Journal of Food Distribution Research
Volume 54, Issue 3, pp. 66–77

In-field Food Waste in California Strawberry Production: An Analysis of Harvester Extraction Rates

Timothy A. Delbridge[a⌽] and Sarah N. Zukoff[b]

[a]*Assistant Professor, Department of Applied Economics,*
Ballard Extension Hall 215, Oregon State University,
Corvallis, OR 97331, USA

[b]*Research Entomologist,*
Zukoff Research Services
Morro Bay, CA 93442, USA

Abstract

In this paper, we report on the collection and analysis of two years of "harvest efficiency" data from commercial strawberry farms in California. Harvest efficiency refers to the percentage of total ripe berries that are successfully harvested from the field and has implications for assessing food waste, the relative attractiveness of robotic harvest innovations, and management decisions related to field sanitation and pest management. Results indicate that within the sampled farms, between 12% and 39% of the total strawberries produced were left in the field, with production practices and the time of year significantly affecting this rate.

Keywords: harvest efficiency, specialty crops, food waste, automation

⌽Corresponding author: Tel: (541) 737-2511
Email: timothy.delbridge@oregonstate.edu

Introduction

The California strawberry industry produces roughly 90% of the total U.S. production of strawberries and generates more than $3 billion per year at the farm-gate (USDA-NASS, 2023). Strawberry harvest is labor intensive, accounting for roughly a third of the total cost of production and employing 50,000 to 60,000 workers per year across the state (Bolda et al., 2021). In this context, the efficient management and execution of harvest operations has clear implications for farm profitability, but also relates to issues of food waste, effective Integrated Pest Management (IPM) strategies, and the relative attractiveness of advances in robotic harvest technology.

In a typical California strawberry production system, berries are picked for fresh market sale every three or four days and packed directly into plastic clamshell containers in the field. This schedule must be sustained over the duration of the growing season or fruit may overripen and become unmarketable. In the early season, there may be light fruit volume and more than enough harvest workers, but growers may find it difficult to secure enough labor to keep up with their harvest schedule in peak production periods. Harvest workers are typically paid on a piece-rate basis, and while their productivity in terms of trays (and thus dollars) per hour is closely tracked, the accuracy or thoroughness of a harvest crew's work is difficult to systematically monitor.

In this paper, we report on the extraction rate or "harvest efficiency" of manual strawberry harvest crews in California during the 2019 and 2020 crop years and estimate the relationship between the quantity of fruit left behind by harvest crews and key attributes of the production system and field conditions. This analysis establishes a baseline on a previously unexplored component of strawberry harvest management and in-field food waste. Our goal in this paper is to foster discussion and motivate future research on the relationship between fruit left in the field and pest and disease pressure, the optimal incentive structure and harvest management practices to maximize farm profitability, and how the strawberry industry can most efficiently incorporate advances in harvest automation.

Although we are aware of no published studies that measure the percentage of strawberries left in the field by harvest workers, the topic has been explored in other specialty crops, and strawberry harvest management has been a topic of considerable research in the agricultural economics and sociology literature. Ampatzidis and Whiting (2013) assess how manual harvest in sweet cherry is impacted by tree architecture. Hill and Burkhardt (2021) and Hamilton et al. (2022) explore issues related to strawberry harvest productivity, but focus on the trays of harvested fruit per worker hour rather than the percentage of fruit successfully harvested. Delbridge (2021) analyzes the economic feasibility of robotic harvesters in strawberry production and shows that the rate of fruit extraction relative to that of human crews is critical for the success of robotic systems. The perspective of the strawberry harvest worker is explored by Soper (2020), who shows that compensation structure incentivizes harvest speed above other considerations, and that harvesters prefer to pursue work in tidy fields with larger berries.

The current paper makes three main contributions. First, we document the severity of the fruit loss problem during the harvest stage of strawberry production. Many growers and harvest managers are not fully aware of the quantity of fruit that is left behind because it is difficult and costly to monitor and verify the work of harvesters. Second, this study will help motivate further research on the impact that the presence of decaying fruit has on pest pressure in strawberry systems. Both insect pests and disease can flourish in the presence of rotting fruit, though there is little understanding of how significantly current harvest practices may contribute to pest losses.

