Foundations for assessing the water footprint of food loss and waste

by

Samuel P. Brown

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Approved by:

Major Professor
Prathap Parameswaran

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Abstract

Food production has made an indelible environmental impact on the landscape of the United States, accounting for nearly three-fourths of the nation's water consumption, 55% of its land use, and a significant amount of energy utilization along the food supply chain (FSC). Yet, much of this resource use does not serve a beneficial purpose - over 33% of the U.S. food supply is lost or wasted between farm and fork. This food loss and waste (FLW) is the largest contributor to municipal solid waste, accounting for 22% of waste in landfills in the U.S. Water scarcity has been identified as a pervasive threat to global society and is expected to intensify with the changing climate and growing population. To our knowledge, no studies have quantified FLW at the county level. We aim to provide the framework which will be used to assess the water footprint of FLW at a county level spatial resolution on the temporal scale of 1997 through 2017 to determine loss rates, loss quantities, and the associated water footprint increases over time in a future study. The purpose of this article will be to determine county level data for FLW rates, quantities, and variations over the aforementioned timescale. Results of this study are anticipated to aid in the determination and targeting of FLW hotspots for reduction efforts.

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Introduction/Background

Over two-thirds of the global population lives under water scarcity (Mekonnen and Hoekstra, 2016). Limited water supplies inhibit economic growth, pose societal health risks, and endanger ecosystems. Measures to reduce water scarcity have primarily focused on developing new water supplies (World Commission on Dams, 2000) and improving water productivity (Marston et al., 2020), particularly in the agricultural sector since it is responsible for over 90% of global consumptive freshwater use (Hoekstra and Mekonnen, 2012). It is suggested that the proportion of global agricultural dry biomass consumed for food is as little as 6%, and 24.8% for harvest biomass (Alexander et al., 2017). During the second half of the 20th century, food production more than doubled and with this came large increases in fossil fuel energy, fresh water, and fertilizer inputs. These increases have contributed to a considerable footprint on the environment. Global water cycles, carbon energy cycle, food production, and climate change are undoubtedly linked. Prolonged droughts and extreme weather events can cause a step change in water supplies and worsen the risk of agricultural food production (Pannell et al., 2006). A foundation for this research has been provided by examining existing studies focusing on the scope of FLW and accompanying impact on water resources. This article aims to extend the existing literature by determining the county level FLW rates, quantities, and variations for a select range of target food crops from primary production through the consumer waste levels over the census years of 1997 through 2017. This research in conjunction with a forthcoming study aimed at estimating the county level water footprint of FLW will lay the groundwork for studies in which the overall county level environmental footprint of FLW can be determined throughout the identified timescale.

Food Loss and Waste Estimates

At least one-third of food is estimated to be lost or wasted globally (Gustavsson et al., 2011). FLW occurs at all points along the FSC: food is lost on farms, at facilities, during storage and distribution, and wasted within retail and households. Global food losses amount to 413 million metric tons at the agricultural production stage, 293 million metric tons in post-harvest handling and storage, 148 million metric tons in processing, 161 million metric tons in distribution, and 280 million metric tons wasted in consumption for a total of 1.3 billion metric tons of annual

FLW (Gustavsson et al., 2011). In the United States alone, total annual FLW across all stages of the FSC is estimated to be 126 million tons, or about 10% of the global total (CEC, 2018). Across commodities, more FLW occurs for root crops (40–50%), fish (35%), and cereals (30%) compared to oilseeds, meat, and dairy products (20%) (Gustavsson et al., 2011).

Food Loss and Waste: Water Footprint Overview

One-fourth of freshwater consumed in global food production is effectively wasted since the food produced with this water is never consumed (Kummu et al., 2012). The blue water footprint (i.e., consumed fresh surface water and groundwater) of global crop production is 723 km3/year, meaning uneaten plant-based food represents 174 km3 of wasted blue water each year (Kummu et al., 2012). If the waste of meat products is considered, (FAO, 2013) estimates 250 km3 of blue water was wasted due to FLW in 2007. Considering the water footprints of primary crops, the global average water footprint per ton of crop increases from sugar crops (200 m3/ton), vegetables (300 m3/ton), fruits (1,000 m3/ton), cereals (1,600 m3/ton), and oil crops (2,400 m3/ton). The water footprint varies across different crop categories and per production region (Mekonnen and Hoekstra, 2011). For certain crops, water scarcity impacts are inversely related to the land resource stress (Pfister et al., 2011). The global water footprint related to crop production from the period of 1996 through 2005 was 7,404 billion cubic meters per year (78% green water, 12% blue water, and 10% gray water) (Mekkonen and Hoekstra, 2011). In its most recent annual risk report, the World Economic Forum lists water crises as the largest global risk in terms of potential impact (World Economic Forum, 2015). Nearly 40% of the world population are suffering from water scarcity (Oki and Kanae, 2006). Agricultural production is responsible for the vast majority of global freshwater consumption (approximately 85%) (Shiklomanov et al., 2004) and is projected to double by 2050 (Tilman et al., 2002). It is suggested that the proportion of global agricultural dry biomass consumed for food is as little as 6%, and 24.8% for harvest biomass (Alexander et al., 2017).

