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Field measurement in vegetable crops indicates need for reevaluation of on-farm food loss estimates in North America

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ABSTRACT

Food loss and waste in the US has been estimated at 40%, a figure that does not include losses at the agricultural level. Consumer food waste is expensive and environmentally damaging as it travels the length of the supply chain and largely ends up in the landfill. Most research and campaigns emphasize the consumer level, which has resulted in the omission of data collection and development of solutions for producers of fruit and vegetable crops. The available estimates of edible produce lost in the field are based on assumptions and estimates, rather than field data. Therefore, this project aimed to measure losses in the field in order to understand if estimates are accurate. Sixty-eight fields of eight vegetable crops were evaluated on nine North Carolina farms during the 2017 production season, using a sampling and scaling method. Combining the unharvested crops of marketable quality and edible but not marketable quality (produce that does not meet appearance quality standards), the average produce volume available after the primary harvest was 5114.59 kg per hectare. Totaling an average of 42% of the marketed yield for these crops, these high figures indicate the need for a reevaluation of the food loss estimates at the agricultural level in the US, and a focus on solutions.

1. Introduction

The portion of the American food supply that is never eaten by consumers has been estimated at 40%, prompting national focus on the issue (Gunders, 2012; Gunders et al., 2017; Hall et al., 2009). This estimate subtracts the food consumed in the US from the total supply of food (Hall et al., 2009), and therefore would be larger if it included food that never reaches distribution: food lost at the stage of agricultural production. Globally, it is estimated that a reduction in food loss and waste of 50% in developed countries could lead to a reduction in the developing world's undernourished population by 63.3 million people (Munesue et al., 2015). The U.S. has now adopted this target, aiming to halve food waste by 2030, without specifically including losses at the farm level (USDA, 2015). Reducing food loss and waste could have far reaching impacts on the triple bottom line of environment, economy, and society in the U.S., and to that end, many solutions have been detailed (ReFED, 2016).

Food loss and waste results in a loss of resources including water, land, fuel, fertilizer, and agricultural chemicals that are either inefficiently used in agricultural production, or required during food processing and disposal (Hall et al., 2009; Kummu et al., 2012). An estimated 21% of water, 19% of fertilizer, and 18% of cropland is devoted to producing food that is not consumed in the U.S. (ReFED, 2016). “Food loss” is considered to be unintended and usually results from limitations in agricultural production such as market conditions or weather impacts on produce quality, while “food waste” is considered to be edible food that is unused as a result of a decision or negligence, and occurs in the distribution, restaurant, retail, and consumer levels of the supply chain (Lipinski et al., 2016).

Food loss and waste has been reported as an economic loss for the US, totaling $218 billion in 2016 when farm level estimates are included (ReFED, 2016), and a loss of over $165 billion in 2008 without including a farm-level estimate (Buzby and Hyman, 2012). In other sectors of the supply chain, an average benefit-cost ratio for investing in food waste reduction was determined to be 14:1, a significant financial incentive for businesses specializing in food manufacturing, retail, hospitality, and food service (Hanson and Mitchell, 2017). Detailing this ratio for agricultural producers first requires accurate assessments of losses. Twenty years ago, data on food loss in the U.S. was recognized as insufficient, and further investigation was suggested (Kantor et al.,

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1997). This idea continues to be echoed by government agencies: the Environmental Protection Agency (EPA), Natural Resources Defense Council (NRDC), National Science Foundation (NSF), and the United States Department of Agriculture (USDA) have all called for increased focus on the issue (Gunders, 2012; Gunders et al., 2017; NSF, 2014; USDA, 2015; EPA, 2015). Studies that estimate fruit and vegetable crops lost at the production level in the US through field sampling are significantly absent from Schnieder's (2013) thorough review of food waste research and Van der Werf and Gilliland's (2017) review because they are almost non-existent. Both reviews list studies that provide data on losses in agricultural production, but these use a calculation approach to determine estimates that are based on assumed or approximated percentages of loss not directly related to actual field estimates.