While this study does not directly assess pest damage, the data and analysis presented here can serve as a baseline for future trials aimed more directly at improving field sanitation and identifying the optimal level of harvest labor input in strawberry production. Finally, this study will contribute to the evolving discussion around the prospect of robotic strawberry harvest. The performance of both human and automated harvesters depends on field conditions that vary across farms and throughout the growing season, and a richer understanding of harvest efficiency will inform choices about how to best integrate robotic harvest technology and human crews.

The paper proceeds as follows: we first describe typical strawberry harvest systems and the ways in which the current systems impact incentives of the worker, the farm manager, and the markets for fresh and processed berries. Second, we describe the methods used to collect data on harvest efficiency during the 2019 and 2020 study periods. Third, we present a simple econometric analysis used to identify the relationship between different production attributes and the percentage of fruit not harvested. We then present the results of the data collection and analysis, and close with a discussion of the implications of the study and specific suggestions for future research.

Background

Harvest labor management is a complex part of the strawberry production system, and harvest managers must continually consider shifting labor markets, field conditions, and fluctuations in fresh and processing market prices. Harvest workers are typically paid a piece rate per tray of harvested fruit, and managers are under pressure to harvest enough area so as not to fall behind their harvest schedule. Keeping up with the flow of ripe fruit becomes particularly difficult during peak production times when it can be challenging for managers to secure their desired number of workers. The compensation structure incentivizes fast work on the part of harvest crews, and some fruit is inevitably overlooked and left in the field. The degree of in-field food waste has not been widely known, as data on abandoned fruit are not routinely gathered.

At some point in the season, growers may switch from harvest for the fresh market to the processed market. While fresh market fruit brings in a higher price than processing fruit, the aesthetics and quality must be pristine, and a smaller proportion of ripe fruit is suitable for sale. A switch to the processed fruit market is often accompanied by a shift in wage structure from piece-rate pay to hourly pay, which decreases the incentive to pick quickly at the same time that the lower quality requirements increases the volume of fruit that is saleable.

Marketable fruit that is missed during a harvest pass represents a significant loss of potential revenue. Missed fruit also rots in the field, leading to pest and disease pressure, ultimately reducing the marketable yields achieved later in the production season (Bolda et al., 2023). Proper field sanitation, defined here as the removal of diseased or pest-infested fruit, is recommended as a critical cultural control method within IPM programs and, in some cases, can prevent new disease infections from occurring or keep existing infections or infestations from worsening (Goodhue et al., 2011; Dara, 2015; Bolda et al., 2023). Field sanitation is the leading method of managing diseases such as Rhizopus and Botrytis fruit rots, as well as insect infestations such as spotted wing drosophila (Bolda et al., 2023). Both fruit rots and spotted wing drosophila infest fruits that are at approximately 80%–100% berry maturity, and any infested berries missed during the harvest pass or follow-up sanitation passes can lead to further infestations on ripening fruit (Baena et al., 2022; Bolda et al., 2023). Even missing a few infested berries can lead to new infestations as spotted wing drosophila, for example, can have up to 10 continuous generations a year and lay 350 eggs per female.

Despite the benefits of field sanitation for the sake of disease and pest prevention, growers do not often pay harvest workers to remove diseased or pest-damaged fruit and there is little incentive for a harvester to reduce their piece-rate volume to keep their assigned rows tidy. Moreover, pest pressure can be spread unevenly across a field in "hot spots," making it unfair to those harvesters who face a greater amount of infested fruit than other workers in their harvest crew. Therefore, many of the diseased, mushy, moldy, or infested strawberries are left on the plants. In this context, it is important to understand how much fruit is being missed by harvest crews, and how the harvest efficiency may vary across fields and time.

The prospect of commercially viable robotic harvest technologies for in-field strawberry production makes an improved understanding of harvest efficiency even more critical. Robotic harvest systems that are currently in the testing and refinement stage in commercial strawberry operations tend to miss more fruit than human workers, with the harvest efficiency lower in fields with larger, more densely placed plants. There are persistent concerns that robotic harvest systems leave too much fruit in the field, that supplementing robots with human harvesters will be too costly, and that robotic harvesters are less effective later in season when the labor supply is most constrained (Delbridge, 2021).

The field structure of commercial strawberry farms in California varies across the region and can include two, three, or four rows of plants together in a single planted bed. Plants tend to become bushier over the course of the growing season, which can make it harder for pickers to quickly spot berries on the plant. Individual cultivars also vary in the amount of vegetative growth and may impact the speed and accuracy of the harvest crew. As an example of differences in field conditions that harvest crews may face, the images in Figure 1 show typical scenes from early and mid-season fields.

