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1Can On-Farm Food Loss Prevent Waste? Insights from California

2Produce Growers

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6Abstract

7 Significant quantities of edible produce are lost at the farm level.

8Amidst growing concern about the environmental impacts of food loss and

9waste, policymakers and advocates have invested in exploring farm-level

10interventions that might reduce the environmental footprint of food. Farmers

11are obvious stakeholders in such efforts, yet their voices are often missing

12from the discussion. Drawing on interviews with 25 growers in California, we

13show how on-farm losses are driven by efforts to mitigate economic risk

14within food supply chains. Buyers minimize risk by demanding consistent

15volumes of perfect produce to offer to consumers, and growers in turn

16minimize their financial risks by holding back “imperfect” and surplus food. If

17food is likely to be rejected further down the supply chain, growers abandon

18it on the farm. Using the EPA food recovery hierarchy and the tools of life

19cycle analysis (LCA), we then compare the environmental impact of farm-

20level loss to downstream alternatives. While landfill disposal is common at

21the retail and consumer levels, food lost at the farm level is tilled back into

22the soil or sold as animal feed. We conclude that some on-farm losses may

23prevent more environmentally harmful “waste,” defined here as landfilled

24food, further down the supply chain. Our analysis argues for a cautious
25approach to remedying on-farm food loss—one that recognizes its structural
26causes and considers the comparative environmental impact of loss and
27waste at different stages of the supply chain.

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31 **1. Introduction**

32 As the topic of food loss and waste (FLW) has garnered increasing
33attention in policymaking and advocacy circles, interest has turned to farms
34as sites of food loss and potential locations for targeting solutions.
35Particularly in the arena of fresh produce, studies suggest that significant
36quantities of edible crop are abandoned at the farm level (Alexander et al.,
372017; Johnson et al., 2018; Neff, Dean, Spiker, & Snow, 2018). In light of this
38information, civil society groups, foundations, government agencies, and
39other actors have invested in exploring the role of farms in reducing FLW.
40Among other objectives, a key goal of such efforts is to reduce the
41environmental footprint of food.

42 While farmers are obvious stakeholders in solutions involving farms,
43we know little about their experiences and perspectives related to food loss
44and waste. Numerous quantitative studies have investigated on-farm losses.
45Yet we are aware of only one peer-reviewed qualitative study documenting
46grower views in Scotland (Beausang, Hall, & Toma, 2017) and two other

47reports on farmer views within the United States (Berkencamp & Nennich,
482015; Milepost Consulting, 2012). These works emphasize farmers' unique
49understanding of the complex factors driving loss and their important roles in
50crafting effective solutions, highlighting the need for further investigation.
51Our research helps to fill the existing gap in the literature by sharing the
52perspectives of fresh produce growers in California, drawing primarily on 25
53semi-structured interviews with growers of leafy greens, tomatoes, and
54peaches.

55 Based on insights from these farmers, we contribute to policy
56conversations by thinking holistically about the drivers of on-farm losses and
57the role that such losses play in the overall environmental impact of FLW. We
58use the term “waste” here to specifically refer to food sent to landfills
59(Bellemare, Çakir, Hikaru, Novak, & Rudi, 2017), as distinct from the broader
60category of “loss.” This definition distinguishes the highest cost pathway of
61landfill disposal (which includes such costs as tipping fees, reduced landfill
62capacity, and emissions of greenhouse gases, GHGs) from other pathways
63that recover at least some value from food that is not consumed by humans
64(e.g. animal feed, anaerobic digestion, composting, and land application).
65Given finite resources, advocates and policymakers must determine which
66FLW interventions will be most efficient and where along the food supply
67chain (FSC) to invest the greatest energy. Thus, we ask: How do practices at
68the farm level impact the production of waste? To what degree would

69reducing on-farm food loss mitigate problematic environmental impacts?

70What kinds of changes could or should occur at the farm level?

71 To address these questions, we begin by reviewing the current interest
72in on-farm losses, noting the need for greater farmer input in the discussion
73and explaining the methods we used to capture their views. The second two
74sections of the article discuss key findings from interviews. First, we explain
75on-farm losses from a political economy perspective, contextualizing farm-
76level decisions to abandon edible produce within an agricultural system in
77which economic risk has shifted toward producers. We then reference the
78Environmental Protection Agency (EPA) food waste hierarchy and the tools of
79life cycle analysis (LCA) to evaluate the comparative environmental impact
80of different loss and waste scenarios in light of what is actually done with
81food left on farms. The concluding section considers implications for both
82research and practice, proposing new areas of investigation.

