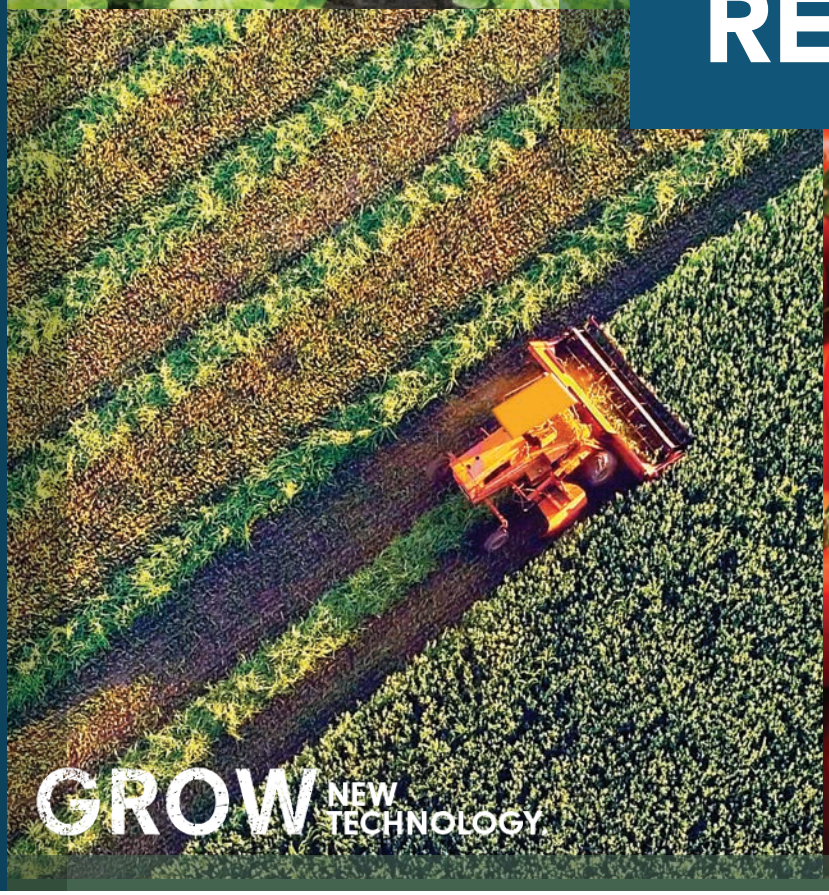
2021

GLOBAL HARVEST AUTOMATION REPORT



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WESTERN GROWERS FOREWORD

By Walt Duflock, Vice President of Innovation at Western Growers

Over the past several decades, labor has been one of the top three challenges facing agriculture (along with water and food safety). Labor is a key requirement for specialty crop growers who produce the fresh fruits, vegetables and nuts that are increasing in popularity among consumers. Crucial tasks include planting, weeding, thinning, harvesting, and transporting workers and product. The problem has gotten worse over the past few decades because the number of farm workers has decreased by 70 percent across the two key categories: (1) family farm workers, whose numbers have dropped as small family farming operators sell out, in many cases to large operators, so they left the ag workforce; and (2) hired farm workers, who have left the ag industry for other industries, with new farm workers difficult to find.

The result is a significant and growing gap between the labor available for specialty crops and the labor needed by specialty crop growers, which worsens each year. As with many ag problems, innovation is the solution. From the green revolution driven by Borlaug's improvements to wheat genetics, to Haber-Bosch's synthetic fertilizer and modern tractors that allow farmers to do more with less manpower than ever, innovation allows growers to grow more today with fewer inputs and fewer people. As harvest labor can represent 20-50 percent of production expenses for specialty crop growers[1], sufficient labor is of vital importance to harvest specialty crops.

To tackle this, Western Growers launched the Global Harvest Automation Initiative in February 2021. One of the main aims was to take a comprehensive look at the entire harvest ecosystem and provide two things to the Western Growers' membership: (1) a quantitative look at how much harvest innovation is impacting their operations across fresh products for specialty crops, where the most progress is occurring, and why; and (2) an in-depth view of the innovators who are doing the heavy lifting by crop type, so growers would know who to contact based on the crops they grow. This report addresses both objectives. It provides a single document for the entire agriculture and agtech ecosystem so that everyone understands the status quo at the end of 2021 and which innovators are leading the way in helping to solve the labor problem.

Western Growers would like to thank the following people for providing major support on the Global Harvest Automation Initiative:

1. Roland Berger team members – Wilfried Aulbur, Giovanni Schelfi, Eva Barbier and Lily Chen, who did a great job of taking this project from idea to execution in less than six months
2. Our partners who helped define the "Tech Stack" – Trimble (Mike Dentinger), Oxbo International (Kathryn Van Weerdhuizen, Scott Korthuis, Chris Schloesser), Ramsay Highlander (Frank Maconachy), NWFM LLC (Keith Veselka), Red Rooster Consulting (Scott Jacky), Milano Technical Group (Dominic Milano, Soummya Datta), Grimmway Farms (Jeff Morrison), Church Brothers (Josh Ruiz), Superfresh Growers (Mike Van Pelt), Bosch in North America (Andreas Fuchs, Fabian Henrici)
3. Western Growers team members who helped get the project to a "Version 1.0" product release with this document with help in a wide variety of areas – Dennis Donohue, Teresa Scattini, Ann Donahue, Cory Lunde, Stephanie Metzinger, Tim Vu, Kendra Clark, Kim Sherman and Emily Lyons. ■

1 Average share of production costs comprised by labor for selected produce crops | USDA

ROLAND BERGER FOREWORD

By Wilfried Aulbur, Senior Partner at Roland Berger

The history of agriculture consists of dramatic efficiency improvements. A hundred years ago, about 30 percent of the U.S. population worked in agriculture and contributed around 14 percent to the nation's GDP.[2,3,4] Today, these numbers are about 1 percent and 0.9 percent, respectively.[5,6,7] As more and more people left agriculture to look for new employment opportunities in cities, farmers found ways to do more with less, to increase output with less workforce and ensure that U.S. families could feed their own at acceptable price levels. As a result, gross value added per employed labor evolved from ~$400 to ~$73,800 over the last century.

In some sense, the challenges that the farming sector is facing today could be more of the same. Yet, the transformation and challenges in terms of climate change, consumer expectations and labor scarcity are coming faster and threaten – at least as far as climate change is concerned – the basis of agricultural existence: fertile, well-watered soils.

Farmers and the agricultural ecosystem will have to face these challenges head on. Success will depend on open communication and collaboration across all stakeholders. Growers, innovators, investors and the government need to work together to ensure sustainable and affordable food production in the 21st Century. In this context, sustainability implies not only environmentally conscious production but also an environment that allows profitable farm operations.

Technology will once again be vital to achieve these goals. Rightly, the focus of the Global Harvest Automation Initiative by Western Growers is on identifying harvesting solutions that complement human labor, reduce physically demanding work, and increase job attractiveness via technology. Western Growers aims to standardize technology interfaces to speed up development efforts and scale up commercial roll out of successful solutions. We at Roland Berger believe that this approach is essential to increase funding for the sector and to drive change within timelines that are meaningful for growers.

Working with Western Growers, its members and various start-ups on this impact and market maturity report has been a real privilege. Understanding growers' needs, their determination to succeed in challenging environments and their openness to leverage technology in the process is an inspiration. We hope that the report will support their efforts in finding automation solutions that meet their needs in terms of cost, quality and overall efficiency. Working with start-ups has also been exciting and we hope that our efforts help them to attract the funding and visibility they need to bring their solutions to market.

Finally, the dedication and competence of Western Growers staff has been a constant source of motivation for us. We are proud and thankful to work alongside an organization that is dedicated to connect all ecosystem participants – growers, start-ups, established companies, investors and government – in the quest to provide sustainable, healthy food, attractive employment and investment opportunities and, last but not least, a stable tax base in the 21st Century. ■

2 Farm Population Lowest Since 1850's | The New York Times (July 1988)
3 Fortunly's Annotated Guide to a Century of US GDP by Year Facts (1920-2018) | Fortunly.com
4 US Department of Agriculture (USDA) data
5 Ag and Food Sectors and the Economy (Updated November 2021) | USDA
6 World Bank data
7 USDA data

1.0

EXECUTIVE SUMMARY

1.0 EXECUTIVE SUMMARY

Growing labor shortage is a source of increasing concern for the global agriculture industry. Over the past decades, the gap between available labor and required labor has increased due to an aging domestic agriculture workforce, growing foreign labor costs and competition for labor from other sectors. Labor is a key requirement to harvest specialty crops such as fresh fruits, vegetables and nuts. It typically represents 20-50 percent of many specialty crop budgets. Recently, the labor gap has grown wider due to the unforeseen market disruptions caused by the COVID-19 pandemic. But like many past evolutions in agriculture, technology can provide solutions. Harvest mechanization and automation can help tackle the growing labor shortage and ensure food security for a growing population, while elevating and upskilling an entire workforce.