The environmental impacts of water consumption and water stress are integral. Aquatic organisms are directly affected by the depletion of freshwater. Water scarcity decreases crop yields and population, especially in the developing world (Pfister et al., 2009). Nearly 40% of the world population are suffering from water scarcity (Oki and Kanae, 2006). Global land and water

resources stress is increasing as a result of population growth. Agricultural production is responsible for the vast majority of global freshwater consumption (approximately 85%) (Shiklomanov et al., 2004) and is projected to double by 2050 (Tilman et al., 2002).

Per Capita Food Loss and Waste - Water Footprint

Global freshwater wasted in FLW per capita per year is ~21 m3 (Chen et al., 2020). However, the water embedded in FLW and its impact on water scarcity varies significantly depending on the person's diet and waste patterns, which is strongly influenced by where one lives (Chen et al., 2020) (Figure 1). High-income countries waste 43 m3 per capita each year, while low-income countries only waste a little over 4 m3 per capita each year (Chen et al., 2020). Food loss and waste is responsible for 7.1% of the freshwater planetary boundary (Chen et al., 2020), which denotes freshwater supplies that can be appropriated to society without causing continental-scale to planetary-scale harm (Rockström and Karlberg, 2010). If the world had a similar diet and pattern of food waste as North America, global FLW would constitute 20% of the freshwater planetary boundary (Chen et al., 2020).

In the methodology below, we describe our process for determining the county level FLW rates, quantities, and variations for the selected target food crops.

Methodology

This article aims to extend the existing literature by determining the county level FLW rates, quantities, and variations for a select range of target food crops from primary production through the consumer waste levels over the census years of 1997 through 2017. An analysis of the determined county level FLW rates, quantities, and variations is included in the results. The analyzed commodities were selected based on availability and reliability of the accessible food crop data. Additional details on crop selection methods are provided in the following Sections.

Target Food Crops for Analysis

We utilized county level crop yield (production) data and harvested area data from USDA's National Agricultural Statistics Service Quick Stats (USDA NASS, 2017) for the following sixteen (16) food crops: barley, canola, total corn products grown for grain, sweet corn, lentils, oats, peanuts, peas, potatoes, rice, rye, sorghum-grain, soybeans, sugarbeets, sugarcane, and tomatoes. FLW rates at each level of the FSC were obtained from the Loss Adjusted Food Availability (LAFA) data from the US Department of Agriculture's Economic Research Service (ERS, 2011b) for each of the evaluated food crops. Loss rates are given in percentage of loss by weight and are provided for the primary production level, retail level, consumer level, and an all-encompassing combined level. Total loss rates which encompass all levels were utilized for FLW quantity estimates in this report. The LAFA data can be accessed online which provides all of the current loss assumptions and structure of the calculations for each food in the data series. Additional information is available in Table 1 below and is summarized on the ERS website (ERS, 2011b).

Table 1: ERS Loss Adjusted Food Availability Data Overview

The ERS's Loss adjusted food availability data are derived from food availability data by adjusting for food spoilage, plate waste, and other losses to more closely approximate actual consumption. This data series is considered preliminary because the underlying food loss assumptions and estimates require further improvement. The Loss-Adjusted Food Availability Data Series can be accessed through Excel spreadsheets and CSV files, which provide all the current loss assumptions for the data series. ERS has completed a set of initiatives to update and document the underlying loss assumptions and further refine the series. Thus, this data series is considered to be preliminary.

Per capita calorie consumption and food pattern equivalents are estimated for more than 200 agricultural commodities from 1970 to the most recent year of data available. Per capita data are reported for both individual commodities and aggregated food groups. The data for individual commodities are aggregated into food groups to facilitate comparison with recommendations for average daily intakes for the U.S. population.