83 **2. Farms and Food Waste: Inserting Growers' Views into the** 84 **Conversation**

85 In the U.S. and other developed countries, most of the attention on
86food loss and waste has focused on the processing, retail, and consumer
87levels rather than on the farm (Alexander et al., 2017; Buzby, Wells, &
88Hyman, 2014; Dou et al., 2016; van der Werf & Gilliland, 2017; Xue et al.,
892017). Yet numerous studies indicate that significant quantities of food are
90discarded or diverted at the farm level, particularly in the arena of fresh
91produce (WRAP, 2011; Gunders, 2012; Brautigam et al., 2014; Berkenkamp

92& Nennich, 2016; Alexander et al. 2017; WRAP, 2017). The United Nations
93Food and Agriculture Organization (FAO) estimates 20% loss in fruits and
94vegetables in North America at the agricultural level (Gustavsson et al.,
952011, p. 7). A study based on grower reports in four Nordic countries
96suggests similar levels of loss, with 10% to 26% of fruits and vegetables
97originally intended for human consumption diverted from the food supply
98chain (Hartikainen, Mogensen, Svanes, & Franke, 2018, p. 508). Based on in-
99field measurements on North Carolina farms, Lisa Johnson found significantly
100higher levels of edible food left in the field, averaging approximately 40%
101loss across eight different fresh vegetables and fruits (Johnson et al., 2018).
102Beyond such statistics, images of seemingly perfect produce abandoned in
103fields or dumped into disposal bins make a compelling case for intervention.

104 In response, foundations, non-profit organizations, government
105agencies, and others are investing in research and projects that explore on-
106farm food loss prevention and recovery options (Berkenkamp & Nennich,
1072016; Harwood and Baker, 2015). For example, the United States
108Department of Agriculture (USDA) recently funded a project to synthesize
109research on quantities and drivers of on-farm losses across various crops.
110Our own qualitative work and associated quantitative field-based studies in
111Florida, California, Vermont, Idaho, and New Jersey is part of a \$1.3 million
112funded by the Foundation for Food and Agriculture Research (FFAR) and the
113Walmart Foundation, with the goal of investigating on-farm loss and recovery
114potential. A key goal driving this agenda is reducing the environmental

115footprint of agriculture—improved food recovery promises more efficient use
116of land and resources to feed a growing population, as well as reductions in
117organic waste disposal linked to GHG emissions.

118 In tackling this issue, applying consistent terminology remains a
119challenge. Researchers, advocacy groups, government agencies, and
120international bodies have adopted significantly different definitions of “food
121loss” and “food waste.” For example, the FUSIONS consortium provides a
122comprehensive definitional framework for waste, understood as all food and
123inedible parts removed from the supply chain (FUSIONS, n.d.). The FAO links
124loss and waste to different points in the supply chain; “loss” is taken to mean
125decrease in edible food mass at the production, postharvest and processing
126stages, while “waste” occurs at the end of the chain as a result of retailer
127and consumer behavior (Gustavsson, Cederberg, Sonesson, Otterdijk, &
128Meybeck, 2011, p. 2). The USDA defines both loss and waste as occurring
129post-harvest, distinguished by the degree of human agency involved; food
130waste is a “component of food loss [that] occurs when an edible item goes
131unconsumed, such as food discarded by retailers due to undesirable color or
132blemishes and plate waste discarded by consumers” (Buzby et al., 2014, p.
133iii). Finally, the EPA distinguishes between “wasted food,” which is food not
134used for its intended purposes, and “food waste,” which is food that has lost
135its value and has to be managed (US EPA, 2015).

136 In light of competing definitions, Marc Bellemare and coauthors
137advocate distinguishing “food actually wasted” (2017, p. 2) from that merely

138removed from the supply chain, asserting, “As long as food does not end up
139in a landfill, it is not wasted” (2013, p. 5). Given our focus on comparative
140environmental outcomes, we follow this approach and use the term “waste”
141to specifically refer to food sent to a landfill at any point along the supply
142chain. As elaborated further below, the disproportionate environmental
143impact of landfill disposal justifies distinguishing it from other potential
144pathways (Scherhauser et al., 2015). Moreover, our interviews alerted us to
145the very different connotations of “losing” versus “wasting” food, with the
146latter implying a need for behavioral change that overestimates the agency
147growers actually exercise within the broader political economy of food.

148 To assess the relationship between on-farm food loss and
149environmental impact, our approach has been to listen carefully to the
150people most directly engaged: farmers. A richer qualitative understanding of
151the processes that drive on-farm losses can support a more realistic
152evaluation of the likely consequences (intended and unintended) of proposed
153solutions.

154 **3. Methodology: Collecting Grower Views**

155 California has the highest agricultural output of any US state, along
156with the largest and most diverse fresh produce sector. Many parts of this
157sector are tightly integrated into the global supply chain system; others are
158part of local and regional food systems that emphasize direct marketing, or
159hybrids doing both. We explored on-farm food loss and recovery possibilities
160in three key California crops: leafy greens, tomatoes, and peaches. The first

two were chosen because of the size and scale of their presence in California, their importance in national and global markets (e.g. as common ingredients for fast food and retail food outlets), and thus their potential for major environmental and social gains or losses. Peaches were selected to determine if the trends observed in annual leafy greens and tomatoes were similar in a perennial tree crop, and more specifically, an orchard crop that is highly perishable.