Figure 1. Pictures of a four-row production system in Santa Maria, CA in late January (left) and a two-row production system in Salinas, CA in July (right).

Data Collection

In this paper, we describe results from two separate periods of data collection on the harvest efficiency of California strawberry production systems. The first data collection period, carried out during eight weeks from June to August of 2019, took place in Santa Maria, CA. Data were collected from two production locations, both growing the "Monterey" cultivar under conventional management. A research assistant visited the fields in the afternoon, and the farm's harvest manager indicated which block would be harvested the following morning. The research assistant marked off four plots of 48 plants each and counted the number of berries on each plant, distinguishing between ripe berries that were marketable, ripe berries that were not suitable for the fresh market, berries that were past ripe, and berries that were "pink" or underripe. The next morning, after the pickers harvested the target block, the research assistant returned and re-counted the number of berries in each of these categories from the same plants.

Harvest efficiency, or the percentage of ripe berries successfully harvested, is the metric of primary interest in this study. Correctly categorizing fruit as ripe (rather than overripe or underripe) and distinguishing between marketable or unmarketable fruit is critically important in evaluating harvest efficiency and the value of missed fruit. Ripe fruit is deemed unmarketable generally if it is undersized, deformed because of poor pollination or other physiological defect, or impacted by pest or decay. Before data collection started on each production location, the harvest manager met with researchers to explain the instructions that were given to pickers regarding fruit classification and size, and a test sample was categorized and then confirmed by the harvest manager.

In 2020, a second, larger effort was initiated and managed by the California Strawberry Commission (CSC). Once again, harvest data were collected on a per-plant basis from eight production locations in Santa Maria, CA, and seven production locations in Watsonville, CA, representing production of three different cultivars under conventional management ("Monterey", "Cabrillo", and "Fortaleza"). Fields in Santa Maria are typically planted with four rows per bed, and fields in Watsonville are typically planted with two rows per bed. Both systems are represented in the data from 2020. The data collection process in 2020 was similar to that of 2019, with a few exceptions. In 2020 the total number of ripe berries was counted before harvest, but the pre-harvest count did not attempt to distinguish between marketable and unmarketable fruit. Rather, total counts of ripe fruit were recorded, and all remaining ripe fruit was picked by the research assistants following the harvest pass. The fruit that remained in the field after harvest was classified as marketable or unmarketable and counted. Underripe and overripe fruit was ignored. This process was repeated 49 times from June 16 to October 28 across the 15 locations. As with the 2019 effort, harvest managers verified the classification of berries as marketable or unmarketable before data collection began.

Empirical Analysis

Improved understanding of harvest efficiency in strawberry production systems can contribute to more accurate analyses of new developments in robotic harvest technology, the design of more effective employee compensation regimes, studies of food waste, and the impact of pest and disease pressure on production and profitability outcomes. The overall level of abandoned or missed fruit is of major interest, but so too are the effects of the production system (two-row versus four-row) and cultivar on harvest efficiency and the way that harvest efficiency evolves as field conditions change over the course of the growing season. To this end, we estimate a linear relationship between the fruit left in the field as a percentage of total pre-harvest fruit loads, and independent variables representing management under two-row or four-row systems (as commonly utilized in Watsonville and Santa Maria, respectively), strawberry variety, week of year to account for changes in the plant structure and field conditions over the course of the growing season, and whether growers harvest for both the fresh and processing markets, which impacts picker compensation and behavior. Our empirical model also controls for the year of the data collection to account for potential differences in data collection procedures.

We estimate a pooled OLS model using a simple linear framework as follows:

$$FNH_{it} = \beta_0 + \boldsymbol{\beta X_{it}} + \epsilon_{it} \quad (1)$$

where FNH_{it} represents the percentage of total berries that are not harvested for producer *i* at time *t*, and $\mathbf{X_{it}}$ is a vector of explanatory variables specific to each producer and sampling event.