Food loss represents the edible amount of food, postharvest, that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (for example, moisture loss); loss from mold, pests, or inadequate climate control; and food waste. In particular, the LAFA data requires estimates of four different conversion or loss factors in its calculations for each covered commodity at three different levels:

Losses at the primary production level (for example, farm to retail weight).

Losses at the retail level, such as in supermarkets, megastores like Walmart, and other retail outlets, including convenience stores and mom-and-pop grocery stores. Losses in restaurants and other foodservice outlets are not included.

Losses at the consumer level. This includes losses for food consumed at home and away from home (e.g., restaurants and fast food outlets) by consumers and foodservice establishments.

Box 1 text was adapted from the ERS website (ERS, 2011b).

Determination of Crop Production Tonnage

Determining the county level crop production data was a time intensive process, particularly because we had to identify and select commodities iteratively on the temporal scale. First, we

identified the 16 food crops previously detailed from (USDA NASS, 2017) to be included in the analysis. Second, we obtained the county level harvested area for the target crops for both irrigated and non-irrigated operations from (USDA NASS, 2017). Third, we obtained the county level yield data for the target crops, both irrigated and non-irrigated, from (USDA NASS, 2017). Fourth, we determined the county level production tonnage data for the target crops, for both irrigated and non-irrigated operations. This process was iterated upon for each available census year until production tonnage, both irrigated and non-irrigated, were determined at a county level scale for each target crop over the analyzed time scale. Temporal data was selected based on available census years. Census years included 1997, 2002, 2007, 2012, and 2017. Production data for census years prior to 1997 was not available or may not exist. Harvested area data for non-census years existed in the form of survey data, however, the available county level survey data for the analyzed crops lacked comprehensive coverage. County level survey data coverage contained significant cavities in data between census years. Adding to these gaps in coverage, the accuracy of survey data which existed for census years collapsed under analysis. County level crop survey data for these census years, dependent on crop type, was inconsistent with its respective year's census data with an error range upwards of 40%. Due to these errors and cavities the survey data proved unreliable, thus data for the census years alone was utilized.

Production estimates for the food crops based on the available harvested area data was determined for each commodity. An example of the method is provided below:

The non-irrigated harvested area for barley in County ID 38031 for the year 2012 was 0.996 hectares (2.47105 acres). Non-irrigated yield for County ID 38031 was 1.2649 tonnes per acre. Utilizing the equation below Equation 1, we determined the total rainfed production tonnage for each County ID. This equation was utilized for both irrigated and rainfed crop production data.

Equation 1

$T = Y*H$

T = Total County Level Production Tonnage (tonnes)

Y = County Yield (tonnes/acre)

H = County Level Harvested Area (acres)

Unit conversions were performed during initial raw data processing. Raw yield records data was not all directly available in a tonnes per acre format. Food crop raw yield records data was provided in inconsistent units, such as bushels per acre, tons per acre, pounds per acre, and hundredweight per acre. All units were converted from the respective initially provided units to metric tonnes per acre. Import and export FLW data related to the analyzed food crops has not been included in this analysis and thus, results may not fully depict the true extent of losses.

County Level Food Loss and Waste Quantities

County level FLW quantities (in tonnes) were calculated from the total county level production tonnage data and LAFA data (ERS, 2011b) FLW rates for each commodity. Rates are given in a percentage of combined losses at the primary, retail, and consumer levels. FLW rates for each commodity are detailed in Table 2 below.

Table 2: LAFA Food Loss and Waste Rates (ERS, 2011b)

LAFA FLW Percentages, All Levels (Primary, Retail, and Consumer Losses)					
Year	**1997**	**2002**	**2007**	**2012**	**2017**
Barley	39	39	39	39	39
Canola	33	33	33	33	33
Corn Products	29.6	29.6	29.6	29.6	29.6
Sweet Corn	78	78	78	78	78
Legumes	15.4	15.4	15.4	15.4	15.4
Oats	39	39	39	39	39
Peanuts	9.8	9.8	9.8	9.8	9.8
Peas	53	53	53	53	53
Fresh Potatoes	32	32	32	33	33
Rice	41	41	41	41	41
Rye	30	30	30	30	30
Sorghum	30.9	31	31.1	29.9	29.9
Soybeans	15.4	15.4	15.4	15.4	15.4
Sugar Cane	41	41	41	41	41
Sugarbeet	41	41	41	41	41
Fresh Tomatoes	38	38	38	38	38

Notes:

1. Yellow highlighting indicates insufficient ERS LAFA data. Associated values were estimated by interpolation.

2. Orange highlighting indicates that the ERS LAFA data had combined FLW percentages for these crops into a major group encompassing multiple crops. FLW percentages for the major crop group were utilized for these values. Details on these crops and their respective major crop groups are identified below:
    a. Lentil FLW percentages were grouped together with total legumes FLW percentages.
    b. Soybeans FLW percentages were grouped together with total legumes FLW percentages.
    c. Sugarcane and Sugarbeets FLW percentages were combined into a Total Cane and Beet Sugar FLW percentage group.
3. Red highlight indicates missing LAFA data.
    a. ERS LAFA data for total grain loss rates was utilized for sorghum grain.

Food Loss and Waste Commodity Food Share Percentages

For each food crop analyzed we developed a food share percentage. This percentage estimates the share of the total crop produced intended for human consumption. For this report, all values except total corn grown for grain products and soybeans were assumed to be 100%. Corn grown for grain products and soybeans food share percentage were derived from estimates by USDA's ERS US Bioenergy Statistics (ERS, 2017). Annual data for the percentage of produced corn grain diverted for bioethanol production and soybeans diverted for biodiesel production for the analyzed years was collected and incorporated into the processed data as a "percentage to human consumption". Total FLW quantities for each food crop (in tonnes) were refined by incorporating the estimated food share percentage. This adaptation on the FLW quantities was used to obtain the FLW quantity intended for human consumption. Equation 2 below details the calculation used to obtain refined FLW quantities.

Equation 2

*FLWi = Pi*Ri*Fi*

FLWi = Total County Level Food Loss and Waste Tonnage for each crop (tonnes)

Pi = County Level Production Data for each crop (tonnes)

Ri = FLW Percentages for each crop (%)

Fi = Food Share Percentage (%)

The food share percentage analysis considers any crops that remain in the FSC, such as livestock feed, processed food goods, and foods directly consumed by humans. This implies that a percentage of food crops not intended for direct human consumption may be present in the analysis. As indicated above, corn grown for grain and soybean percentages directed for biofuel and biodiesel production were removed from total losses using the described food share percentage analysis. The small percentage of corn for grain still diverted for biodiesel production was not included in the US Bioenergy Statistics database and is noted to be included in the food share percentage. Additional crops such as stover and sorghum-grain that have potential uses in waste-to-energy and biofuel production are noted to be included in the food share percentage analysis as data is limited on the percentages of these crops diverted from human consumption.

Results

Results of the analysis are provided and analyzed in the following section.

Food Loss and Waste - The National Picture

In this paper we identify the total county level FLW rates, quantities, and variations for the analyzed time period. We identify the major contributing crops to the environmental footprint of FLW and such crops FLW growth rates over the analysis period.

Due to the FLW percentage data only being available at a national scale and for the purposes of this article, it was assumed that FLW is evenly distributed among all of the production locations, such that the national overall FLW percentages for each identified crop held constant in each location of the crops production. Evenly distributed FLW percentages implies similar waste rates in all locations, which may not necessarily hold true from region to region. Further shortcomings on FLW percentages are noted in the Discussion section.

Using the methods described Equation 2, Methodology, the total county level FLW tonnages were determined from the county level production data and the LAFA data and are presented below in Table 3.

Table 3: Total FLW Metrics

Total Losses (Tonnes)						
Crop Log Name	**Commodity**	**1997**	**2002**	**2007**	**2012**	**2017**
Barley	Barley	2,932,754	1,823,921	1,758,447	1,826,123	1,372,398
Canola	Canola	95,921	216,485	212,336	356,475	458,856
Sweet corn	Corn (Sweet)	2,946,077	2,633,759	2,642,076	2,534,419	2,853,785
Corn, grain	Corn (Grain)	61,846,480	57,700,672	71,450,189	43,275,736	68,423,750
Lentils	Lentils	16,295	17,107	26,019	40,699	54,825
Oats	Oats	873,185	621,789	506,694	371,612	285,344
Peanuts	Peanuts	151,978	139,472	164,612	296,072	316,275
Peas, green, (excl southern)	Peas	233,287	168,323	217,106	200,762	159,375
Peas, green, southern (cowpeas)		23,849	22,887	26,881	22,048	16,281
Peas, chinese (sugar & snow)		3,561	2,395	2,764	2,817	3,276
Peas, dry, southern (cowpeas)		9,016	8,670	8,943	8,207	10,526
Peas, dry edible		134,242	112,820	410,922	287,452	368,689
Peas, austrian winter		3,962	4,923	3,074	3,913	3,207
	Peas (Total)	407,916	320,019	669,690	525,199	561,355
Potatoes	Potatoes	6,802,517	6,613,059	6,487,964	7,065,200	7,331,419
Rice	Rice	3,419,296	3,912,085	3,692,278	3,723,905	3,278,228
Rye	Rye	46,781	55,271	50,695	50,724	79,413
Sorghum, grain	Sorghum	4,463,914	2,625,987	3,811,265	2,007,631	2,694,211
Soybeans	Soybean	10,728,342	11,280,475	9,167,444	9,506,825	12,779,848
Sugarbeets	Sugarbeet	10,703,558	10,337,538	11,878,955	13,173,390	13,248,669
Sugarcane, sugar	Sugarcane	11,897,156	13,137,041	11,577,709	11,258,683	11,511,703
Tomatoes, in the open	Tomatoes	1,798,987	2,388,388	2,279,130	2,063,619	4,583,147