Table 1. Economic and Physical Scale of Peach, Tomato, and Lettuce Production in California

Crop Type	CA Share of US Receipts	Acreage Harvested (1,000 Acres)	Production (1,000 Tons)	Total Value (\$1,000)
Peaches (Freestone)	NA	20	244	NA
Fresh Tomatoes	27.1	NA	330.8	206,413
Lettuce (Heads)	63.7	83.5	1,523.9	993,567

Source: (California Department of Food and Agriculture, 2018)

We used semi-structured interviews to capture grower perspectives on how much food is lost on their farms, the causes and effects of these losses, and potential solutions. Open-ended interviews are a methodology well-suited to exploring complex processes and generating propositions about causal relationships. Semi-structured interviews are oriented around a series of broad questions, but allow the respondent to help guide the discussion by raising new issues in spontaneous conversation (Hammer & Wildavsky, 1993). This approach is ideal for respondents who might feel reticent about

180being interviewed, as well as for preliminary research in which the goal is to
181explore the range of views within a given group.

182 We recruited initial interviewees through contacts established through
183the University of California Cooperative Extension system (UCCE), the
184California Food Waste Roundtable, and the researchers' professional
185networks. We then used a process of "snowballing," where each respondent
186indicates potential interviewees. Initial recruitment efforts were challenging
187—some growers were distrustful of researchers who might portray them as
188wasteful and wary of the potentially burdensome new regulations.
189Responding to grower sensitivities, and in light of conflicting definitions
190discussed above, we eliminated the terms "waste" or "loss" from our
191interviews, instead asking growers to comment on "crops that do not make it
192to primary markets."

193 In total, we interviewed 25 growers of leafy greens, fresh peaches, and
194fresh tomatoes, roughly split between the three crops. Farms ranged in size
195and reflected the organizational diversity of California agriculture, in which
196"no single structure can be considered a prototype" (Carman, Cook, &
197Sexton, 2003, p. 99); they varied in degree of vertical integration, reliance on
198contracts versus spot markets, and type of contractual arrangements,
199among other factors. The category "grower" included people holding
200different roles on the farm, such as harvest manager, owner, sales
201representative, and other positions. Interviews lasted approximately one
202hour and were mostly conducted on farms, unless farmers requested a

203phone interview. We recorded all in-person interviews except for one case in
204which a grower requested not to be recorded. For phone interviews, we took
205detailed notes throughout the conversation to generate close transcriptions.
206We guaranteed the confidentiality of participants and their businesses.

207 Our sample was small relative to the number of farmers growing these
208crops in California, was based on convenience and previous researcher
209connections, and—given the resistance we initially encountered—was likely
210biased in favor of growers more open to the idea of addressing food loss.
211Thus, our findings cannot be interpreted as a general representation of
212grower views. They offer instead an important initial look into the range of
213opinions growers might have, generating insights that can inform
214subsequent research and policy.

215 Table 2. Distribution of interviews and farm visits among the 3 crops.

	Farmers interviewed	On-farm site visits
Leafy greens	9	5
Fresh peaches	7	5
Fresh tomatoes	5	4
Combination of these products	4	4
Total:	25	18

216

217All interviews were professionally transcribed and uploaded to a qualitative
218data analysis software program. Multiple readings of the transcripts
219generated codes for both manifest and latent themes, as we sought to
220capture both visible content and underlying meanings (Babbie, 2015) and

221refined these through iterative discussions. Organizing interview excerpts by
222code, we then generated a comprehensive report summarizing key findings.

223 Our qualitative work generated two core insights for designing FLW
224solutions involving farms. The first is the need to understand how on-farm
225losses are structured by the way economic risk is borne within the current
226agricultural system. The second is the need to assess the relative
227environmental impact of food lost at the farm as compared to other points
228along the supply chain. The next two sections explore these findings in
229greater detail.

230 **4. Risk Mitigation and On-Farm Loss: Farmer practices amidst** 231 **integrated supply chains**

232 Growers are faced with the challenge of optimizing their farm
233performance in the context of broader economic, political, and
234environmental conditions. Further, these conditions are changing. The past
235few decades have featured dramatic structural changes in the political
236economy of food and agriculture, including the increasing concentration of
237power in fewer corporate firms (Hendrickson, Wilkinson, Heffernan, &
238Gronski, 2008; Howard, 2016) and the “transition from independent
239economic stages coordinated primarily by markets to much more tightly
240aligned food supply or value chains coordinated by various forms of
241negotiated linkages” (Boehlje, 1999, p. 1040). The majority of US fresh
242produce production is governed by these structural arrangements; while a
243small percentage of fresh fruits and vegetables are distributed through direct

244marketing channels, most growers today rely on others to sell their product
245(Cook, Roberta L, 2011). The perishability of fresh produce has always
246limited the bargaining power of producers as compared to buyers, but recent
247structural shifts have deepened these power imbalances (Carman et al.,
2482003, p. 101). Growers now compete with each other for a limited number of
249increasingly demanding buyers (Boehlje, 1999, p. 1040). As evidence of
250growers' relative weakness within this system, the farmer share of the food
251dollar has been steadily shrinking over time (Economic Research Service,
252USDA, 2018).