The most reliable estimate of agricultural losses of fruit and vegetable crops for North America has been provided by the Food and Agriculture Organization of the United Nations (FAO), suggesting 20% of the marketed yield of these crops remain unharvested in the field, or are sorted out during packing (Gustavsson et al., 2011), leading to the assumption that 10% of the marketed crop is left unharvested in the field, and 10% is lost during packing. This estimate carries forward figures based on approximations for pathogen-based losses from the 1960's (Cappellini and Ceponis, 1984; Golumbic, 1964; Harvey, 1978; Kader, 2005; LeClerg, 1964; Parfitt et al., 2010).

The need for more accurate estimates is necessary in order to determine the true environmental, economic, and societal costs of food loss and waste. However, as consumer-level food waste is assumed to represent the highest value contributor to food loss and waste in the supply chain, and because it may be easier to quantify than agricultural losses, emphasis has remained on consumer-related waste (Griffin et al., 2009; Gustavsson et al., 2011). Focusing on consumer-level waste has driven the development of interventions such as toolkits to reduce waste, software for tracking and utility, economic analysis, and a national consumer campaign. The US EPA has produced several guides to measure and reduce food waste at the distribution, retail, restaurant, and foodservice sections of the supply chain, in addition to a guide for schools and an overview for any food business (EPA, 2014, 2017, 2018). Other groups, such as the Food Waste Reduction Alliance have also created detailed guides for reducing losses and waste (FWRA, 2015; ReFED, 2018). The same types of tools could be utilized to reduce loss in agricultural production.

The omission of the farm level loss discussion in the US is further evidenced by reports and datasets that provide information on food loss and waste, yet are unable to report farm level loss due to a lack of data (Buzby and Hyman, 2012; Gunders, 2012; Hodges et al., 2011; Kantor et al., 1997). The US Department of Agriculture's Economic Research Service collects the most comprehensive data available on the US food supply, and their "Loss-Adjusted Food Availability" dataset omits available supply on the farm (Buzby et al., 2014). The USDA's National Agricultural Statistics Service comes closer to reporting on farm supply that is unutilized, reporting grower survey data on planted area that was not harvested in each year's vegetables annual summary (USDA-NASS, 2017). However, this data leaves out fields that have been harvested once or several times, but are still producing a viable crop that is subsequently destroyed.

Fruit and vegetable crops are lost at higher estimated rates than other food groups globally due to their perishable nature, and in developed countries are lost at the agricultural level at higher estimated rates than during postharvest, processing, distribution, and consumption (Gustavsson et al., 2011). At the agricultural level, produce is lost when it is left unharvested in the field, or sorted out during washing and packing. Some of this loss is due to damaged, diseased, or overmature produce. A portion of the food lost is edible, as many variables need to coalesce in order to bring product to market, including price, buyer availability, and quality. Produce recovery from farms can be straightforward, however, as it requires no change to the harvesting, marketing and handling systems in place, and uses current labor structures. Additionally, fresh produce has the potential to be a more recoverable food group than meat, dairy, and grains, as it requires little or no processing before distribution (Garrone et al., 2014). A recent report from a collaborative focused on reducing food loss and waste has provided a volume estimate, suggesting that 9.2 billion kg of produce remains on the farm in the U.S., basing this figure on interview estimates from small farms and national data on planted acreage that was not harvested (ReFED, 2016; Berkenkamp and Nennich, 2015; USDA-NASS, 2017).

Field measurement of unharvested crops has been used as a strategy to estimate losses in a few studies in Europe, and a replicable sampling method adaptable to a wide variety of crops has now been described for US production (Johnson, 2018; Johnson et al., 2018). As underreporting is a common problem when using grower estimates (Franke et al., 2016; WRAP, 2017), field sampling provides systematic evidence of the quantity and quality of crops left unharvested in the field, and is considered vital when losses are not known (Franke et al., 2016). In US studies, grower estimates and not field sampling have been used to determine losses in the field. Berkenkamp and Nennich (2015) reported that most cabbage growers and nearly half of summer squash growers surveyed estimated the rate of cosmetic imperfection found in these crops was between one and 10%. Snow and Dean (2016) reported that small, diversified farms in Vermont leave just 5% of edible vegetables unharvested in the field. Estimated head lettuce left in the field according to grower interviews on large commercial farms in California was reported as 4–10% (Milepost, 2012).