This report is the first in a new annual series that will track, measure and report on industry progress in harvest automation across the fresh produce industry. The report is a unique combination of information gathered via public sources (USDA, CFDA, UC Davis, FAO etc.), and dedicated interviews with industry experts (growers, start-ups, investors etc.), complemented with insights from two sets of surveys; one directed at specialty crop growers and one at start-ups. The report provides a comprehensive view of the status and impact of harvest automation and highlights innovation leaders. Special focus for this edition was on selected crops, namely apples, blueberries, strawberries, broccoli, lettuce and almonds.

Primarily, the study finds that the overall advancement of harvest automation in the fresh produce industry is so far limited, mainly due to the technical difficulties in replicating the human hand to harvest delicate crops. The only exception is almonds where virtually 100% mechanization has been achieved over the past decades. However, progress is being made on other crops. Around 65 percent of participating growers indicated to have invested in automation over the past three years, with an average annual spend of $350,000-400,000 per grower. Most progress appears to occur on pre-harvest (weeding, thinning etc.) and harvest assist activities (harvesting platforms, autonomous ground vehicles). Impact on cost, quality and food security is so far limited, in line with the rate of automation, and most growers are keen to adopt automation to bridge the growing labor gap and

ensure crops can be picked in time, rather than to save money. Looking ahead, growers have high expectations of advancement across pre-harvest and harvest assist activities, reaching an average of 30-60 percent by 2025. Expectations for harvest automation are more reserved, reaching on average 20 percent by 2025.

Our market traction analysis of harvest automation start-ups confirms the early development stage of the market, measured in terms of funding received, number of paying customers and number of robots in service. Approximately 75 percent of participating start-ups are in the pre-venture (35 percent) or seed (40 percent) round, while the remaining 25 percent have recently completed Round A or Round B funding. No start-ups reported completion of a C+ funding round. Most (approximately 75 percent) have fewer than five paying customers, and a similar proportion have fewer than five robots in service. To date, most market-ready automation start-ups in the specialty crop sector focus on comparatively easier harvest assist and pre-harvest activities. Naïo Technologies and Burro are identified as innovation leaders in pre-harvest and harvest assist, respectively. Yet, several harvest-focused start-ups are making progress and have established an initial customer base. For example, Advanced Farm and Tortuga developed strawberry picking solutions and are scaling their technology across other crops.

To accelerate harvest automation across the fresh produce industry, Western Growers is playing a unique role in bringing together the entire agriculture community. First, Western Growers is driving collaboration with non-harvest technologies that support harvest automation, including promoting genetic seed innovations, conducting research around new farming practices and fostering industry collaboration. Second, Western Growers can support additional R&D and commercialization of new technologies through increased access to funding, establishment of public-private partnerships and coordination of public funding opportunities. Third, Western Growers is exceptionally well-positioned to support start-ups in their development path by connecting them with growers, facilitating access to supplementing technology and providing data transparency in terms of quality and costs. Progress of actions and impact of harvest automation will be consistently tracked and reported in future reports. ■

2.0

INTRODUCTION

2.1
OBJECTIVE OF THE GLOBAL HARVEST AUTOMATION INITIATIVE (GHAI)

Western Growers launched the Global Harvest Automation Initiative in February 2021. It aims to drive sustainable and domestic food security by accelerating harvest automation across the fresh produce industry, with the ambition of automating 50 percent of harvest in the U.S. within 10 years. The initiative also seeks to close the growing gap between agricultural labor needs and available farm labor by helping to progress and deploy innovative automation solutions. As well as bridging the growing labor gap, harvest automation has the power to improve the overall employment attractiveness of the agriculture harvesting work by introducing new skill sets and career paths to an entire labor force.

To achieve its objective, the Global Harvest Automation Initiative launched several key projects. These are uniquely designed to solve the agriculture industry's labor woes, and simultaneously help harvest automation start-up companies commercialize and scale at a more rapid pace. Ongoing projects are:

- A technology stack and innovator cohort: Builds a platform to allow harvest automation start-ups to commoditize 60-80 percent of the technology stack (a documented set of technical interfaces that will help startups leverage industry-standard components so their solutions can get into fields and markets faster), and provides commercialization support for a cohort of start-ups with proven traction in the market

- Impact and market traction analysis: Sets common metrics and tracks industry-wide impact to demonstrate value and drive adoption of harvest automation, as well as identifying innovation leaders gaining most traction

This report embodies the first version of the impact and market traction analysis. It will be updated annually to track and report on the industry progress around harvest automation in the fresh produce industry.

2.2
OBJECTIVE OF THE GLOBAL HARVEST AUTOMATION REPORT

The Global Harvest Automation Report combines the findings from the impact and market traction analyses. It aims to achieve three main objectives. First, it describes the global agriculture environment and its main challenges with a focus on the U.S. fresh produce industry and illustrates the main challenges harvest automation presents from a grower and start-up perspective. Second, the report provides transparency about the status of harvest automation in the fresh produce industry and establishes a baseline for future benchmark exercises. The metrics gathered measure the aggregated impact of automation across harvesting cost, produce quality and food security across a variety of specialty crops, including fruits, vegetables and nuts. Third, the report identifies and highlights current leading start-ups that focus on automating harvest and harvest-related activities for the fresh produce industry.

To reflect these objectives, the report is structured around four main chapters. Chapter 3 highlights the main challenges facing the agriculture industry and harvest automation, from a grower and start-up perspective. Chapter 4 summarizes the main findings of the impact analysis, with a general automation status report across all specialty crops, and a more detailed status and impact assessment for six specific specialty crops, namely apples, blueberries, strawberries, broccoli, lettuce and almonds. Data was gathered through dedicated interviews and by surveying grower members of Western Growers and associated partner organizations. Chapter 5 summarizes the main findings of the market traction analysis, identifying innovation leaders in terms of total funding raised, number of paying customers and number of robots in service. Data for this analysis was gathered through dedicated interviews and by surveying global harvest automation start-ups active in the fresh produce industry. The chapter does not provide an exhaustive overview of all harvest automation start-ups, rather those who took part in the survey. Lastly, Chapter 6 provides overall conclusions and considerations for future reports. ■

3.0

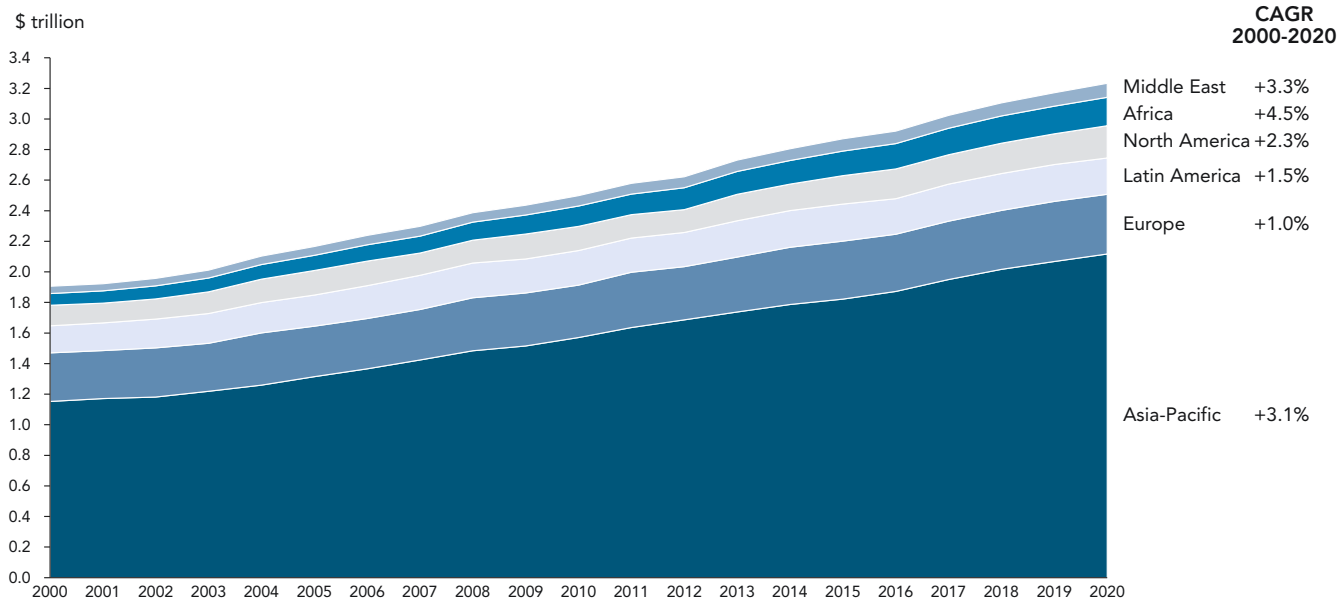
MAIN CHALLENGES IN THE AGRICULTURE INDUSTRY

3.1
INDUSTRY OVERVIEW

The global value added of the agriculture, forestry and fishing industry reached $3.2 trillion in 2020, representing about 4 percent of global GDP that year.[8,9,10] Asia and the European Union (EU) are the largest agriculture regions, accounting for 65 percent and 12 percent of global value added respectively (see Figure 1). Between 2000 and 2020, all regions experienced an increase in agriculture value added. Africa, Asia-Pacific and the Middle East saw the most growth, realizing a CAGR of 4 percent, 3 percent and 3 percent respectively. The largest agriculture products include broadacre crops, meat, and fruit, which accounted for 73 percent of gross production combined in 2020 (see Figure 2). Overall, the agriculture industry has proven resilient during the COVID-19 pandemic due to the continued need for food. This is reflected by a 4 percent increase in global value added between 2019 and 2020.