The dataset depicting each county's FLW tonnages for each identified commodity was larger than we were able to illustrate in this report, thus the FLW tonnage data for each commodity was combined for each county. Combined county level FLW quantities are shown in Table 1. FLW

tonnages for each commodity can be found in the raw and processed data which is included in the appendices.

Food Loss and Waste Quantity Comparisons

Plotting the total county level FLW quantities revealed the overall trend upwards in FLW quantities over the analyzed timescale. The target food crops were separated into two similar-waste quantity graphs in order to clearly depict FLW quantities for each food crop. A logarithmic scale was adopted for both graphs to neatly present all commodities on the graphs. Figure 1 includes barley, sweet corn, corn grown for grain, potatoes, soybeans, sugarbeet, sugarcane, and tomatoes. Figure 2 includes canola, lentils, oats, peanuts, peas, rice, rye, and sorghum grain. FLW quantity data points are presented for each census year on the commodities. Graphs depicting data from Table 3 can be found below in Figure 1 and Figure 2.

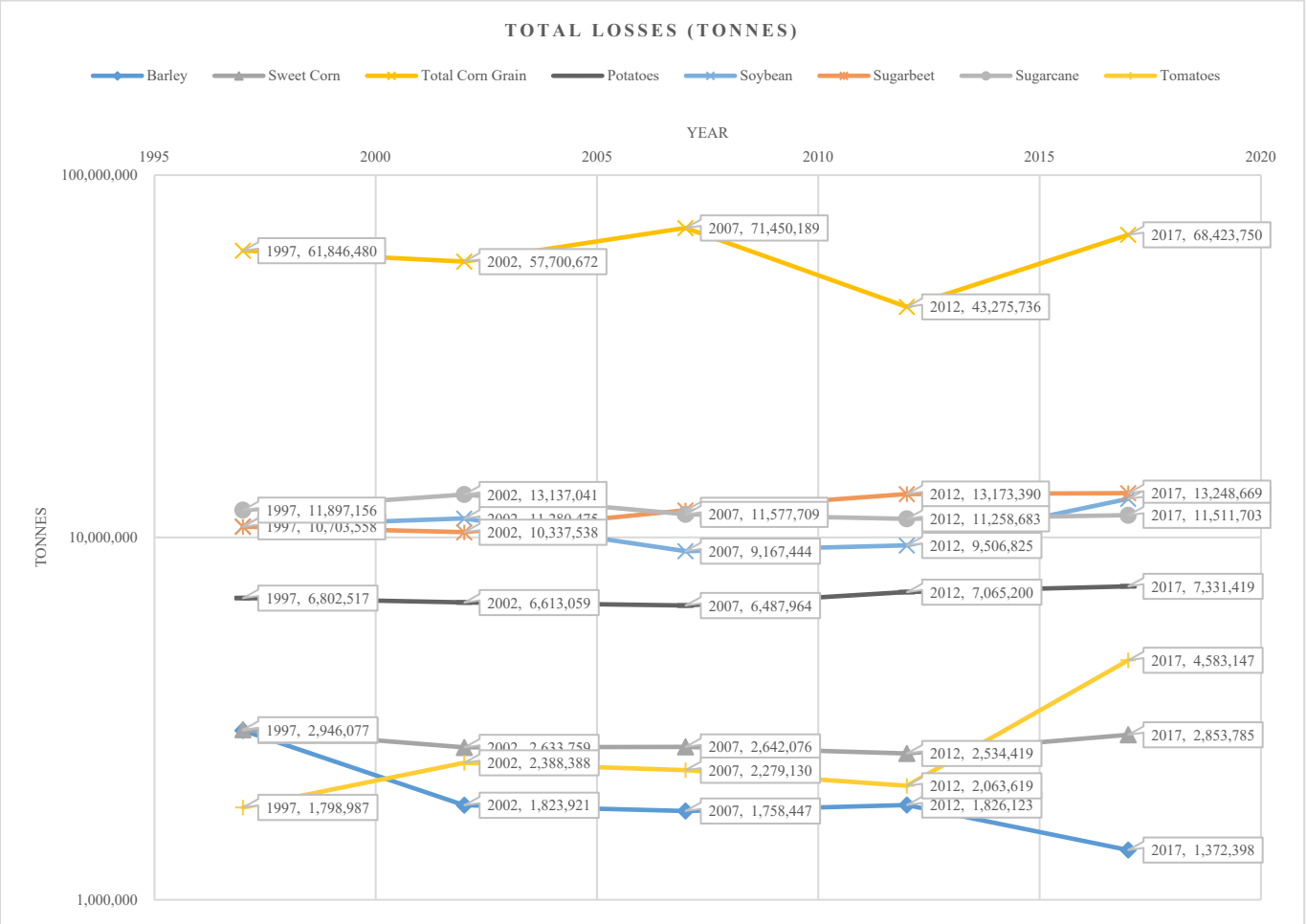

Figure 1: Total FLW Quantities Graph, Part 1/2

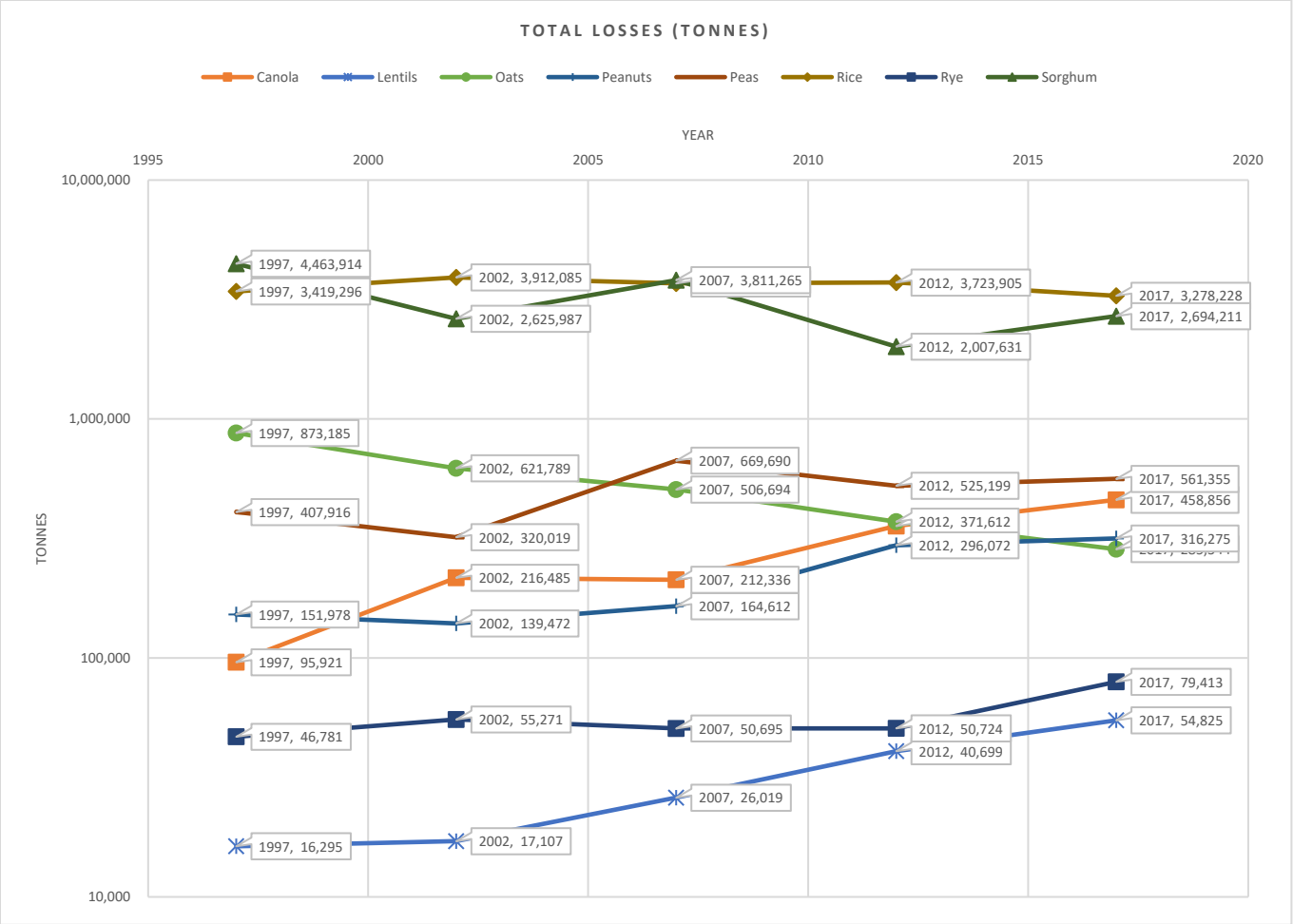

Figure 2: Total FLW Quantities Graph, Part 2/2

Both Figure 1 and Figure 2 illustrate the overall trend of FLW in the upwards direction over the analysis period. This data is particularly useful in targeting the food crops experiencing high quantities of waste or those experiencing increased FLW year-over-year for reduction efforts. These targeted food crops are suitable for a comparative analysis within hotspot regions (counties with high levels of FLW) for determining where FLW reduction efforts should be directed.