We anticipate that a four-row production system results in more crowded beds, more obscured fruit, and a higher rate of fruit left in the field than in a two-row system. Different strawberry varieties have differences in plant structure and growth patterns, and it is possible that the robust plant growth seen with the Monterey variety increases the percentage of ripe fruit missed by harvesters. As such, we include a binary variable distinguishing Monterey from other varieties and expect a coefficient estimate with a positive sign. We would expect the week of the year to have a positive relationship with the percentage of fruit left behind, as strawberry plants get larger with more foliage obscuring the fruit as the growing season progresses. It is considered a best management practice to instruct pickers to remove all ripe fruit from the field, regardless of whether processing fruit is also collected for sale. However, in cases in which processing fruit is also collected and sold, pickers may be incentivized to harvest more fruit and we would expect a negative sign on the parameter for the binary "fresh market" variable.

Table 1. Sample Sizes and Percentages of Missed Fruit across Two Seasons of CA Strawberry Harvest for Two-Row and Four-Row Plantings

	N			Avg. Ripe Berries per Plant		Avg. % Ripe Berries Not Harvested		
	Locations	**# of obs.**	**Plants per obs.**	**Pre-harvest**	**Post-harvest**	**Market-able**	**Unmarket-able**	**Total**
4-row 2019	2	11	192	2.21	0.88	19.8%	58.2%	38.7%
4-row 2020	8	26	160	2.64	0.71	*	*	29.6%
2-row 2020	7	23	160	3.10	0.38	*	*	12.2%

Note: *Marketable and unmarketable berries were not differentiated in pre-harvest counts in 2020.

Results

Figure 2 presents the percentage of abandoned fruit, including both marketable and unmarketable berries for each data collection date in both the 2019 and 2020 study years. This figure shows that the percentage of missed fruit increased over the course of the growing season, was higher in the four-row beds than in two-row beds, and was found to be consistently higher during the 2019 study year. In the four-row production system sampled in 2019, 39% of all ripe berries, including 20% of the production suitable for the fresh market and 58% of unmarketable fruit, was left in the field (see Table 1). The harvest efficiency was higher in the 2020 study year, with 30% of all ripe berries left behind in the four-row system, and only 12% left behind in the 2020 two-row system (see Table 1). Because pre-harvest counts did not distinguish between marketable and unmarketable fruit in the 2020 study year, it is not possible to compare the harvest efficiency in marketable and unmarketable fruit separately.

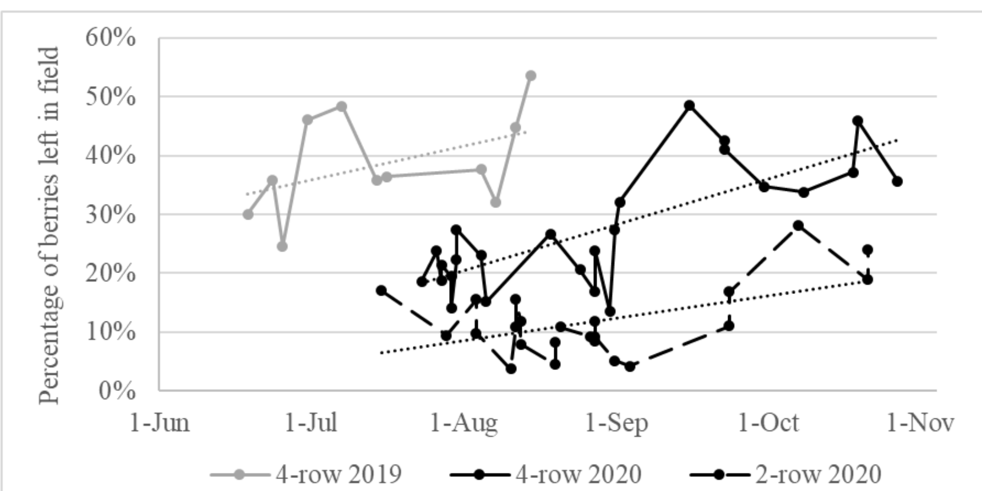

Figure 2. The percentage of berries left in the field over the course of the growing season for each cropping system and data collection year. Includes total berries (marketable and unmarketable) and all growers and cultivars.

In addition to a general decrease in harvest efficiency over the course of the growing season, the underlying data also show meaningful variability across farms. Figure 3 presents the average percentage of fruit left in the field for each individual farm over the growing season, with separate data series for the 2019 four-row, 2020 four-row, and 2020 two-row farms. Total fruit loss percentages range from 9.1% to 16.4% in the two-row system in 2020, 19.8% to 34.9% in the four-row system in 2020, and 37.7% to 42.5% in the four-row system in 2019. This variation across farms and years could be due to differences in harvest management strategies, including picker instructions regarding field sanitation, pay structure, and field conditions. It is also important to emphasize that these numbers count all ripe fruit, including berries that are not suitable for sale in the fresh market.