THE GLOBAL VALUE ADDED BY THE AGRICULTURE, FORESTRY AND FISHING INDUSTRY REACHED $3.2 TRILLION IN 2020, REPRESENTING ~4% OF GLOBAL GDP IN 2020

Global agriculture, forestry and fishing value added, 2000-2020 [$ real trillions]

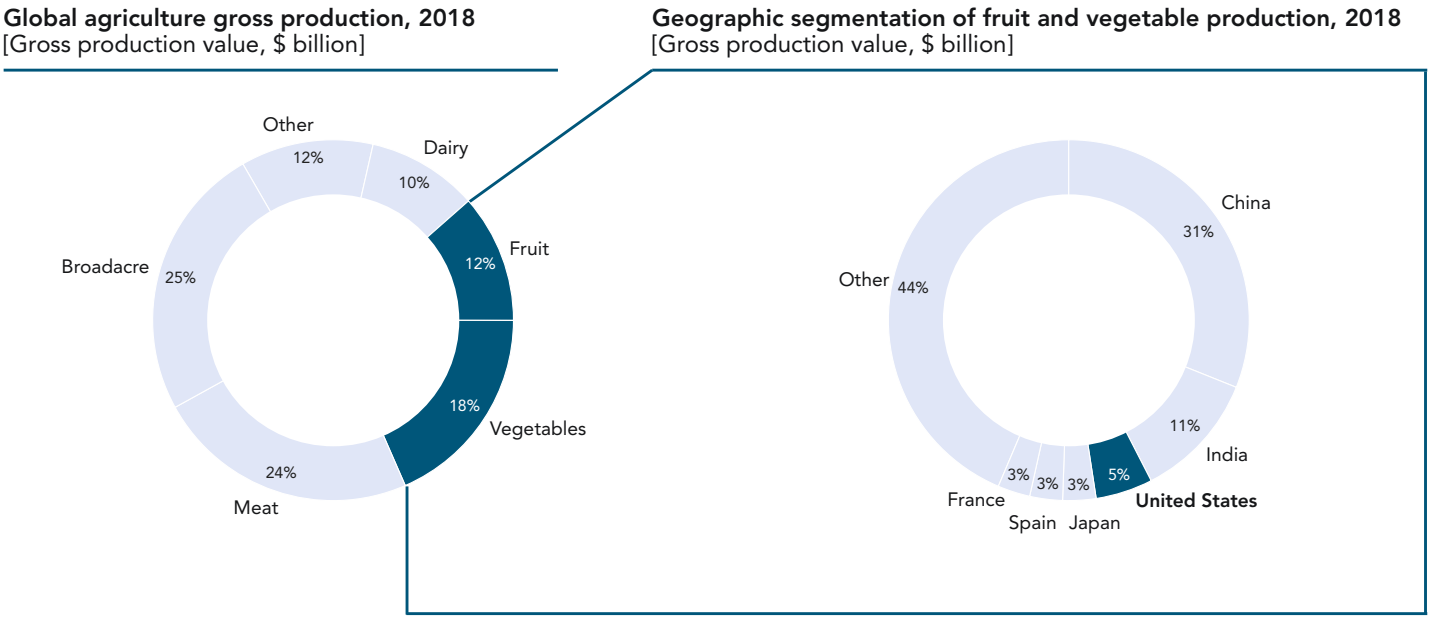


Source: IHS, Roland Berger

Figure 1 Global agriculture, fishing and forestry added value, 2000-2020 [real $ trillion]

8 Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs
9 Agriculture, forestry, and fishing, value added (current US$) | Data (worldbank.org)
10 GDP (current US$) | Data (worldbank.org)

VEGETABLE AND FRUIT PRODUCTION ACCOUNTED FOR ~30% OF GLOBAL AGRICULTURE GROSS PRODUCTION VALUE IN 2018, WITH THE U.S. AS THE THIRD LARGEST PRODUCER AFTER CHINA AND INDIA



Source: FAOSTAT, Roland Berger

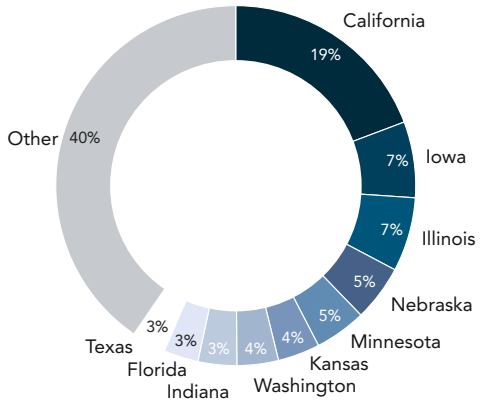
Figure 2 Global overview of crop segmentation in GDP, 2020 [$ billion]

The agriculture industry is a key component of the U.S. economy. Agriculture, food, and related industries contributed $1.1 trillion to the country's GDP in 2019, a 5 percent share of the total, according to the U.S. Department of Agriculture (USDA). America's farms contributed $136 billion, or about 1 percent of U.S. GDP. Crops accounted for around 50 percent of farm contribution.[11] Crop production is concentrated mainly in California and the Midwest, with California, Iowa, and Illinois accounting for around 33 percent of total U.S. crop cash receipts.[12] The largest agricultural crop products include corn, soybeans, and vegetables. Specialty crops – defined as fruits, vegetables, tree nuts, dried fruits, horticulture and nursery crops by the USDA – account for 26 percent of total crop cash receipts (see Figure 3). This report focuses primarily on specialty crops grown in the United States.

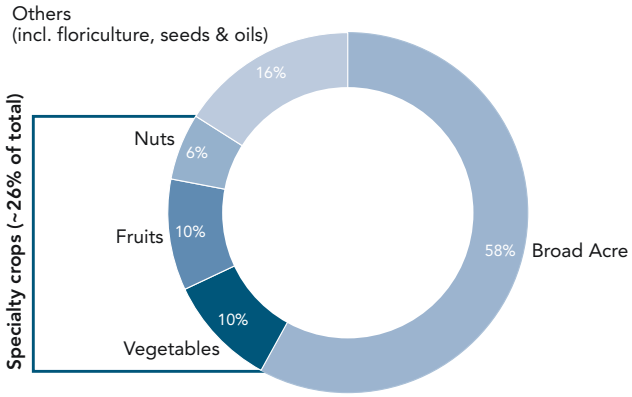
11 Ag and Food Sector and the Economy | USDA
12 Cash receipts include all cash received from an external source (e.g., customers, government grants, loans)

U.S. CROP PRODUCTION IS MAINLY CONCENTRATED IN CALIFORNIA AND THE MIDWEST, ACCOUNTING FOR ~50% OF TOTAL U.S. CROP CASH RECEIPTS IN 2020 – SPECIALTY CROPS ACCOUNT FOR ~25% OF TOTAL CASH RECEIPTS

Top 10 US crop-producing states, 2020
[Crop cash receipts, $ billion]



US crop segmentation, 2020
[Crop cash receipts, $ billion]



Source: USDA, Roland Berger

Figure 3 Overview of the agriculture industry in the United States, 2020 [$ billion]

California is the main producer of U.S. specialty crops, growing around 60 percent of the U.S. total in 2020.[13] More precisely, the Golden State grows over a third of the country's vegetables and two-thirds of its fruits and nuts.[14] Most grower survey responses which helped to inform this report originate from producers in the California region, as they make up the largest share of Western Growers members. Nevertheless, this report addresses the main challenges using a global lens, providing examples from around the world, including other U.S. states and Europe.

The agriculture industry is facing a multitude of challenges which are further elaborated in Chapter 3.3. In short, a growing population, farm labor shortages, increasing labor costs and regulatory burdens are putting pressure on growers globally. Modern farming practices could help growers overcome certain challenges. This paper further examines the opportunity and impact of harvest automation for growers of specialty crops as elaborated in the next chapter.

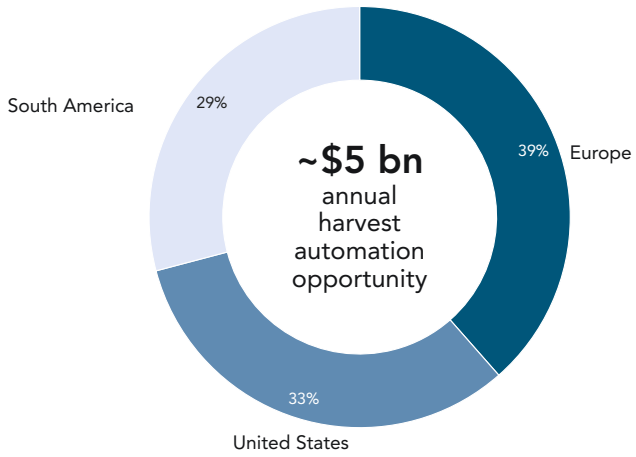
13 Value added years by State (2012-2021) | USDA
14 California Agricultural Production Statistics | California Department of Food and Agriculture (CDFA)

3.2
THE HARVEST AUTOMATION OPPORTUNITY

Modern farming practices could help growers overcome some of the challenges they currently face, from farm labor shortages to an ever-increasing population. The use of harvest automation in specialty crop production is among the most promising. Today, the harvest automation industry is still at an early development stage, with many technologies and solutions in R&D and pilot phases. As the industry continues to develop, markets such as the U.S., Europe, and South America could present a total opportunity of around $5 billion annually. Europe would represent the biggest opportunity, at $1.8 billion annually, followed by the U.S. at $1.5 billion and South America at $1.4 billion (see Figure 4). The first version of the report focuses on limited regions with reasonable data. Subsequent versions could look at other regions such as Asia.