This project aimed to determine if the current food loss estimates available would change if they were supported by data, using field sampling to quantify edible vegetable crops at the production level in the US. The focus of this study is on medium to large-scale production in the southeastern region. The first step in understanding the true cost of food loss at the farm level in the U.S. hinges on accurate estimation of the volumes of losses.

2. Materials and methods

This section provides a condensed version of the method used by the author to harvest and evaluate field samples of eight different crops, which were then used to estimate the produce remaining per acre in the field after the grower determined their harvest was complete (Johnson, 2018; Johnson et al., 2018). The reporting includes several elements in order to be in compliance with the Food Loss and Waste Accounting and Reporting Standard (Lipinski et al., 2016), which are described here. The material collected was food and its associated inedible parts, such as watermelon rind, or cabbage and pepper stems and cores. The produce was destined to be sold unprocessed and intended for the fresh market, conforming to the definition of the fresh vegetable category [GSFA 04.2.1.2] (FAO-WHO, 2016). "Growing of vegetables and melons, roots and tubers" represents the correct International Standard Industrial Classification of All Economic Activities Rev. 4 code 0113 that corresponds to the life cycle stage of the produce (UNSTATS, 2017). Samples were harvested and evaluated entirely in North Carolina, USA, in 2017. Losses reported here were left unharvested by the producer and after measurement, were either incorporated into the soil or destroyed in order to plant another crop, as the final disposition intended by the grower. Measurements did not include water or packaging, and pre-harvest losses such as losses of plants due to insect or disease damage were not considered.

A total of 68 fields of eight vegetable crops were evaluated on nine commercial farms in eastern North Carolina, an important production region in the state. Farm identification began two years prior, through the use of a survey instrument which opened discussion on the topic of farm surplus with vegetable growers at commodity meetings. Growers interested in further discussion were invited to participate in an on-farm interview, and about half of the growers interviewed provided access to fields during the growing season for field measurement.

Operations that marketed primarily fresh, and into wholesale channels were targeted, a parameter which aimed to limit the study to management trends of mid-size or large operations. Many of these farms produced more than one crop, and the number of fields and farms assessed for each crop was variable. However, the sampling and calculation method for estimation was the same for each crop. The fresh market crops were sweet potato (*Ipomoea batatas*), watermelon (*Citrullus lanatus*), cabbage (*Brassica oleracea*), summer and winter squash (*Cucurbita spp*), cucumber (*Cucumis sativus*), bell pepper (*Capsicum annuum*), and sweet corn (*Zea mays* L.).

Three rows of 15.24 m length were identified at random, a method described by Johnson (2018). Rows were marked, and separately harvested, collecting any remaining crop, whether damaged or whole. In larger fields, more than three rows were evaluated in order to sample at least 0.1% of the field area. Surviving plants in each marked row were counted in order to adjust the growers' provided plant density to the figure more representative of the field conditions.

The sample collected was sorted into categories of marketable, edible but not marketable, and unfit for human consumption, using USDA quality indicators and equipment for produce inspection (USDA-AMS, 2016). Produce quality indicators such as size, shape, and maturity were used to evaluate each vegetable to determine whether or not it met the requirements for marketable quality, which was considered U.S. No. 1 grade or higher (such as U.S. Fancy) common to the fresh produce trade. Although the market available to each grower differed, the minimum requirements for quality reported by each grower met the description of U.S. No. 1 for each vegetable crop evaluated. Attention was given during sorting to the difference between quality and condition, in order to comply with USDA Agricultural Marketing Service instructions for inspection (USDA-AMS, 2017). *Quality* refers to unchanging aspects of produce quality such as size, shape, and scarring. Therefore, produce of sound quality and desirable maturity was considered marketable or edible, depending on whether traditional specifications for size and shape were met. *Condition* refers to any blemish or state of a progressive nature that could reduce the shelf-life of the produce. Therefore, produce that displayed bruising, cracking, decay, or other physical damage was considered unfit for consumption.