253 Within this context, sociologist Zsuzsa Gille (2012) advocates for
254placing the question of risk at the foreground of food loss analysis. Using the
255term "waste" in a general sense, she asserts, "Economic risks are a key
256aspect of the production of waste...efforts to shield oneself from economic
257uncertainties generate waste in different stages of production and
258consumption" (Gille, 2012, p. 32). The production and sale of fresh produce
259are inherently risky endeavors, as both Mother Nature and consumer
260markets are fickle, and the perishability of the product means short timelines
261for turning a sale (Carman et al., 2003, p. 101; Minor et al., 2019, p. 3). As
262Gille notes, one exercise of power is the ability to transfer risk to other
263actors. In today's agricultural system, retailers can shield themselves from
264financial uncertainty by demanding consistent volumes of perfect produce to
265offer to consumers; to obtain and retain a buyer, growers must ensure
266reliable quantities and meet rigid quality standards. Power imbalances

267manifest in the form of unsold food on farms, as growers must plant
268sufficient quantities to allow for fluctuations in yield and quality and then
269leave unharvested or cull unwanted product (Gille, 2012, p. 35).

270 Interviews with California produce growers reveal two broad categories
271of food abandoned at the farm-level as a result of economic risk
272management within this structure: edible food that does not meet quality
273standards, often termed “imperfect produce,” and perfect produce for which
274there may not be a buyer, termed “surplus produce.” Growers gave broad
275estimates of quantities of edible food lost and, as in other qualitative studies,
276discounted their accuracy by emphasizing significant variance by year and
277within a given season (Beausang et al., 2017, p. 181). Tomato and peach
278growers reported losing approximately a quarter of fruit, with tomato losses
279primarily occurring in the field and peach losses occurring at the packing
280shed. Leafy greens growers’ estimates varied by crop but ranged from less
281than 5% to close to a quarter. The economic risks that drive the loss of
282imperfect and surplus produce are discussed in turn.

283 Edible food is often discarded because it fails to meet established
284quality specifications for size, ripeness, or cosmetic features. In the case of
285peaches, growers described marks from hail pellets or rubbing branches.
286Fresh tomatoes with sunburn or “catfacing”—an abnormal cracking and
287dimpling of the skin—are discarded. Leafy greens growers noted that romaine
288with a bit of tip damage from wind, or iceberg heads with a “football” rather
289than spherical shape might get left behind during harvest. Standards may be

290set by retail firms, government agencies or industry associations, and can
291vary for specific markets or grades. In the case of fresh peaches, for
292example, some growers pack a smaller sized peach in parallel to their
293“number ones.” In contrast, a lettuce grower described rigid size
294requirements for romaine lettuce: “If you need a 10-inch head of romaine,
295and there’s a 7-inch head of romaine, [the pickers] are just going to walk
296right by it... There’s not like, medium romaine, large romaine. So, if it doesn’t
297meet that minimum criterion, it just gets left behind” (Interview 26).

298 Growers described two underlying justifications for disposing of
299“imperfect” food. The first is the risk that produce would become inedible by
300the time it reaches consumers. In researchers’ analysis of food lost on farms,
301it is often unclear whether they are considering edibility on the day of the
302assessment or in the context of the required transport/storage/handling for
303successful passage through the supply chain (Johnson et al., 2018; Neff et
304al., 2018). In contrast, growers explained culling for quality based on what
305produce would look like when it reaches an end destination. As one peach
306farmer commented, “Very few of them [the culls] are not edible. Even the
307soft is edible. It's just too soft to handle to get it to anybody... That's what I
308take home to eat, to my grandkids. But it doesn't have to ride on a machine
309or go on a five-day truck ride to the East Coast, you know? It just won't make
310it” (Interview 15). Culling for size has practical as well as aesthetic
311importance, as a precisely packed box can prevent damage in transport. A
312lettuce harvest manager explained that small heads get left behind “because

313we need that full box. If you got lettuce rolling around the box it'll get
314rejected" (Interview 2). Relatively small cosmetic blemishes could develop
315into decay over time, as another grower explained: "If it's imperfect because
316it's got a flaw, it might be minor at the field level when they're looking at it,
317but it might be a ball of mush by the time it gets to the consumer level"
318(Interview 32). Another farmer elaborated:

319 The biggest thing is that when you have these different products and
320 you start trying to extend their marketing ability, if there's
321 imperfections, that can lead to breakdown...A lot of times if it's product
322 that's either past what we call its bloom, it's not going to have the
323 shelf life. And if you start trying to push that into regular channels or
324 into other channels, it may lead to food safety issues... (Interview 5).
325
326As he concluded, the possibility that imperfect produce might decay further
327down the supply chain drives heavy culling at the field level.