Food Loss and Waste Quantity Changes Analysis

A further analysis of the Total FLW quantities for the target crops reveals that although a general trend upwards in FLW quantities exists, only 5 commodities experienced large increases in the levels of total FLW quantities from 1997 through 2017. Canola (55%), lentils (37%), peanuts (24%), peas (17%), and tomatoes (19%). Sweet corn, potatoes, rice, soybeans, and sugarcane

held relatively constant. Oats FLW quantities decreased by approximately 24%, sorghum grain decreased by 13%, and Barley decreased by 16%. The FLW quantity variation analysis was performed by taking the year-to-year FLW quantity changes for each commodity over the analyzed period and determining an average rate for each food crop. The FLW quantity changes described above are detailed in Table 4 below.

Table 4: Average FLW Quantity Changes

Commodity	1997 to 2002	2002 to 2007	2007 to 2012	2012 to 2017	Average
Barley	-38%	-4%	4%	-25%	-16%
Canola	126%	-2%	68%	29%	55%
Corn (Sweet)	-11%	0%	-4%	13%	0%
Corn (Total)	-7%	24%	-39%	58%	9%
Lentils	5%	52%	56%	35%	37%
Oats	-29%	-19%	-27%	-23%	-24%
Peanuts	-8%	18%	80%	7%	24%
Peas	-22%	109%	-22%	0%	17%
Potatoes	-3%	-2%	13%	-4%	1%
Rice	14%	-6%	-11%	14%	3%
Rye	18%	-8%	57%	-36%	8%
Sorghum	-41%	45%	-29%	-25%	-13%
Soybean	5%	-19%	39%	-26%	0%
Sugarbeet	-3%	15%	12%	-1%	6%
Sugarcane	10%	-12%	-1%	-2%	-1%
Tomatoes	33%	-5%	101%	-55%	19%