AS HARVEST AUTOMATION IN THE FRESH PRODUCE INDUSTRY CONTINUES TO DEVELOP, MARKETS SUCH AS EUROPE, THE U.S. AND SOUTH AMERICA COULD PRESENT A TOTAL OPPORTUNITY OF ~$5 BILLION ANNUALLY

Annual harvest automation opportunity in the specialty crop industry [$ billion]



Source: USDA, FAOSTAT, Roland Berger

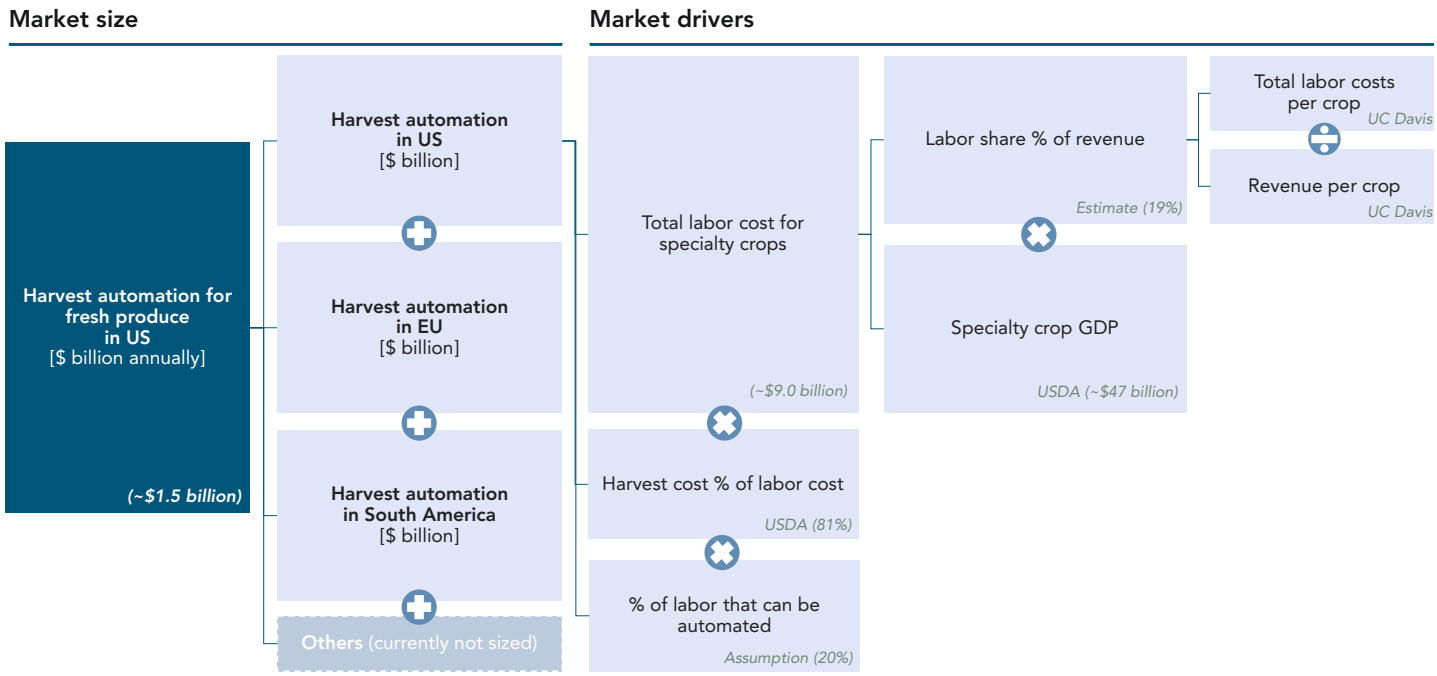
Figure 4 Annual harvest automation opportunity in Europe, U.S. and South America [$ billion]

The key market drivers behind these opportunities are total harvest labor cost and the share of labor that can be automated. These were used to derive the regional market figures, as shown in Figure 5.

As demand for food increases to sustain the growing population, value added from specialty crops, or specialty crop GDP, will continue to grow.[15] According to USDA, crop cash receipts are projected to increase by 16 percent between 2020 and 2030.[16] Additionally, fresh fruits and vegetables are expected to grow by around 2 percent per year, giving a total increase of 30 percent over the next decade.[17] As labor becomes more expensive and labor shortages more prevalent, farmers will turn to harvest

15 USDA Agricultural Projections to 2028 | USDA
16 USDA Agricultural Projections to 2030 | USDA
17 Specialty Crops in 2020: COVID-19 and Other Challenges | NC State Extension

THE KEY MARKET DRIVERS OF THE HARVEST AUTOMATION OPPORTUNITY ARE TOTAL HARVEST LABOR COST AND SHARE OF LABOR THAT CAN BE AUTOMATED, AND HAVE BEEN SYSTEMATICALLY ASSESSED FOR THE U.S., EU AND SOUTH AMERICA



Source: USDA, UC Davis, FAOSTAT, WorldBank, Roland Berger

Figure 5 Market drivers for harvest automation opportunity in Europe, U.S., and South America

automation solutions to mitigate the growing costs and guarantee food security. Increasing demand for specialty crops and increasing share of automation will further increase the harvest automation opportunity in the fresh produce industry. Based on the results from the grower survey, most growers have indicated a high level of interest in harvest automation solutions.

The harvest automation opportunity also could enable fundamental change in the agricultural industry. First, automation has the ability to improve labor conditions by automating arduous manual activities such as carrying heavy sacks, picking crops in extreme weather conditions, bending over, and allowing for more rewarding labor opportunities. Second, new innovations in agriculture allow the industry to attract more talent through exciting labor opportunities. Third, higher efficiency drives sustainability that benefits overall food security in the long run. Such benefits can help keep the production of specialty crops in current U.S. locations rather than moving operations abroad.

Despite the opportunities, the agriculture industry, as well as harvest automation itself still face several challenges.

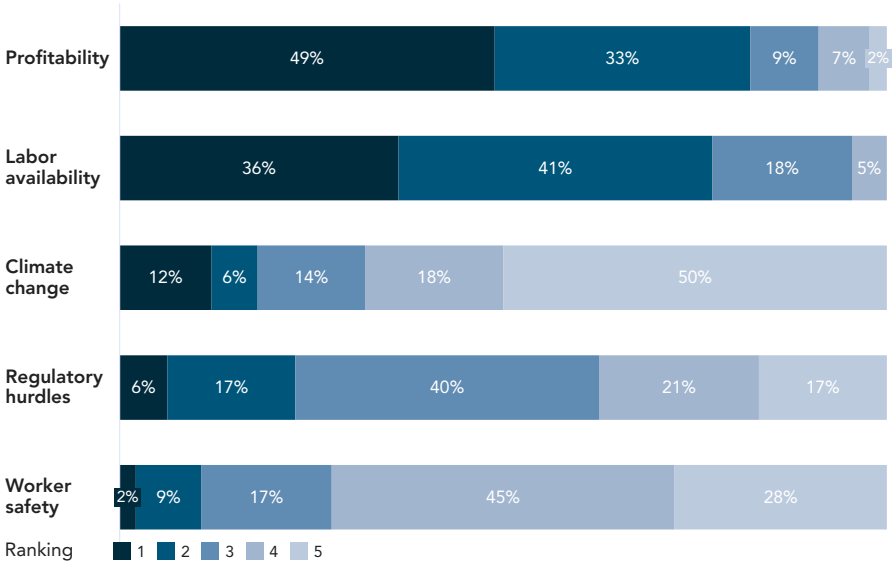
3.3
CHALLENGES FACING THE SPECIALTY CROP INDUSTRY

Today's agricultural industry is facing a multitude of challenges, such as a growing world population, farm labor shortages, aging farmer and farmworker populations, increasingly stringent regulatory environments, changing consumer preferences and climate change. As many of these challenges affect the cost of production and yield of crops, growers are struggling to remain profitable and sustain their farming operations.

Ensuring sufficient food for a growing population is the primary challenge. According to a recent UN report, the global population of 7.6 billion in 2017 is expected to grow to 8.6 billion by 2030 and 9.7 billion by 2050 – an increase of 13 percent and 29 percent, respectively.[18] Demand for food and other agricultural products is projected to increase by 50 percent, putting pressure on farmers to keep up supply.[19] To guarantee future food security, the industry is undergoing a major transformation, with specialty crop farmers accelerating modern farming practices and adopting new technologies. A similar transformation was seen with broad acre farms more than 80 years ago, when the introduction of combines helped to reduce labor costs and time in the field which relieved pressure on farmers. As such, the experience of the broad acre industry could help provide guidance in the development of the harvest automation for specialty crops.