328 The second justification for abandoning imperfect produce is the risk
329that the product will be undesirable to consumers. As a leafy greens farmer
330commented, "Customers, they eat with their eyes. So if the product doesn't
331look good on the shelf, if there's any discoloration, or any little thing,
332customers won't eat it, or buy it" (Interview 2). He went on to explain how
333such consumer preferences drive losses. "So sometimes, with romaine there
334could be a little bit of wind damage just on the very tip—the little tip burned
335—and a bad market, we'll walk away from that" (Interview 2). Asked what
336portion of his tomato culls is edible, one farmer summarized, "Whatever the
337culls, if it's just the color, or the catfacing, all of that is edible. It's just the
338view of it" (Interview 11). A peach farmer commented, "I could take you to a
339packing shed and you'd watch the cull line and you'd go, why are you

340throwing that away? But that's how particular the market is" (Interview 21).
341Though growers talked about consumer preferences, quality specifications
342reflect buyer interpretation of such preferences. A leafy greens farmer
343commented, "What we think there's a market for, and the retailers we sell
344for think that there's a market for, it's a different story. We are doing what
345the retailer wants to do. We don't know the consumers" (Interview 1).

346 Ultimately, a more immediate risk to growers compels them to
347abandon imperfect produce—the risk that the product will be rejected further
348down the supply chain. In cases of rejection, suppliers not only risk losing a
349buyer, they are also responsible for disposal of the rejected product, which
350may involve additional financial costs. Even small percentages of borderline
351produce can spur retailers to reject an entire load, prompting growers to err
352on the side of caution in meeting quality specifications. As one grower
353summarized, "If you're going to have waste, better to have it here at this
354level, rather than ship something of questionable quality." In her study of six
355vegetable crops on a North Carolina farm, Lisa Johnson (2018) found that,
356even when significant portions of a field are top quality, farmers might
357discontinue harvesting to avoid inadvertently including imperfect product in
358a shipment— potentially prompting rejection and tarnishing the farmer's
359reputation (248).

360 What constitutes "questionable quality" varies based on market
361conditions. Weak markets can effectively narrow quality specifications. A
362tomato farmer described what would currently be considered "overripe,"

363commenting, “And now the market is so low, any pink [on the tomato], they
364[the pickers] will throw it away” (Interview 11). A peach grower explained:

365 If there's too much fruit, nobody wants these bottom sizes. Two years
366ago, there was no
367 market basically for medium to small fruit because there was so much
368fruit and there was
369 plenty of big. So the packers were telling guys, just leave those small
370 ones on the tree—don't bring them into us because it wouldn't pay for
371 the picking and the packing...
372 (Interview 16)

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374The risk of retailer rejection also expands in cases of oversupply, making
375growers more cautious in assessing imperfections. As a leafy greens grower
376commented, “When the market is bad, that is when you’re most likely to
377step over something, or really get picky. So maybe you don’t take a chance
378putting a short head of lettuce in, or something ugly” (Interview 25). Buyers
379have relatively unchecked power to determine when rejection is justified—
380although suppliers have the legal right to demand external inspections, their
381position in relation to buyers can make this impractical—meaning that
382quality complaints may be used to mask rejections based on decreased
383demand (Eriksson, Ghosh, Mattsson, & Ismatov, 2017). A study from Sweden
384showed how retailer power to make suppliers absorb costs of quality and
385quantity fluctuations— through unchecked reclamations and, in some cases,
386“buy-back” agreements for unsold food—both expands overall levels of food
387loss and shifts loss toward suppliers (Eriksson et al., 2017)

388 Relatedly, growers also incur loss in the form of surplus perfect food. In
389weak markets, they may leave superior quality produce unharvested for risk
390of failing to recover additional variable costs. A lettuce harvest manager

391 explained that, when sales are unsure, “we won’t even harvest it, because
 392 then we pay for it twice.” He elaborated, “We pay for it to be harvested and
 393 cooled, and then it just sits there, and then we have to pay for it to get
 394 disposed of, so it’s cheaper to just cut your losses with the growing costs”
 395 (Interview 2). While most US fresh fruits and vegetables are sold in spot
 396 markets, a significant portion is produced under contract (MacDonald & Korb,
 397 2011, p. 5). Some growers commented on how contractual arrangements
 398 might impact loss due to surplus—one lettuce grower explained how the
 399 expansion of contracting has helped growers fine-tune planting and
 400 harvesting schedules with more predictable sales (Interview 6). On the other
 401 hand, to fulfill contracted volumes and maintain buyers, growers must plant
 402 sufficient quantities to account for fluctuations in yield (Minor et al., 2019, p.
 403 34). Thus advantageous as much as adverse weather may provoke loss, as
 404 bumper crops can mean that food sits in the field (Gille, 2012, p. 34). One
 405 grower described high levels of loss “when it was just a great year for
 406 tomatoes and we have more than we have markets committed” (Interview
 407 11).

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420 In sum, growers abandon or discard food due to the exigencies of an
421 increasingly competitive market and their desire to minimize financial loss.
422 Fluctuations in yield and quality are endemic to farming fresh fruits and
423 vegetables, and buyers have the power to shield themselves from economic
424 risk by demanding consistent supplies of perfect produce, pushing losses
425 back to the farm level. As one farmer commented, “They [retailers] are the
426 big players in the game. They make the rules and they make the calls. I’d
427 like to say we’re in control, but they’re the giants” (Interview 3).