Table 1 in Methodology illustrates that FLW percentages for the majority of the target food crops held constant over the census years, ruling out FLW rates as a culprit for significant variations in loss quantities over time. Large fluctuations in FLW quantity variation rates, such as those seen in canola from 1997 to 2002, peas from 2002 to 2007, and tomatoes from 2007 to 2012 may represent impacts brought on by severe weather events, changes in harvested area, overproduction/underproduction (changes in yields), unstable market conditions, or processing problems. The potential also exists for specific crop areas shifting between irrigated and non-irrigated between census data years. Additionally, these fluctuations may be the result of poor census data during a specific year. Future research is required to determine the causation of these large fluctuations in loss rates. Further limitations of the data are discussed in Section 5: Discussion.

Discussion

To our knowledge, there are no existing studies which have determined the US FLW temporal quantities and variations at the county level. We aimed to fill this knowledge gap by estimating FLW tonnage for 16 target food crops utilizing county level census crop production data from USDA's National Agricultural Statistics Service Quick Stats (USDA NASS, 2017). Loss adjusted food availability (LAFA) data from the US Department of Agriculture's Economic Research Service (ERS, 2011b) was utilized for national FLW percentages. Percentages of food crops diverted from human consumption for purposes such as bioethanol and biodiesel production were derived from USDA's ERS US Bioenergy Statistics (ERS, 2017). It is our goal to utilize this data to identify hotspot counties with high levels of waste as targets for FLW reduction.