In the following sub-chapters this report will provide more detail on the three main challenges facing the specialty crop industry, as highlighted in the grower survey: profitability, labor availability and climate change (see Figure 6). Survey respondents included members of

THE TOP 3 CHALLENGES IDENTIFIED BY SPECIALTY CROP GROWERS IN THE SURVEY ARE PROFITABILITY, LABOR AVAILABILITY AND CLIMATE CHANGE



1 = most important; 5 = least important

Source: Grower survey, Western Growers, Roland Berger

Figure 6 Ranking of industry challenges based on survey responses

18 Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100 (June 2019) | United Nations Department of Economic and Social Affairs

19 The future of food and agriculture: Trends and challenges (2017) | Food and Agriculture Organization of the United Nations

Western Growers and other partner associations, such as the Washington Tree Fruit Research Commission.

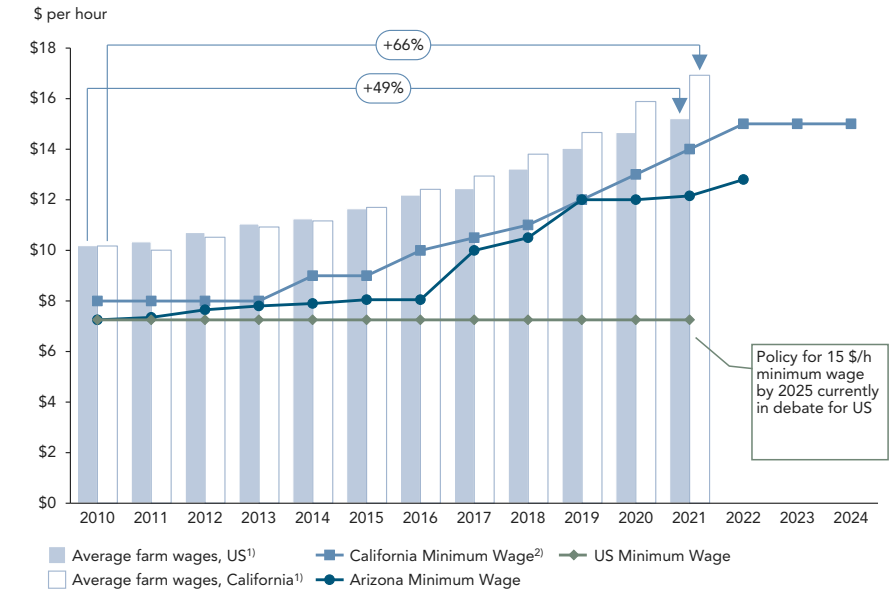
3.3.1 PROFITABILITY

Farm profitability is under pressure due to increasing operating costs and stagnating market prices. For specialty crop growers, there are four main drivers behind these issues. The first is rising labor costs. In California between 2012 and 2018, labor costs experienced their greatest dollar increase due to new requirements on piece-rate pay, overtime work (see Figure 7), paid sick leave and health care policies creating a negative impact on overall farm profitability.[20] The focus of regulations is aimed to improve workers' welfare, safety, and make farm work more attractive, however increased costs need to be overcome by increased farm productivity.

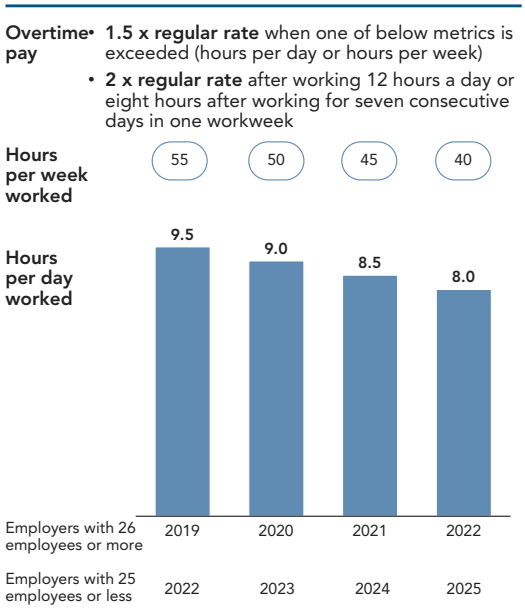
Survey findings confirm that labor costs are growing as a share of total costs, with the average labor cost exceeding 50 percent of total production costs in 2021. Looking ahead, around 50 percent of respondents expect labor costs to increase by 10-30 percent in the next 3-5 years, while 40 percent project that costs will rise by more than 30 percent (see Figure 8).

AVERAGE FARM LABOR WAGES IN CALIFORNIA HAVE RISEN BY 66% SINCE 2010 AND OVERTIME RULES ARE TIGHTENING

Average farm labor wages in US, California and Arizona, 2010-2024F [$ per hour]



Overtime rules in California



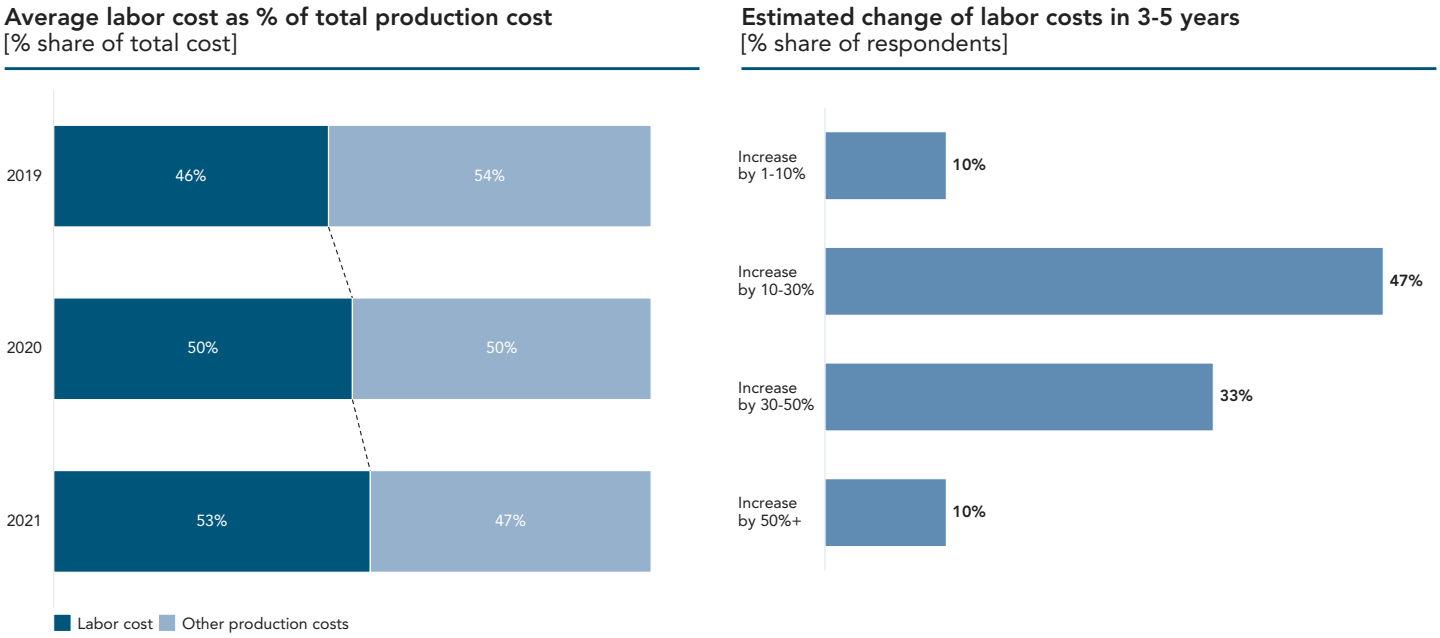
1) Only concerns field workers and not working in the livestock field
2) California minimum wage is taken for companies with over 26 employees; smaller company wages are lagging one year and reach USD 15 / h in 2023

Source: USDA, Cal Poly, Trading Economics, Industrial Commission of Arizona, Roland Berger

Figure 7 Average U.S. and California farm labor cost evolution, 2010-2025 [$ per hour]

20 Assessing the Economic Impacts of Agricultural Equipment Emission Reduction Strategies on the Agricultural Economy in the San Joaquin Valley: Phase Two, 2018 Costs | Michael McCullough, Lynn Hamilton | Cal Poly, 2021

SURVEY RESULTS SHOWED THAT AVERAGE LABOR COST SURPASSED ~50% OF TOTAL COSTS IN 2021, AND MOST GROWERS ANTICIPATE LABOR COSTS TO RISE BY 10-30% IN THE NEXT 3-5 YEARS



Source: Grower survey, Western Growers, Roland Berger

Figure 8 Historic and anticipated evolution of labor costs based on survey responses

The second driver is the tightening of regulatory controls, which have increased expenses for specialty crop growers. For example, the U.S. Food and Drug Administration (FDA) passed the Food Safety Modernization Act (FSMA) produce safety rule in 2011 which required additional testing and audits as of 2016 for fresh produce to protect consumers, increasing farmers' regulatory costs by 350 percent on average.[21] While this and other laws aimed to improve the health and safety among consumers, it also increased the total regulatory costs for specialty crop growers by 265 percent between 2012 and 2018.[22] The overall effect was a rise in the share of regulatory costs as a percentage of total costs from 1.2 percent to 8.9 percent.[23] Dr. Lynn Hamilton, Ph.D. Agribusiness Principles, Policy, and Senior Research Methods at Cal Poly has done extensive research on regulatory costs in the fresh produce industry and key takeaways from her work are highlighted below (see Figure 9).