Weights were recorded in kilograms, using A CAS PB300 Bench Scale (CAS Corporation, East Rutherford, NJ, USA), and each row was evaluated as a separate unit. The mean volume harvested per plant was calculated in each of the three quality categories, and the adjusted plant density was used to scale the sample to one hectare, resulting in a unit of kilograms per hectare. Growers that participated in measurement did not perceive the volume left unharvested in the field, or its value, to be of economic consequence to their operations. The possibility exists that farmers conducted more thorough harvests on the fields for which data collection was to occur. This was not assessed, but assumed highly unlikely due to the intensity of farming during the harvest season taking precedence over research, in addition to farmers' overall attitudes towards field losses.

3. Results and discussion

The 2017 field study provided a snapshot of losses in the field and details that provide insight into potential missed opportunities to reduce field loss in vegetable production. Sixty-eight fields were evaluated. The mean field size for each crop ranged from 1.07 ha to 11.13 ha, and averaged 4.70 ha (Table 1). Crop data was collected immediately after communication with growers that indicated the crop had been abandoned and destruction through herbicide application or disking was imminent. The target sample area was at least 0.1% of the field area, and the mean field size for each crop is presented (Table 1).

This target was reached in all of the crops evaluated except the winter squash (n = 4, 2 farms). All crops were hand harvested except two fields of sweet corn (n = 4) on the same farm, which were mechanically harvested on one date. All of the crops were produced using conventional fertility and pest and disease control methods, with the exception of three cabbage fields, which were produced using organic methods. Taken together, these farms represent approximately 7% of the state's land area devoted to vegetable and sweet potato production. In North Carolina, agriculture represents the state's most valuable industry, at $84 billion, and employs 686,000 people (USDA-NASS and NCDA and CS, 2017).

Table 1
Description of fields sampled for vegetable loss study in North Carolina. Includes the number of fields sampled (n), the number of farms on which the samples were collected, the mean field size (ha), and the portion of the field area that was sampled.

	Fields sampled (n)	Farms sampled	Mean field size (ha)	Portion of field area sampled (%)
Cabbage	7	3	2.51	0.36
Summer squash	12	4	2.82	0.69
Cucumber	9	3	2.54	0.40
Bell pepper	9	3	5.12	0.19
Sweet corn	4	2	1.07	0.78
Winter squash	4	2	11.13	0.06
Watermelon	10	4	8.17	0.19
Sweetpotato	13	4	5.29	0.14

3.1. Field measurement indicates high volumes left unharvested

The volume of crop remaining unharvested per plant was calculated. The mean volume collected per plant for each crop in the Marketable category ranged from 0.011 kg in cabbage, to 2.473 kg in watermelon, with high relative standard deviation across all crops (Table 2). The mean volume of edible produce that was left unharvested per plant also ranged widely and displayed high overall standard deviation suggesting high variability. The harvested volume per plant that was unfit for consumption is also reported.

A comparison of minimum, maximum, and average quantities per hectare in each category can be used to identify potential business opportunities (Table 2). Growers can use data specific to their farm using the same method to determine which of their crops may have the potential for higher utility and possible profit. Marketable volumes found in the cases of bell pepper, sweet corn, watermelon, and sweet potato were determined to be above 2000 kg/ha on average. The volumes remaining in the field that were of edible quality were higher than the marketable volumes overall, suggesting an opportunity exists for further utility, possibly in foodservice, processing, alternative markets, or the emergency food supply. With averages exceeding 3000 kg per hectare, cabbage, cucumber, bell pepper, sweet corn, and watermelon may all be good candidates for exploration of alternative markets that have interest in these crops. In this region, companies that accept a wider range of produce quality are emerging, particularly those that provide a subscription service, and programs in foodservice distribution are accepting blemished and misshapen produce. The dataset is not considered to be normally distributed (Fig. 1), which is common with a small sample size.