428 **5. Lost But Not Wasted: The comparative environmental impact**
429 **of food loss on farms**

430 When assessing environmental impact, not all food loss is equal—
431 *where* and *how* loss occurs along the food supply chain dictates its effects.
432 Thus, a second step in assessing the role farms and farmers can and should
433 play in food waste reduction is to consider the comparative environmental
434 impact of on-farm food loss. Life-cycle assessment (LCA) methods are one
435 means of measuring the comparative environmental impact of loss and
436 waste at different stages of the food supply chain, where the resource inputs
437 and waste emissions are analyzed across a product life-cycle, from “cradle to
438 grave” (i.e. production to disposal). Existing studies that apply LCA

439methodology to the food supply chain have highlighted the cumulative
440increase of embedded resource use (e.g. water, energy, and other material
441inputs) as food items pass through the value chain (Bernstad, Cánovas, &
442Valle, 2017). For example, one can consider energy as an input at each stage
443of the supply chain from producer to consumer, along with transportation
444energy to convey the products between stages (Canning, Charles, Huang,
445Polenske, & Waters, 2010; Pelletier et al., 2011). The further down the supply
446chain that food is either lost or wasted, the greater the embedded energy
447costs of the forfeited food item; in comparative terms, pushing loss
448“upstream” toward producers represents reduced environmental impact.

449 In assessing environmental impact, we also need to consider what
450happens to lost food. The EPA has developed the food recovery hierarchy as
451a heuristic model for prioritizing food loss and waste solutions based on total
452environmental, social, and economic benefits (US EPA, 2017). In order of
453preference, the EPA suggests reducing the volume of food loss and waste at
454the source; feeding hungry people with surplus food; diverting food scraps to
455animals; industrial valorization of food waste through recovery of
456biochemicals, fuels, and energy; composting for nutrient recovery; and
457finally, landfill and incineration as a last resort. The significant difference in
458environmental outcomes justifies distinguishing food truly “wasted” in
459landfills from that lost or diverted in other ways. Not only is the potential to
460recover valuable nutrients lost via landfill disposal, the decay of the organic
461food material in anaerobic landfill conditions produces methane, a GHG that

462 is 25 times more potent than carbon dioxide (CO₂). In the United States, it is
463 estimated that methane emissions from food disposed in landfills represents
464 26% of the total GHG emissions of food loss, which in turn is estimated to be
465 1.8 kilograms (kg) of carbon dioxide-equivalents (CO₂-eq) per person per day
466 (Heller & Keoleian, 2015). Unfortunately, the EPA estimates that only 5.1% of
467 the food waste portion of all municipal solid waste (MSW) in 2014 was
468 diverted from landfills and incinerators for composting (US EPA, 2016b).

469 Location and mode of food loss are interrelated; as food moves down
470 the supply chain, the odds of it being diverted to a landfill increase
471 significantly (Hoover & Moreno, 2017; Thyberg et al., 2015; Scherhauser et
472 al. 2015). While on-farm loss is common and significant, actual “waste” in
473 the sense of landfill disposal is a rarity on farms. One grower summarized,
474 “We are effectively a zero landfill farm” (Interview 25). As growers explained,
475 the easiest and most cost-effective ways to dispose of imperfect or surplus
476 product is to till it back into the soil. Leafy greens are packed in the field, so
477 anything that does not meet standards will simply be left behind by pickers
478 and disked under when the field is prepared for the next planting. Similarly,
479 with fresh tomatoes, pickers toss imperfect fruit on the ground. Beyond
480 economic efficiencies, growers saw this practice as environmentally
481 beneficial, or at least neutral. As one greens grower commented, “Well it’s
482 good for the field because we are returning, essentially, all the nutrients or
483 at least part of them down to the organic matter, and back to the soil”
484 (Interview 1). An organic tomato grower explained, “So when people say that

485 food is being wasted, maybe it's just not going through the traditional
486 distribution system. Everything that we grow in some way makes it back into
487 the natural system of recycling nutrients" (Interview 12).

488 Growers also reported diverting unused produce to animals—an option
489 which ranks relatively high in EPA's food waste recovery hierarchy. In the
490 case of peaches, fruit left on trees or in the orchard can be an attraction for
491 pests, therefore most growers reported harvesting virtually all produce in
492 multiple picks, leaving most culling for on-site packing houses. Post-harvest
493 culls were then sold as animal feed at a minimal price. A peach farmer
494 explained: "These extra softs, those go to the cows. They volume-fill trucks,
495 and they haul them out and dump them in these vats that they grind them
496 up with straw, so they make the straw real palatable for the cows" (Interview
497 15). As found in other qualitative work, growers often highlighted the
498 relatively productive uses of food lost at the farm level (2017, p. 180).

