wickramasinghe, & Rayner, 2012; Song et al., 2016) or a single environmental indicator such as GHG emissions (Heller & Keoleian, 2014; Tongwane et al., 2016; Vetter et al., 2017), or water use (Jalava, Kuumu, Porkka, Siebert, & Varis, 2014; Vanham, Hoekstra, & Bidoglio, 2013). However, none of the previous studies have focused on pulse crops. The purpose of this study was to collect production information from US-based pulse crop growers and then apply standard life cycle assessment methodologies to calculate national average greenhouse gas emissions and irrigation water use in the production of pulse crops.
2. Materials and methods

A form was developed to collect the needed information from pulse crop growers across the US (see Figure 1). The form was distributed to growers in ten states (see Table 1), with the goal of collecting information on ten different pulse crops (see Table 2). As indicated in these two tables, data were ultimately returned by growers in six of the target states on five of the target crops. This level of response was deemed sufficient to calculate national averages. Although the states with respondents are all in the northern part of the country, this is where pulse crop production is concentrated in the United States.
2.1. Irrigation water consumption
Water consumption and scarcity has become a local environmental issue of international concern. Demands on water are many and without an adequate and timely supply of water, crop yield and agricultural efficiency is affected. The average use of irrigation water by the growers in this survey (m³/kg) was used to estimate water use by all US pulse crop growers. This total amount of water use is then normalized by total pulse crop production on all production acres (irrigated and rain-fed) in order to calculate a yield-weighted overall average water footprint for US pulse crops. Weighting by crop yield is needed in order to account for the higher yields that are typically obtained under irrigation.

2.2. GHG emissions
The PAS 2050 method (2011) for GHG emissions assessment was used to define cradle to field gate, and the characterization of, greenhouse gas emissions into CO₂ equivalents. Cradle to field gate captures agrochemical, fuel and electricity production, transport, field activities and harvesting. Other studies (CropLife International, 2012, FAOSTAT, 2012; IFEU, 2007) have identified fertilizer production, fertilizer N₂O emissions from soil, and farm energy use, as being the primary drivers of GHG emissions with fertilizer being the most critical. Standard methods, similar to those available in the Cool Farm Tool (Hillier et al., 2011), were used to estimate GHG emissions for each of the recorded field operations and then calculate total GHG emissions per unit of production (kg CO₂e/kg) for each grower.

The spreadsheets and data associated with all of the calculations are available from the author upon request.

Table 1. Targeted states
| State         |
|---------------|
| California    |
| Colorado      |
| Idaho         |
| Michigan      |
| Minnesota     |
| Montana       |
| North Dakota  |
| Texas         |
| Washington    |
| Wisconsin     |

Note: x indicates data received.

Table 2. Targeted pulse crops
| Crop              |
|-------------------|
| Black beans       |
| Blackeye peas     |
| Chickpeas         |
| Dark red kidney beans |
| Dry peas          |
| Great northern beans |
| Lentils           |
| Lima beans        |
| Navy beans        |
| Pinto beans       |

Note: x indicates data received.
3. Results and discussion

Example data are shown in Figures 2 and 3 for an irrigated and a rain-fed field, respectively. All personal identification information has been removed to preserve confidentiality. Example calculations for these two fields are as follows. For the irrigated field, WI-DRKB-01, the yield is 2.49 MT/ha, the water footprint is 1.02 m³/kg, and the GHG emissions are 0.44 CO₂e/kg. For the rain-fed field, WA-DRYP-01, the yield is 1.51 MT/ha and the GHG emissions are 0.28 CO₂e/kg.

Shown in Table 3 are the average GHG emissions, irrigation water use, and crop yields for all surveyed pulse crop growers. As indicated therein, GHG emissions were somewhat higher for pulse crops under irrigation, 0.31 kg CO₂e/kg, compared with 0.26 kg CO₂e/kg for growers in rain-fed systems. This difference is to be expected, due to the consumption of energy (and associated GHG emissions) that are involved in the irrigation operation. The growers that were under irrigation consumed an average 0.79 m³/kg of irrigation water, and (as expected) obtained somewhat higher pulse crop yields (2.81 MT/ha) than their rain-fed counterparts (2.03 MT/ha). These observed yields were used to calculate the production-weighted national average GHG emissions and irrigation water use.
Table 3. GHG emissions and irrigation water use in surveyed pulse crop production fields

| Production system | GHG emissions (kg CO₂e/kg) | Irrigation water use (m³/kg) | Crop yield (MT/ha) |
|-------------------|-----------------------------|------------------------------|-------------------|
| Irrigated         | 0.31                        | 0.79                         | 2.81              |
| Rain-fed          | 0.26                        | 0                           | 2.03              |

Table 4. Average national GHG emissions and irrigation water use for pulse crops in the United States

| GHG emissions (kg CO₂e/kg) | Irrigation water use (m³/kg) |
|----------------------------|-----------------------------|
| 0.27                       | 0.19                        |
values shown in Table 4, based on the reported (USDA, 2016) percentage of US pulse crop area that is under irrigation (19%).

The GHG emissions for pulse crops reported here are somewhat lower than those given in a recent report for Canadian production systems (Serecon, 2011), which reported values in the range of 0.41 to 0.45 kg CO₂e/kg. This is likely due to the lower N₂O crop emission figures that were used in this LCA modeling, based on more recent estimates (Jeuffroy et al., 2013). The carbon footprints reported here for pulse crops are somewhat higher than those recently reported (Gustafson et al., 2013) for soybeans (0.1 kg CO₂e/kg), which is reasonable due to the lower yields and lower crop competitiveness typically exhibited by pulse crops, relatively to soybeans, the most intensive of the legumes in the United States. As noted earlier, this lack of competitiveness requires the use of extensive weed control methods (either tillage or herbicides or both), all of which adds to the carbon footprint. The water footprint of pulse crops reported here is intermediate between the values reported for maize (0.15 m³/kg) and soybeans (1 m³/kg) and is much lower than cotton, which consumes approximately 4 m³/kg (Gustafson et al., 2013). Pulse crops are thus seen to have relatively high water use efficiency.

Looking at pulse crops as a source of food, it is clear that both the carbon and water footprints compare very favorably to all other food groups (Gephart et al., 2016; Scarborough et al., 2012; Song et al., 2016). Diets based on higher proportions of plant-sourced vs. animal-sourced proteins have been widely documented to have lower carbon footprints (Heller & Keoleian, 2014; Tilman et al., 2013; UN, 2016). Water footprints are also lower. According to figures reported by Mekonnen and Hoekstra (2011), the water required per unit of protein is 1.5 times higher for milk, eggs, and chicken, relative to pulse crops. The ratio is even higher for pork (3×) and beef (6×). The results given in this paper confirm these conclusions: the inclusion of higher amounts of pulses in US diets would bring significant environmental advantages, in terms of lower GHG emissions and irrigation water use in the food system of the United States.

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Competing Interests
The author declare no competing interest.

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