21 A Decade of Change: A Case Study of Regulatory Compliance Costs in the Produce Industry | Lynn Hamilton | Cal Poly, 2018
22 Assessing the Economic Impacts of Agricultural Equipment Emission Reduction Strategies on the Agricultural Economy in the San Joaquin Valley: Phase Two, 2018 Costs | Michael McCullough, Lynn Hamilton | Cal Poly, 2021
23 A Decade of Change: A Case Study of Regulatory Compliance Costs in the Produce Industry | Lynn Hamilton | Cal Poly, 2018

>> Interview

Dr. LYNN HAMILTON

Ph. D., Professor of Agribusiness at Cal Poly, San Luis Obispo

Author of "A Decade of Change: A Case Study of Regulatory Compliance Costs in the Produce Industry (2018)" and "Assessing the Economic Impacts of Agricultural Equipment Emission on the Agricultural Economy in the San Joaquin Valley: Phase Two, 2018 Costs (2021)"

Purpose of research studies

The regulatory burden for the agriculture industry has been increasing drastically over the last years. While growers know that both direct and indirect costs have been growing, there is limited visibility about the actual financial impact. My studies aim to bring transparency on the evolution of regulatory costs in the fresh produce industry.

The research showed a drastic increase of regulatory cost for the fresh produce industry, with an average increase of 265% between 2012 and 2018. This has forced farms to structurally change to comply with increasing regulatory burden, sometimes even leading to farmers exiting the industry.

Next to increased transparency, the research was leveraged by growers to have thoughtful discussions with policy makers about potential regulatory revisions and financial support.

Future outlook

The level of uncertainty regarding the regulatory landscape is highly unclear, so it is difficult to predict future outlook. However, current regulatory costs are not expected to flatten or decrease, and, on the contrary, there are several laws that are starting to be phased in which will contribute heavily to the rising costs.

For example, the Air Resources Board completely banned agriculture burning this year, which will require farmers to find alternative (and more costly) methods to dispose of agriculture waste.

Policies are reviewed regularly and there is a short phase-in time, typically two years, which forces growers to adapt quickly to the changing policies. This short turnaround time makes it challenging for growers to adapt and to make sound investment decisions.

Harvest automation opportunity

Harvest automation provides a great opportunity for the entire agriculture industry to move forward. Many growers are looking forward to technology solutions that can alleviate cost burdens and can help to solve the labor shortage issues.

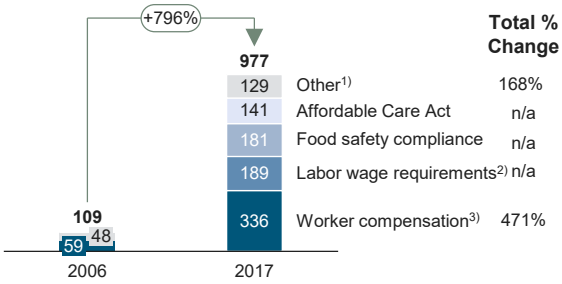
Next to solving labor shortage issues, automation provides a chance to upgrade the workforce as labor intensive activities are substituted for more skilled work. This could help the industry attract and retain workforce, which has traditionally been a big challenge.

Harvest automation is something that will likely benefit large growers first as it requires significant capital investments. Over time, as automation solutions become more widespread, all growers will hopefully have the chance to take advantage of new technology solutions.

>> Dr. Lynn Hamilton research studies – Key takeaways

A Decade of Change: A Case Study of Regulatory Compliance Costs in the Produce Industry (2018)

Regulatory Cost Changes for Salinas Valley Lettuce Grower, 2006 to 2017 [USD per acre]

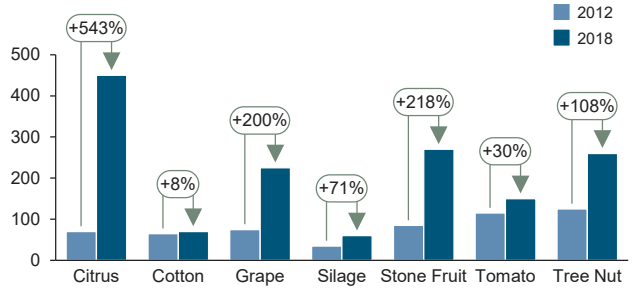


Key Takeaways

- Assessment of regulatory costs for lettuce grower in California found that regulatory costs increased by 795% between 2006-2017, while total production costs increased by 25% over the observed period
- As a result, share of regulatory costs rose from approximately 1% to 9% of total production costs between 2006-2017
- Notable regulatory changes include food safety, air and water quality, labor health and safety, and worker compensation

Assessing the Economic Impacts of Agricultural Equipment Emission on the Agricultural Economy in the San Joaquin Valley: Phase Two, 2018 Costs (2021)

Average total regulatory costs per acre by commodity type, 2012 & 2018 [USD per acre]



Key Takeaways

- Research extended across 22 farms, seven crop types and three farm sizes to broaden the view of regulatory hurdles for various growers
- Total regulatory costs increased on average 265% while total production cash costs increased by an average of 22% between 2012-2018
- Average regulatory costs were higher for permanent crops (tree nuts, citrus, stone fruit and grapes) than for field crops (cotton, silage and tomatoes)
- As a result, many operations have changed or are considering switching to commodities and/or technologies with lower labor costs (e.g., nuts vs. tree fruit)

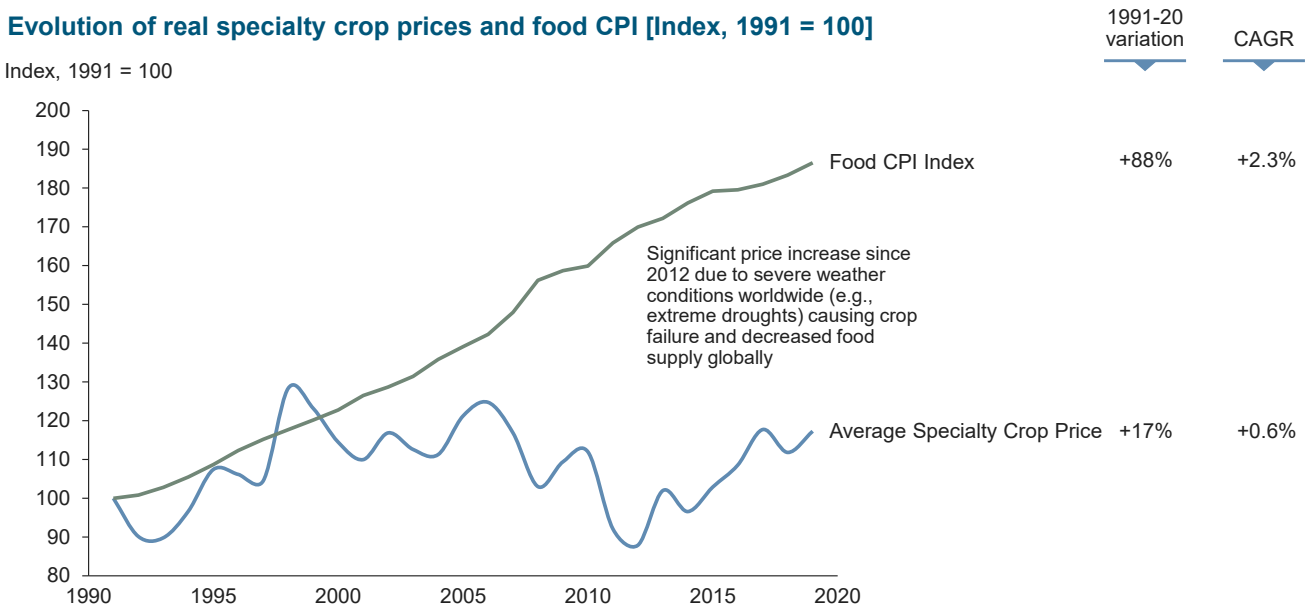
1) Others include pesticide regulation, health and safety, education and training, water and air quality assessments
2) Labor wage requirements includes time spent in filing employee paperwork and taxes primarily with respect to the workforce
3) Worker compensation includes required insurance for workers and claims for injuries

Figure 9 Interview with Dr. Lynn Hamilton and summaries of her research studies (Cal Poly) – Regulatory burden

Pricing pressures from retailers are the third driver. Since 1990, real prices for U.S. specialty crops have been stagnating, with only a 0.6 percent annual increase; this compares to a 2.3 percent annual increase in the food CPI index (see Figure 10).[24] In contrast, product and labor costs in California have increased by around 18 percent annually.[25,26,27] As a result, farmers have been operating at lower margins and are facing increased financial risk. Since 1990 the ratio of net to gross farm income has fallen by 12 percent in the U.S. and 15 percent in California (see Figure 11 and Figure 12). Especially during the last five years, California farm profitability has decreased from around 35 percent to around 28 percent between 2015 and 2020.