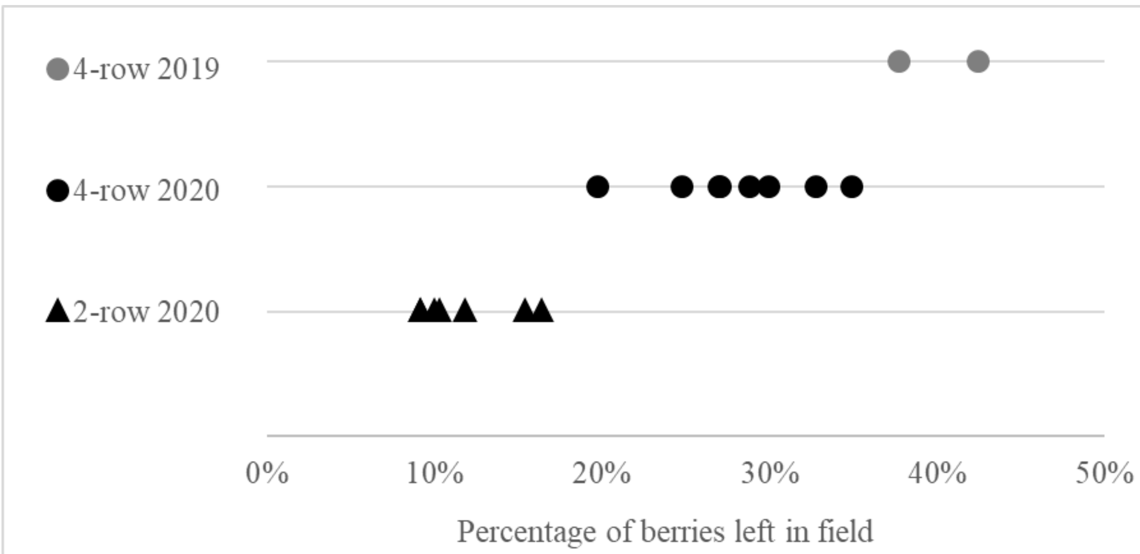

Figure 3. The average percentage of total berries left in the field for each cooperating grower over the course of the growing season. Each data series reflects a different row-spacing and data-collection year combination.

Table 2 presents the parameter estimates from two alternative specifications of the econometric model. Model 1 is the simplest model, including the percentage of total fruit not harvested as a linear function of the year of data collection, whether the data come from a two-row or four-row production system, the week of the calendar year in which data were collected, and a constant term. The regression results confirm what we visually detect in Figures 2 and 3. The two-row planting system common in the Watsonville region is associated with a 16 percentage point reduction in missed fruit relative to the four-row system most common in the Santa Maria area. The coefficient on the "week number" variable indicates that each passing week of the growing season is associated with an increased fruit loss of 1.8 percentage points, likely due to deteriorating field conditions and larger plants. Finally, there is a large difference between the harvest efficiency data collected in the 2019 effort relative to the data collected in 2020. All else equal, the 2019 crop year is associated with a level of missed fruit that is 21 percentage points higher than the 2020 crop year.

Model 2 includes two additional binary variables. The first is the "fresh market" variable, indicating whether harvest managers instructed crews to collect only the fruit that is suitable for the fresh market (= 1) or if fruit for the juice market is also harvested (= 0). The second binary variable indicates whether the field is planted with the Monterey cultivar (= 1) or one of the other cultivars (= 0). The sign and statistical significance of each variable included in Model 1 is maintained in Model 2. Neither the "Monterey" nor the "fresh market" variable are found to have a significant effect on the percentage of fruit left in the field, and the overall model fit declines slightly relative to that of Model 1 as measured by the adjusted R2.