Research Shortcoming and Limitations

Several shortcomings identified in this research include the FLW percentages in the LAFA data, food crop import and export data, harvested area data for non-census years (county level survey data), food share percentages for crops other than those identified by this study (corn grain and soybeans), and the limited target crops analyzed.

Due to the FLW percentages data only being estimated at a national scale, it was assumed that LAFA loss rates were evenly distributed among all of the production locations. Evenly distributed FLW percentages implies similar waste rates in all locations, which may not necessarily hold true from region to region. This limitation, to our knowledge, has not yet been identified nor bridged by existing literature.

Food crop import and export data was not considered in the primary data collection stage for this study. Estimating county level FLW quantities without the consideration of food crop imports and exports may over or underrepresent the true extents of losses in each county.

Harvested area data for non-census years existed in the form of survey data, however, the available county level survey data for the analyzed crops lacked comprehensive coverage.

County level survey data coverage contained significant cavities in data between census years. Adding to these gaps in coverage, the accuracy of survey data which existed for the utilized census years collapsed. County level crop survey data for these census years, dependent on each crop, was inconsistent with its respective year's census data with an error range upwards of 40%. Additionally, national production data for census years prior to 1997 was not available or may not exist.

Food share percentages for corn grown for grain and soybeans were determined from USDA's ERS US Bioenergy Statistics (ERS, 2017). These percentages removed the share of each crop diverted for the non-human consumption purposes of bioethanol and biodiesel production, however, overall the food share percentage analysis considered any portion of the crops that remain in the FSC, such as livestock feed, processed food goods, and foods directly consumed by humans. Food share percentage data for the remaining crops (other than corn grown for grain and soybeans) was assumed to be 100% and thus may include portions that remain in the FSC not directly intended for human consumption.

Limitations in availability of crop data are apparent based on the number of target crops analyzed as part of this study. LAFA data is available for more than 200 agricultural commodities from 1970 through 2017, however, sparse production and harvested area data for these commodities resulted in a largely reduced analysis.

Future Research

This article aims to lay the groundwork for future studies in which the total water footprint and in time the overall environmental footprint of FLW can be determined. Additionally, we will utilize the results to identify high FLW counties (hotspots) which should be targeted for FLW reduction measures. To do so, limitations within the current literature and this study must be addressed. Additional literature is needed to identify food crop import and export data, harvested area data for non-census years (county level survey data), food share percentages for crops other than those identified by this study (corn grain and soybeans), and a significant expansion to the limited target crops analyzed by this study. Additional limitations in the data necessitating future research presented themselves while determining FLW quantity changes. Undetermined

fluctuations in the loss rates with various potential causations require a future evaluation in order to pinpoint the source, whether that be brought on by severe weather events, changes in harvested area, overproduction/underproduction (changes in yields), unstable market conditions, or processing problems. In order to determine the overall environmental footprint of FLW at a county level, future research is needed on the limitations and shortcomings detailed above.

Conclusion

In this paper, we estimated temporal FLW rates, quantities, and variations at the county level in the United States' crop production regions during census years from 1997 through 2017. Our results indicated that although FLW percentages at primary, retail, and consumer levels remained constant for the majority of crops from 1997 through 2017, total losses on average increased. The research suggests that targeting loss reduction in the high loss rate food crops, particularly soybean, sugarbeets, sugarcane, and total corn products grown for grain, would have the highest impact in biomass FLW reduction.

Global crop production is imparting pressure on local energy, land, and water resources in many places. The related environmental impacts of food commodities traded along the FSC should be considered and dealt with accordingly. It has become clear that due to increasing demand, water scarcity is becoming an increasing threat to the sustainable development of human society. Global land and water resources stress is increasing as a result of population growth. Losses at every stage of the FSC influence the magnitude of commodity losses. This study in addition to future extensions have implications for revealing potentially unsustainable conditions in irrigated agriculture and the FSC worldwide.

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Appendix A - County Level FLW Data Spreadsheet

This Spreadsheet was utilized to process raw harvested area and yield data and estimate FLW quantities and variations over each census year.

Glossary of Terms

ERS = Economic Research Service

FLW = Food Loss and Waste

FSC = Food Supply Chain

LAFA = Loss Adjusted Food Availability

USDA = United States Department of Agriculture