499 Figure 3 illustrates the comparative environmental impact of typical
500 on-farm losses as compared to loss further down the supply chain, showing
501 the total estimated GHG emissions (or global warming potential, GWP) for
502 two example scenarios for fresh tomato losses. Estimates of GHG emissions
503 are presented for losses by stage of the food supply chain as well as the
504 most likely food waste disposal option for each scenario. The first scenario
505 represents losses in the field that are ultimately ploughed back into the soil;
506 the second scenario represents food waste at the point of consumption that
507 ends up being landfilled. The data presented were consolidated from a report

508by the European Union (EU) FUSIONS project, and thus are biased towards
 509European production and waste management systems (Scherhauser et al.
 5102015). Further, while the report specifies GWP specifically for tomato
 511production, the GWP estimate for disposal is limited to the broader category
 512of organic waste (specific estimates for fresh tomato disposal were
 513unavailable).

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 517Figure 3. Comparison of global warming potential (GWP) for two illustrative
 518scenarios of tomato loss pathways, incorporating the impact of the food
 519supply chain and organic matter disposal options (data consolidated from
 520Scherhauser et al. 2015)

521 For Scenario 1, the total GHG emissions factor is estimated to be 0.31
 522kg CO₂-eq per kg tomato, based on emissions factors of 0.25 kg CO₂-eq/kg
 523for tomato cultivation and 0.06 kg CO₂-eq per kg of organic material that
 524decomposes in the field. The estimated GWP for Scenario 2 (1.55 kg CO₂-eq

525per kg tomato) is five times greater than Scenario 1, since it incorporates
526GHG emissions factors for each stage of the tomato supply chain (0.10 for
527processing, 0.22 for transportation, 0.02 for retailing and distribution, 0.09
528for packaging, and 0.11 kg CO₂-eq per kg tomato for food consumption) as
529well as the much higher emissions factor for landfill disposal (0.76 kg CO₂-eq/
530kg organic material).¹

531 Not only are downstream losses far more environmentally costly than
532on-farm losses, we might also conclude based on the previous section's
533discussion of risk that Scenario 1 may help prevent Scenario 2. First, growers
534did report sending food to landfills in rare cases where they made the wrong
535call on harvesting and packing surplus or imperfect food. One grower
536observed how this might play out in the case of product lacking a buyer:
537“Maybe a grower who has nowhere to put something, packed a lot of bad
538stuff, maybe that's where they would take it...” (Interview 12). A leafy greens
539grower also related sending food to a landfill in cases where a retailer had
540rejected a load and he was unable to find other outlets for sale or donation.
541As he explained, “Yes, it [sending food to a landfill] could happen, but very
542rarely. You realize that if you already packed something, for that product to
543hit the landfill, something really bad needs to happen. It would have to be a
544recall” (Interview 1). Landfill disposal after picking and packing a product-
545and particularly after sending it to a retailer only to face rejection and incur

1 ¹ GHG emissions for “food consumption” in the original study reflects
2consumer travel for purchasing as well as home refrigeration.

546additional costs for disposal—is a worst-case financial scenario for farmers.
547Thus, grower’s efforts to mitigate financial risk by erring on the side of
548caution when deciding what to leave behind or discard may also mitigate
549environmental impact. While it expands levels of on-farm food loss, holding
550back borderline product may reduce actual waste in the form of landfill
551disposal.

552 Much of the food that growers abandon is not borderline but rather
553clearly fails to meet quality standards—standards that, as growers explained,
554address underlying risks that produce might become inedible in transit or
555might be unacceptable to consumers. More broadly then, to the extent that
556on-farm culling prevents potentially unstable or undesirable product from
557moving further down the supply chain, economic risk mitigation strategies
558may also mitigate environmental impact. Buyers’ efforts to shield
559themselves from potential financial loss drive on-farm losses. But they may
560also inadvertently lessen environmental risks, including additional resource
561inputs and increased likelihood of food ultimately ending up in a landfill. As
562growers often commented, if loss is to occur, the farm is the best place for it.
563Put succinctly, and somewhat counterintuitively, some on-farm food loss may
564help prevent actual waste.

565 **6. Conclusions**

567 We have drawn on qualitative data captured through interviews with
568California fresh produce farmers to consider the role of farms and farmers in
569reducing food waste. Our analysis focused specifically on the environmental

570benefits of waste reduction, thus distinguishing the most ecologically costly
571“waste,” in the sense of landfill disposal that contributes to greenhouse gas
572emissions, from food diverted from supply chains in other ways. While the
573ideal is to prevent any form of food loss along the supply chain, we take a
574pragmatic approach that seeks to identify the least bad option in
575environmental terms.