Table 2. Regression Results from Two Linear Models of the Percentage of Berries Not Harvested in CA Strawberry Fields during 2019 and 2020 Crop Years

	(1) Fruit Not Harvested	**(2) Fruit Not Harvested**
Constant term	-0.363*	-0.355**
	(0.14)	(0.13)
Two-row system	-0.164***	-0.143***
	(0.02)	(0.03)
Week number	0.018***	0.019***
	(0.00)	(0.01)
2019 study year	0.213***	0.240***
	(0.03)	(0.05)
Fresh market		-0.025
		(0.03)
Monterey		-0.022
		(0.05)
N	60	60
Adj. R-squared	0.676	0.670
Model F	41.176	24.911

Note: Standard errors are in parentheses *** $p < .01$, ** $p < .05$, * $p < .1$

Limitations

There are a number of limitations that must be kept in mind when interpreting these results. As previously discussed in the data section, the pre-harvest counts in 2020 did not distinguish between marketable and unmarketable fruit. This precludes us from extrapolating the results of this analysis to an industry-wide estimate of the market value of in-field food waste. Although the collected data show that the post-harvest proportions of marketable and unmarketable fruit were similar in both years, we cannot estimate with certainty how much fruit destined for the valuable fresh market was lost. Thus, further in-field data collection would be necessary for more robust analysis of picker compensation schemes or other research questions that depend critically on the market value of abandoned fruit.

Another limitation is that the data from the 2020 growing season include 15 different growers, and each grower and individual harvest manager may place a different level of emphasis on field sanitation when interacting with harvest crews. These management factors are difficult to account for with a small dataset, and the variability that we see in harvest efficiency across farms cannot be attributed to management and other potential causes (e.g., field conditions) separately. Although growers have a strong interest in these harvest efficiency results because of their potential to inform management changes, a different experimental design would be required to identify the effectiveness of different harvest management strategies and incentive structures.

Finally, the difference in harvest efficiency rates between the 2019 and 2020 data collection processes warrants further attention. While the data collection efforts were managed by different groups, and the data collected by different individuals, neither the data collection processes nor the harvest systems were substantially different in the two years. A potential explanation could be that overripe or underripe berries were miscategorized in 2019 and were rightly passed over by the harvest crew. This finding would inflate the percentage of fruit perceived as "missed" in 2019. However, not only did research assistants confirm their categorization process with harvest managers at the beginning of the season, a closer look at the primary data suggests that miscategorization is not a likely explanation.

The 2020 data show a pre-harvest average of 3.1 and 2.6 berries per plant in the two-row and four-row systems, respectively (see Table 1). After the harvest pass, the plants in the 2020 two-row system had an average of 0.3 berries remaining, and plants in the 2020 four-row system had an average of 0.7 berries remaining. The data from 2019 show considerably more fruit remaining on the plants after harvest (0.88 berries per plant), but only 2.2 ripe berries per plant in the pre-harvest count. That is, fewer berries were recorded on each plant prior to harvest in 2019 than in 2020, suggesting that miscategorization of underripe or overripe fruit in 2019 is an unlikely explanation for the difference in results.

Conclusions

With this study we present the first assessment of "harvest efficiency" (defined as the percentage of ripe berries that is successfully harvested) in California strawberry production and show that a significant amount of fruit is routinely missed in harvest operations. High rates of missed fruit in human harvest passes are relevant to questions involving the relative attractiveness of robotic harvest systems and the pest and disease dynamics observed in strawberry production. Although a robust analysis of the value of in-field food waste in California strawberry production is beyond the scope of this study, our results can provide some guidance on the scale of the issue. In calendar year 2020, roughly 1.7 billion pounds of conventional strawberries were produced in California (USDA-AMS, 2023). If we apply the more conservative harvest efficiency rates for two-row and four-row plantings from the 2020 data collection year to corresponding regional production volumes, we estimate that approximately 200 million pounds of conventional strawberries suitable for the fresh market were left in the field in 2020. The volume of unmarketable berries passed over by harvest crews would be nearly three times that amount.

Discussions with strawberry growers indicate that these results are surprising and warrant further study. If we assume profit maximizing behavior, growers are signaling that they believe the current harvest management systems and compensation structures are economically efficient. That is, the additional cost required to adopt a slower, more careful harvest would be greater than the value of the resulting increase in harvested fruit. The results presented here may lead to reconsideration of current practices, as the volume of missed fruit is greater than many have previously assumed.