Sweet potato is the most important crop in the state, with nearly 40,000 ha in production (USDA-NASS and NCDA and CS, 2017). It is gaining in popularity in European markets and is often exported from North Carolina. The recent disappearance of several local processing facilities that have the capacity to handle surplus may have contributed to an excess of marketable, but small, potatoes in the field. Limited storage capacity on farms also leads to an emphasis on harvesting just the potatoes that meet standards for retail and restaurant use. This long-storing, nutritious crop is often the target of organizations such as the Society of St. Andrew, who gleaned 7.6 million kg of produce from fields and farms in 2016 (SoSA, 2017). Applying the 3167 kg/ha marketable mean representing four farms (n = 13) to the area devoted to the crop statewide (39,659 ha; USDA-NASS and NCDA and CS, 2017)

Table 2
Minimum, maximum, mean volume (kg) and standard deviation as calculated per plant and per hectare in the sample area for each crop within quality categories evaluated in a North Carolina study of vegetable losses in the field. Shapiro-Wilks test indicated datasets with a *p*-value greater than 0.05 are assumed to be normally distributed.

	Marketable					Edible					Unfit				
	Min	Max	Mean	Std dev	p-Value	Min	Max	Mean	Std dev	p-Value	Min	Max	Mean	Std dev	p-Value
kg/plant															
Cabbage	0	0.025	0.011	0.009	0.4460	0.014	0.490	0.142	0.148	0.0111*	0.006	0.342	0.150	0.134	0.1136
Summer squash	0	0.014	0.004	0.005	0.0062*	0.001	0.100	0.046	0.031	0.5474	0.043	1.213	0.271	0.317	0.0007*
Cucumber	0	0.105	0.050	0.031	0.9555	0.035	0.539	0.213	0.127	0.0097*	0.020	1.210	0.229	0.351	0.0002*
Bell pepper	0.056	0.222	0.106	0.049	0.0256*	0.061	0.221	0.114	0.051	0.1576	0.046	0.209	0.085	0.051	0.0066*
Sweet corn	0.001	0.086	0.036	0.032	0.8984	0.018	0.080	0.051	0.027	0.4154	0.030	0.087	0.063	0.023	0.6406
Winter squash	0	0.192	0.079	0.073	0.9029	0.083	0.211	0.148	0.048	0.9999	0.295	1.500	0.773	0.446	0.6866
Watermelon	0	7.087	2.473	2.245	0.3297	0.142	6.921	2.310	1.800	0.0562	2.171	8.047	4.338	1.849	0.3473
Sweetpotato	0.040	0.261	0.110	0.056	0.0555	0.019	0.189	0.066	0.044	0.0125*	0	0.049	0.011	0.012	0.0012*
kg/ha															
Cabbage	0	695	307	272.7	0.2766	328	9547	3407	3011.3	0.1250	192	7624	3694	3426	0.0686
Summer squash	0	332	89	113.5	0.0110*	18	1367	871	554.4	0.7429	1096	10,598	6095	9499	0.0000*
Cucumber	0	3180	1887	1100.7	0.3990	4697	16,320	8125	4514.3	0.9474	561	37,840	7997	11,416	0.0003*
Bell pepper	1495	6022	3212	1497.4	0.0436*	2239	5995	3394	1369.5	0.0377*	1430	5336	2464	1255.8	0.0129*
Sweet corn	77	4956	2089	2114.2	0.9127	1061	4659	3065	1865.7	0.2219	1877	5017	3720	1511.7	0.4841
Winter squash	0	3973	1427	1813.1	0.4156	682	3357	2198	1126.7	0.9767	3688	30,944	12,722	12,644	0.2206
Watermelon	0	37,361	12,425	12,785	0.1307	650	39,467	11,572	10,936	0.0139*	9653	36,794	20,494	8885.4	0.6018
Sweetpotato	1347	8413	3577	1853.6	0.0480*	620	6419	2153	1548.1	0.0084*	0	1652	365	437.4	0.0010*

* p-Value less than 0.05 indicates the dataset is assumed to be not normally distributed, according to Shapiro-Wilks test.