Moreover, retailers and consumers are demanding higher quality produce, which comes at a greater

WHILE CONSUMER PREFERENCES AND QUALITY REQUIREMENTS HAVE INCREASED, PRICES PAID BY RETAILERS FOR SPECIALTY CROPS HAVE REMAINED RELATIVELY STABLE SINCE 1990, INDICATING PRESSURE ON MARGINS OF SPECIALTY CROP GROWERS



Source: FAOSTAT, Federal Reserve Bank of St. Louis, USDA, US Bureau of Labor Statistics, Roland Berger

Figure 10 Real commodity specialty food prices from 1990 to 2020 [index, 1990 = 100]

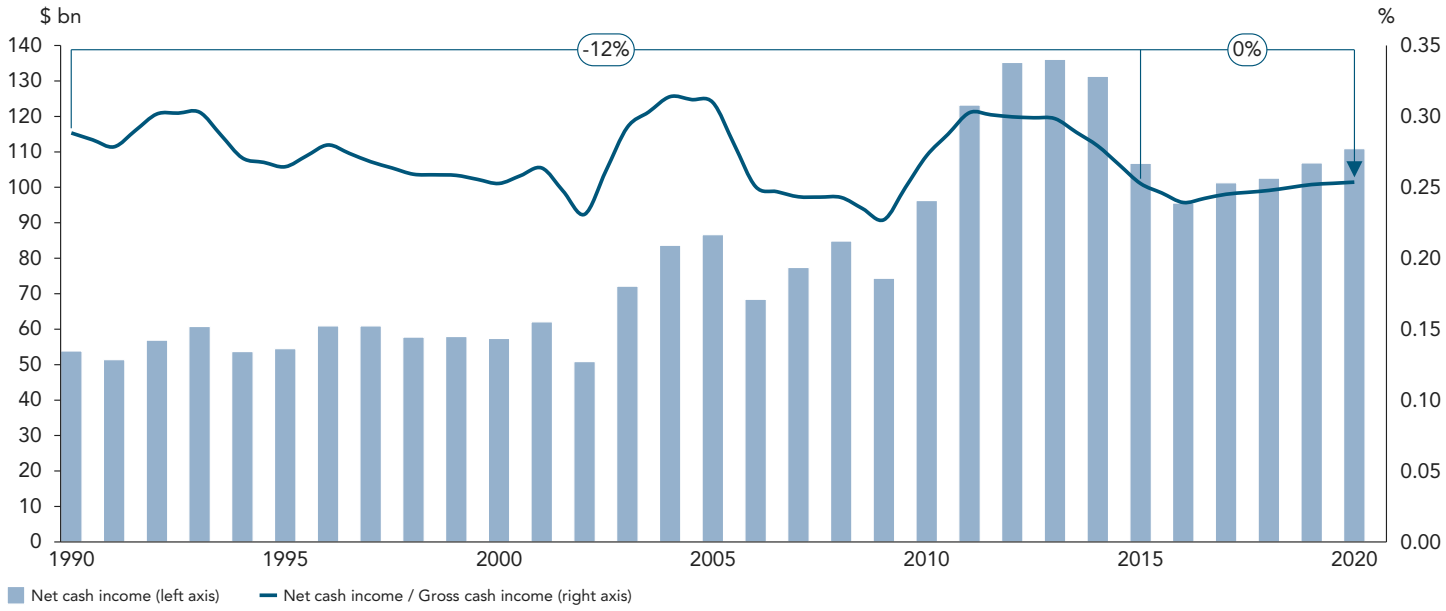
24 Agricultural Research, Productivity, and Food Commodity Prices | Alston et al. | University of California, 2008
25 Prices for Fruits and Vegetables, 2000-2021 | in2013dollars.com
26 Assessing the Economic Impacts of Agricultural Equipment Emission Reduction Strategies on the Agricultural Economy in the San Joaquin Valley: Phase Two, 2018 Costs | Michael McCullough, Lynn Hamilton | Cal Poly, 2021
27 Value added years by State (2012-2021) | USDA

production cost, but are not willing to pay higher prices. In addition, farmers have limited ability to pass on the extra costs to retailers or consumers, mainly due to their size relative to large retailers. In 2019, there were more than 27,000 farms in California with an average size of 48 acres.[28] In San Joaquin Valley, where many specialty crops are cultivated, around 55 percent of farms have fewer than 50 acres.[29]

The fourth and final driver is unforeseen market disruptions. These have large negative effects on the agriculture supply chain resulting in decreased profitability. For example, the COVID-19 pandemic has increased constraints on workers and forced essential businesses such as farms to implement time-consuming measures to ensure worker and food safety. Additionally, travel restrictions reduced the number of workers allowed to migrate to farms and harvest crops. Furthermore, global lockdowns and food service closures

BETWEEN 1990 AND 2020, THE RATIO OF NET TO GROSS FARM INCOME HAS DECREASED BY 12% IN THE U.S. – LEVELS HAVE BEEN RELATIVELY STABLE SINCE 2015

US farm profitability evolution, 1990-2020 [$ billion; %]



Source: USDA, Roland Berger

Figure 11 Farm profitability evolution in U.S. since 1990 [$ billion; percent]

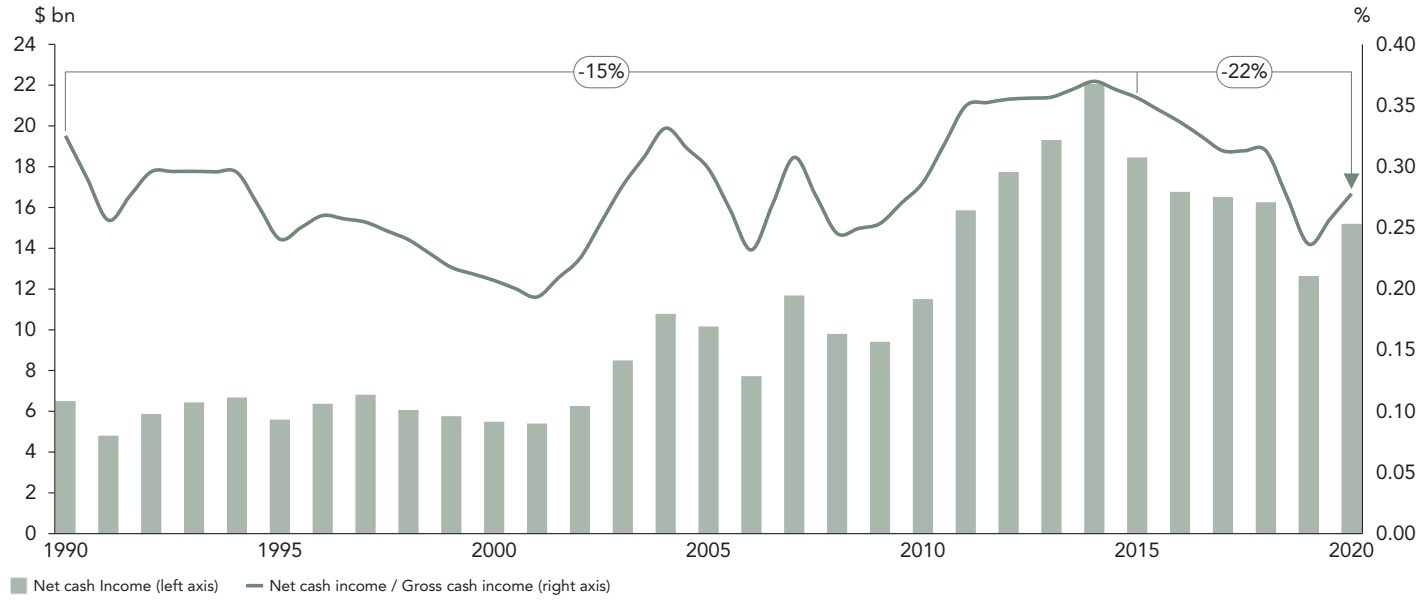
28 Farms and Land in Farms: 2019 Summary | USDA
29 Farms and Land in Farms: 2019 Summary | USDA

resulted in loss of harvest-ready products and products already harvested and in the commerce stream. Overall, the disruptions caused by COVID-19 negatively impacted the viable yield for growers, a key factor in farm profitability.

In short, increasing farm operating costs and stagnant market prices are squeezing specialty crop production in the U.S. and California and impacting its competitive edge. One grower mentioned that many crops are moving south of the U.S. border due to the cheap labor supply. Specifically, the share of broccoli produced south of the U.S. border grew drastically over the past decade. Furthermore, green onion production has disappeared from Salinas, Calif. and moved virtually 100 percent to Mexico. Possible future market disruptions may further hit profitability. If this cycle continues, more growers may be forced to change operations, either by diversifying their crop base and/or changing locations.