While we have contributed to the understanding of harvest efficiency levels in California strawberry production, it is unknown how much indirect damage, through additional pest and disease pressure, the abandoned and rotting fruit may cause over the course of the growing season. Future studies on IPM methods in strawberry production may focus on setting a "threshold" of fruit that is acceptable to be left in the field. This type of guidance, common in pest management extension and outreach efforts, is meant to provide growers with an achievable target that could improve economic outcomes, lower fruit waste, and align with best practices for pest control. Establishing such guidance is difficult for two reasons. First, research trials aimed at quantifying the relationship between harvest efficiency and pest pressure require large blocks and labor intensive treatment and data collection efforts. Second, differences in growing practices, crop value (within and across growing seasons), and variation in disease or insect resistance across cultivars could make a meaningful threshold difficult to establish.

The harvest efficiency results that we present in this paper can be seen as somewhat positive for the prospect of robotic harvest technology in strawberries. Preliminary analysis of robotic harvest systems assumed harvest efficiency rates that were much lower than those achieved by human harvest crews (Delbridge, 2021). Our results suggest that robotic systems may not be as far behind as previously understood. However, we find that manual harvest efficiency is highest in two-row plantings and early in the production season, which are also the conditions under which robotic harvesters are likely to perform best. Further study will be needed to assess the feasibility of continually improving robotic systems and how they can most effectively supplement human labor.

Acknowledgements

The authors would like to acknowledge the data collection support of the California Strawberry Commission, participation of cooperating strawberry growers, and research assistance provided by Kale Varvel and Luis Isaiah Valdez.

References

Ampatzidis, Y.G., and M.D. Whiting. 2013. "Training System Affects Sweet Cherry Harvest Efficiency." *HortScience* 48(5):547–555.

Baena, R., E.S. Araujo, J.P.A. Souza, A.M. Bischoff, P.H.G. Zarbin, M.A.C. Zawadneak, and F.L. Cuquel. 2022. "Ripening Stages and Volatile Compounds Present in Strawberry Fruits Are Involved in the Oviposition Choice of Drosophila Suzukii (Diptera: Drosophilidae)." *Crop Protection* 153:105883.

Bolda, M.P., J. Murdock, B. Goodrich, and D.A. 2021. *Sample Costs to Produce and Harvest Strawberries*. Davis, CA: University of California, Davis, Extension Publication. Available online: https://coststudyfiles.ucdavis.edu/uploads/pub/2022/01/04/strawberrycentralcoastfinaldraft-121321.pdf.

Bolda, M.P., S.K. Dara, O. Daugovish, S.T. Koike, A.T. Ploeg, G.T. Browne, S.A. Fennimore, T.R. Gordon, S.V. Joseph, B.B. Westerdahl, and F.G. Zalom. 2023. *UC IPM Pest Management Guidelines: Strawberry*. Davis, CA: University of California, Davis, UC ANR Publication 3468. Available online: https://ipm.ucanr.edu/agriculture/strawberry/.

Dara, S.K. 2015. "Integrated Pest Management." In S.K. Dara, M. Bolda, B. Faber, J. Fallon, M. Sanchez, and K. Peterson, eds. *Strawberry Production Manual*. Santa Maria, CA: Cachuma Resource Conservation District, pp. 61–74.

Delbridge, T. 2021. "Robotic Strawberry Harvest Is Promising but Will Need Improved Technology and Higher Wages to Be Economically Viable." *California Agriculture* 75(2):57–63.

Hamilton, S.F., T.J. Richards, A.P. Shafran, and K.N. Vasilaky. 2022. "Farm Labor Productivity and the Impact of Mechanization." *American Journal of Agricultural Economics* 104(4):1435–1459.

Hill, A.E., and J. Burkhardt. 2021. "Peers in the Field: The Role of Ability and Gender in Peer Effects among Agricultural Workers." *American Journal of Agricultural Economics* 103(3):790–811.

Goodhue, R.E., M.P. Bolda, D. Farnsworth, J.C. Williams, and F.G. Zalom. 2011. "Spotted Wing Drosophila Infestation of California Strawberries and Raspberries: Economic Analysis of Potential Revenue Losses and Control Costs." *Pest Management Science* 67:1396–1402.

Soper, R. 2020. "How Wage Structure and Crop Size Negatively Impact Farmworker Livelihoods in Monocrop Organic Production: Interviews with Strawberry Harvesters in California." *Agriculture and Human Values* 37(2):325–336.

U.S. Department of Agriculture. 2023. *Specialty Crop Movement Reports*. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service. Available at https://www.ams.usda.gov/market-news/custom-reports.

U.S. Department of Agriculture. 2023. *QuickStats*. Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service. Available at http://www.nass.usda.gov/Quick_Stats/.