576 Our research contextualizes on-farm food loss within the broader
577political economy of food production. We show farm-level losses as the result
578of a system in which buyers shield themselves from financial risk by
579demanding consistent volumes of perfect produce, and in which growers
580bear this risk by absorbing fluctuations in yield and quality in the form of
581unsold food. Disposing of “imperfect” food on the farm mitigates two
582underlying forms of risk. The first is that produce will not be desirable to
583consumers, falling beyond standards of what constitutes marketable food.
584The second is that relatively minor imperfections at the field level might,
585over the course of the trip to the end user, worsen and render the food
586inedible. For growers, the immediate risk is investing additional resources in
587food that may either be rejected on quality grounds further down the supply
588chain—jeopardizing a relationship with a buyer and resulting in potential
589disposal costs— or, in cases of oversupply, may never find a buyer at all.
590“Your first lost is your best loss” is the governing logic for growers competing
591in an agricultural system in which they have diminishing power.

592 This logic also applies, however, to the environmental costs of lost
593 food. Embracing a food systems perspective, and using the EPA’s food waste
594 and recovery hierarchy to prioritize different potential pathways for food, we
595 show the farm as the best place for loss to occur. Environmental resources
596 accrue as food moves along the supply chain, thus upstream loss is by
597 definition preferable. Growers we interviewed almost never sent surplus or
598 imperfect produce to landfills. Virtually all such food is either tilled back into
599 the soil or sold as animal feed, both of which rank as preferable options
600 within the EPA hierarchy. In contrast, food lost further down the supply chain
601 is far more likely to be landfilled, causing disproportionately greater
602 environmental harm and contributing to GHG emissions. Grower financial risk
603 mitigation strategies that cause food to be lost on farms rather than further
604 down the supply chain may help mitigate environmental harm as well.

605 Claiming that some on-farm food losses may prevent food waste within
606 the current agricultural system is certainly not to advocate for the status
607 quo. First, our analysis does not address the potential social impact of
608 recovering food from farms. Emphasizing humanitarian rather than
609 environmental considerations alters the calculation of when it is worth
610 recovering underutilized food from farms, even if some of it may ultimately
611 end up in a landfill. More importantly, “win-win” solutions with both social
612 and environmental benefits are possible—and, in some cases, underway. We
613 intend with this analysis to help clarify parameters for thinking about such
614 solutions. Markets with more flexible quality and quantity requirements can

615move more food off of farms. But to avoid the unintended consequence of
616turning on-farm loss into downstream waste, efforts to recover imperfect or
617surplus product should carefully address two key questions: What is the
618likelihood that this food will ultimately make it to a consumer? And what will
619happen to it otherwise?

620 We need more rigorous research on the comparative environmental
621impact of food loss along the supply chain and related calculations of the
622probability that food retained at the farm level would become waste further
623downstream. A number of LCA studies exist that compare the environmental
624impact of recycling options (e.g. composting and anaerobic digestion) for
625food loss and waste relative to the landfill (Edwards, Othman, Crossin, &
626Burn, 2018; Gao, Tian, Wang, Wennersten, & Sun, 2017; Mata-Alvarez, Macé,
627& Llabrés, 2000; Takata et al., 2012). This work could be extended to make
628more direct comparisons between these downstream recycling options
629relative to tilling produce back into the field (or collection for animal feed) at
630the production stage. Further, and significantly more challenging, would be
631to quantify the risk of produce being lost/wasted at each stage of the supply
632chain based on quality parameters determined at harvest. However, with
633advancements in traceability and transparency of food products through the
634supply chain (Bosona & Gebresenbet, 2013), models could be developed to
635optimize the selection of produce to maximize the probability of reaching the
636consumer, while minimizing economic and environmental costs from a life-
637cycle perspective. Building on European case studies, further work might

638also explore how the technical terms of contractual arrangements, marketing
639standards, and other details of producer-buyer relationships influence farm-
640level losses (Eriksson et al., 2017; Hornibrook, Fearne, & Duffy, 2003; Mena,
641Adenso-Diaz, & Yurt, 2011), as well as the ways that different organizational
642structures and distribution channels (e.g. grower cooperatives, farmers
643markets) shift risk calculus and thus loss.

644 From a practitioner viewpoint, our findings suggest the need to adopt a
645broad perspective in analyzing the problem of on-farm loss and potential
646solutions, reassessing the role that farmers could and should play in waste
647reduction. We do not see the current scenario, where large quantities of
648potentially edible produce are never consumed as food, as inevitable or
649acceptable; nor do the growers we interviewed. Addressing this problem,
650however, requires recognizing “waste as a function of social relations” and
651avoiding the tendency “to assume that the causes of food waste reside
652within the stages within which they appear” (Gille, 2012, p. 38). Growers
653repeatedly insisted they are doing their best to maximize efficiency and
654minimize loss—of food, but also of revenue—within a market-based system
655controlled by more powerful actors. They are constantly striving to reduce
656loss levels by improving the quality of what is produced, thus allowing them
657to sell greater portions of what they grow. Growers would certainly welcome
658changes down the supply chain that would alter the decision-making
659scenarios they face when determining what to leave behind. As one lettuce
660farmer put it, “You may not be talking to the right people. We are just the

661executors” (Interview 1). Without addressing larger market structures that
662perpetuate oversupply and cause "imperfects" to be rejected by retailers and
663consumers, growers may be doing the best they can by absorbing significant
664levels of loss.

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