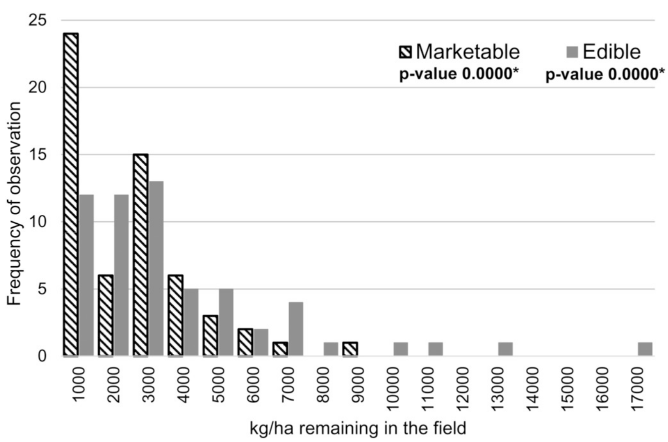

Fig. 1. Histogram showing marketable and edible vegetable crop volumes left unharvested in the field during a North Carolina study. Shapiro-Wilks test indicated datasets with a *p*-value less than 0.05 are assumed to be not normally distributed.

suggests over 125 million kg of marketable sweet potatoes may be available in the field after the primary harvest has been completed.

Combining the marketable and edible volumes available in the field provides insight into the opportunity for further utility through alternative channels, which is a loss-reduction strategy that has been suggested (Gunders et al., 2017; ReFED, 2016). Also, produce recovery has been recommended as a solution that reduces losses at the agricultural level (Gunders, 2012; Gunders et al., 2017; EPA, 2015; Neff et al., 2015; ReFED, 2016). The grand mean of produce remaining in the field that was either edible or marketable (excluding watermelon) was 5114.59 kg/ha.

A recent estimate suggests over 9 billion kg of fruit and vegetables are lost from packinghouses and left unharvested in fields, a figure derived from the combination of grower estimates from small farms and data on unharvested acreage (Berkenkamp and Nennich, 2015; ReFED, 2016; USDA-NASS, 2017). Applying the grand mean from this study to U.S. vegetable planted acreage in 2016 (1,145,260 ha; USDA-ERS, 2017), again excluding melons, suggests nearly 5.9 billion kg of vegetables are left in fields in the U.S. This calculation does not include fruit, nor losses from the packinghouse level. With the addition of field-derived data like this, estimates can be strengthened through the reduction of underreporting and minimization of assumptions. However, this approach also suggests more data is needed, and that the incorporation of field data may raise estimates of produce lost on-farm.

An important reason growers cite as leading to unharvested crops is that the market price offered does not support subsequent harvests after the highest quality has been collected (Gunders, 2012; Gunders et al., 2017). The harvest cost can total 60–75% of production costs (Berkenkamp and Nennich, 2015), so each harvest event raises costs dramatically, without a guaranteed return.

The available volumes remaining in the field present an opportunity to impact society through making more produce available to the emergency food supply, but may not result in profit to growers as the supply chain market system in the U.S. is based on demand. Policy such as providing more resources to food recovery organizations has been suggested in order to improve public health in the U.S. (Neff et al., 2015). Dietary change that moves the population closer to a plant-based diet could mean more land availability to support the food supply, while utilizing more vegetable crops (Chartres and Noble, 2015). Krebs-Smith et al. (2010) suggested that the vegetable supply needed to increase by 70% to meet the dietary needs of the U.S. population based on current FDA recommendations. While farm losses were not included in a recent investigation of the nutrients lost as food is wasted, the results suggest 5.9 g of fiber per capita per day (2.0 g fiber from a vegetable source) are lost in the waste stream, equivalent to 19% of the recommended daily allowance for adults (Spiker et al., 2017). The consumer waste stream, now estimated at 422 g per capita per day, contains 39% fruit and vegetables, a rate higher than all other food groups (Conrad et al., 2018). An Oregon Food Bank study revealed that approximately 16% of the distributed foods were vegetables, closely matching the combination of the discretionary and condiment categories (15%), which suggests need for improvement in nutritional quality of emergency foods (Hoisington et al., 2011). However, 94% of food banks have a commitment to nutrition, and the food banks with related policies, identify fresh fruit and vegetables as a desirable target for procurement at a rate of 60% (Campbell et al., 2013). An increase of vegetables in the U.S. food supply could have a variety of positive impacts on public health and food security, but an increase in demand may be necessary for current agricultural practices to change.

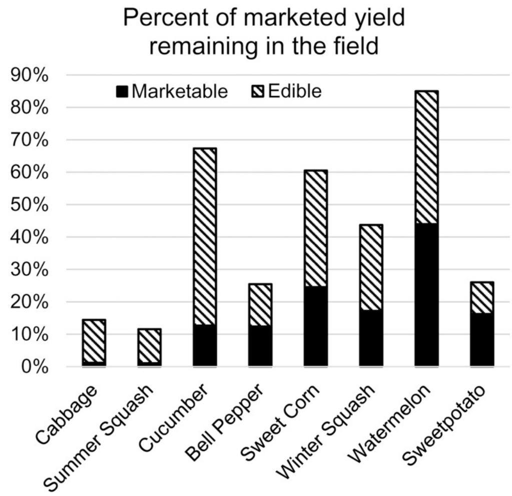

Fig. 2. The portion of the 3-year average North Carolina marketed yield that remains in the field for eight vegetable crops. Percentages included are marketable produce that meets traditional buyer specifications for quality, and produce that is edible but may not meet specifications.

3.2. Field losses in comparison with marketed yields higher than previously approximated

The volumes of produce lost in the field were compared with the most recent three-year average marketed yields available for each crop in North Carolina (USDA-NASS and NCDA and CS, 2016; 2017). Growers often make the decision to stop harvesting fields based on their perception of reduced marketable quality available in the field, which was confirmed by the relatively low average rates of marketable quality left in the field (black bars; Fig. 2).

In the current study, the overall average of the marketable crops left unharvested totaled 16% of the marketed yield, which aligns with current national estimates, revealing the possibility that growers consider only the marketable crops left behind as a loss when providing estimates. Marketable cabbage and summer squash left unharvested totaled just 1% of the marketed yield, which could serve to confirm very low estimates provided by growers in U.S. interview studies, depending, again, on what growers consider edible produce in their reported figures. The only studies to date that have investigated unharvested crops in the field in the U.S. and report related figures are based on interviews and surveys with growers, which may be influenced by negative perceptions surrounding food loss and waste (Berkenkamp and Nennich, 2015; Snow and Dean, 2016; Milepost, 2012). The studies providing the most detail on crop-specific losses are focused on diverse, small farms under 10 ha, many of which use alternative growing practices (Berkenkamp and Nennich, 2015; Snow and Dean, 2016).

When edible produce of correct maturity and condition conducive to long shelf-life are included, a more accurate picture of the produce that could be recovered and utilized available in the field is presented which increases the rate of losses in all crops (Fig. 2). Results indicate that the overall average rate of produce crops evaluated remaining in the field that could be utilized (including the marketable and edible quantities) was 42% of the three-year average marketed yield in North Carolina. The estimate derived from this study is much higher than national estimates, suggesting more field-based measurement is needed in order to generate more reliable estimates, an idea that has been promoted by FAO itself for decades (Parfitt et al., 2010), suggested during the renewal of interest in food loss and waste (Gunders et al., 2017; ReFED, 2016; Kader, 2005), and requested in proposed U.S. policy (HR 4184, 2015).

In the absence of U.S. field-derived estimates of losses, comparisons with other developed countries can be made. In European countries, field measurement has resulted in carrot, onion (Franke et al., 2016), and lettuce (Strid et al., 2014; WRAP, 2017) estimates, which determined that 26% of the marketed carrot crop, 15% of the marketed onion crop, and 16.8% to 19% of the marketed lettuce crop was left unharvested in the field in primary production. In Australia, field measurement of tomatoes indicated 28.7% of the marketed yield was left unharvested in the field (McKenzie et al., 2017). The Australian study indicated that this figure included field-graded tomatoes that had been discarded on the ground by pickers or dumped from harvest-aides, which this study would have considered unfit for human consumption due to food safety concerns. The Swedish and English studies on carrot, onion, and lettuce indicated that edible volumes were included in their estimates, rather than marketable volumes only, which was consistent with this study.

A concern with emphasis on interview estimates from growers is that only the marketable portion may be considered, and comparison between interview estimates and field measurement in the UK revealed that growers' estimates can be unreliable (WRAP, 2017). Differences in crop types studied, production regions, and sampling methods used could lead to differences among the studies, which is true in this case as well. Additionally, differences in what has been included in reported figures can confound comparison, so clear boundaries need to be specified in reporting (Beausang et al., 2017). However, consistent among the field-based studies in developed countries is the belief that field sampling is necessary to corroborate qualitative data based on growers' perceptions of losses in the field (Franke et al., 2016; McKenzie et al., 2017; Strid et al., 2014; WRAP, 2017). The primary benefit of field measurement is that it provides assumption-free, sample-derived estimates of the amount of edible produce lost, rather than a broad rate of loss that does not distinguish what is included. Because estimates of food loss and waste at the national level can vary widely based on data sources and assumptions, systematic research is necessary to determine baselines for reduction (Bräutigam et al., 2014).

4. Conclusion

This paper represents the first exploration of using field measurement to determine losses of a wide range of vegetable crops grown at the commercial scale in the US. A straightforward, replicable method was used to collect field data (Johnson, 2018; Johnson et al., 2018), leading to more accurate, field-based estimates. Excluding melons, the grand mean of produce left unharvested in the field after the primary harvest was completed was 5114.59 kg/ha. The average rate of losses when compared to North Carolina marketed yields was 42%. These figures are offered to supplement the current estimates (20%; Gustavsson et al., 2011), and highlight the need for further research in this area, as they are much higher than the assumption and interview-based estimates currently used to calculate economic, environmental, and social costs of food loss and waste in the U.S.

The emphasis on the consumer level of food waste in the discussion of food loss and waste is driven by the great economic losses generated by food that has traveled through the supply chain. Farm-level losses aren't as visible and have less economic value than consumer food waste. However, the value to society that could come from recovering these nutrient-dense crops is potentially high, and could positively impact public health and the emergency food supply in the U.S., as well as the environment, as the energy required for production is redirected through more efficient utility (Beddington et al., 2012). As food insecurity affected 15.6 million households in the U.S. in 2016, redirecting food loss and waste into the emergency food system could positively impact this population (Coleman-Jensen et al., 2017; EPA, 2015). Utilizing more produce while reducing agricultural inputs such as land, water, and chemicals falls under the definition of sustainable intensification (Godfray, 2015), a concept that has been embraced by the federal government (NRC, 2010), but which lacks directives to implementation (Pretty and Bharucha, 2014). The results from this study contribute missing information to the discussion on food loss and waste reduction at the agricultural level. Further data collection using comparable methods in vegetable production regions around the country will continue to strengthen U.S. estimates, leading to a greater understanding of the most cost effective solutions to reduce losses.

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