BETWEEN 2015 AND 2020, THE PROFITABILITY OF CALIFORNIA FARMS FELL FROM ~35% TO ~28% BASED ON NET CASH INCOME

California farm profitability evolution, 1990-2020 [$ billion; %]



Source: USDA, Roland Berger

Figure 12 Farm profitability evolution in California since 1990 [$ billion; percent]

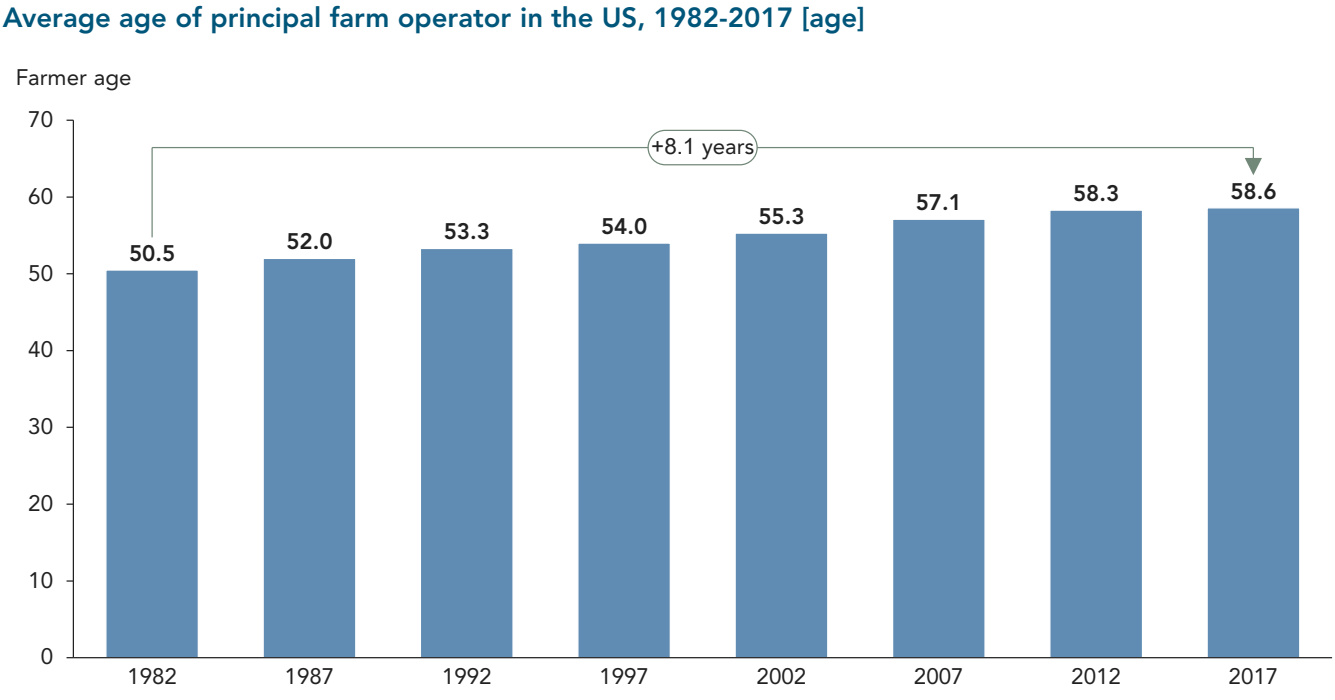
3.3.2 LABOR AVAILABILITY

Scarcity of available farm labor is a growing global issue. From 1991 to 2016, the share of U.S. domestic farm labor decreased from 42 percent to 28 percent, highlighting the lack of interest shown by local workers in farming and harvesting related activities.[30] As more people pursue other careers rather than taking manual labor jobs, this trend has continued to grow. This can lead to labor-intensive crops being left unharvested, which in turn contributes to food waste and increasing food insecurity.

In the U.S., and California in particular, agriculture wages have been increasing in an effort to attract more farmworkers. However, while wages have increased, many growers still struggle to attract sufficient workers during the harvest season. Few new workers enter the agriculture sector. Hence farmers that increase wages to attract workers are merely poaching farm labor from other growers. To add to this, domestic worker retention and loyalty is a serious issue for growers. Once a worker is hired, they are not obliged to work for the entire harvest season. Workers can leave if they find higher-paying work at another farm. This lack of labor security reduces farmers' ability to forecast how much they can harvest in a season.

To compound the problem, fewer young people are entering the agriculture industry and workers are getting older. In 2017, the average age of the principal farm operator in the U.S. was 58 years old, up eight years from

THE AVERAGE AGE OF A PRINCIPAL FARM OPERATOR IN THE U.S. ROSE BY EIGHT YEARS BETWEEN 1982 AND 2017



Source: USDA, Roland Berger

Figure 13 Average age of principal farm operator in U.S., 1982-2017

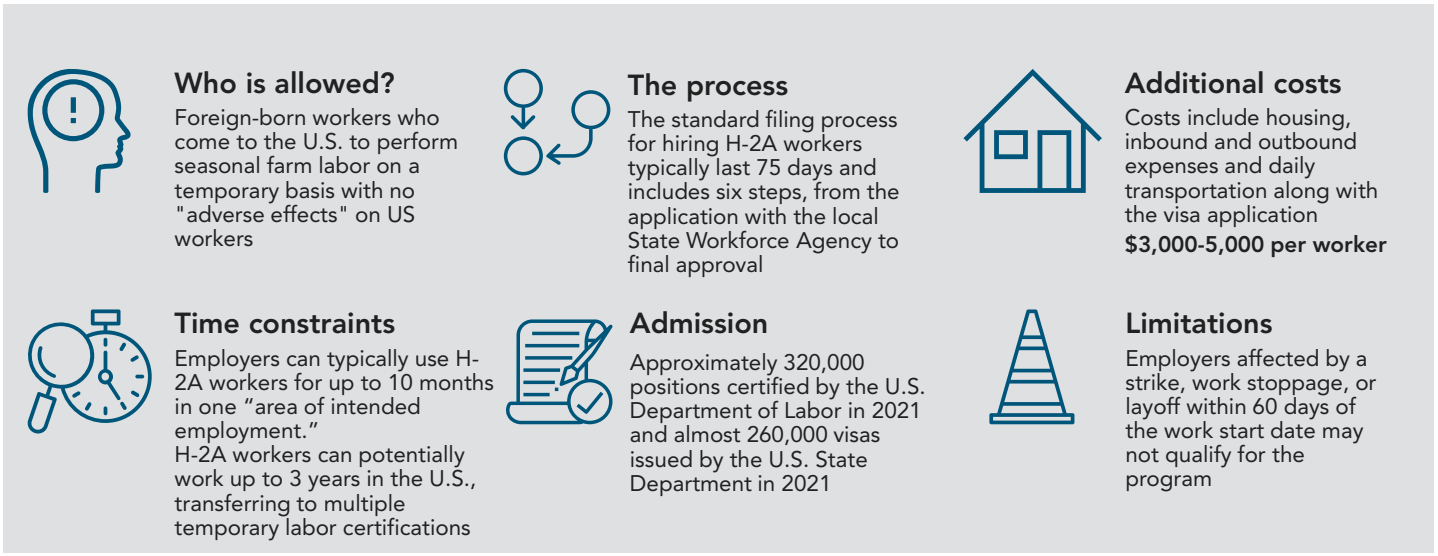
30 Size and Composition of the US Agricultural Workforce | USDA

1982 (Figure 13).[31] Furthermore, the average age of farm laborers, graders and sorters in 2019 was 39 years old. As fewer young immigrants are entering the agriculture sector, the average age of foreign-born farmworkers has risen, pulling up the average for the entire workforce. The average age of immigrant farmworkers rose by 6 years between 2006 and 2019. In contrast, the average age for U.S.-born farmworkers has remained roughly constant over this period.[32] The aging workforce is a pressing issue as without younger workers, there is uncertainty as to how the agriculture industry will continue to operate efficiently after the current generation retires.

A recent survey conducted by the Californian Farm Bureau Federation and UC Davis[33] found the following:

- More than 50 percent of participating farmers had been unable to hire all the employees they needed in 2019
- Labor scarcity increases annually
- Around one-third of farmers are switching acreage, either by switching to less-labor intensive crops, such as tree nuts or row crops, or by decreasing their overall acreage
- Farmers rely on the H-2A visa program to bring in migrant workers to fill domestic labor gaps during harvesting seasons.[34]

THE H-2A VISA PROGRAM ALLOWS U.S. EMPLOYERS TO BRING FOREIGN WORKERS TO FILL TEMPORARY JOBS, BUT THE PROCESS IS OFTEN LENGTHY AND COSTLY AS GROWERS NEED TO COVER FOR ALL EXPENSES, INCLUDING HOUSING, TRAVEL AND MEALS



Source: USDA, CATO Institute, US DOL, US Immigration Services, Roland Berger

Figure 14 Illustration of H-2A process

31 2017 Census of Agriculture | USDA
32 Farm Labor | USDA
33 Still Searching for Solutions: Adapting to Farm Worker Scarcity Survey 2019 | California Farm Bureau Federation and UC Davis
34 The Farm Labor Problem | J. Edward Taylor and Diane Charlton | UC Davis, 2018

The H-2A visa program allows U.S. employers to hire foreign workers to fill temporary jobs. Over the past fifteen years, the number of H2-A positions requested and approved has increased more than fivefold, from just over 48,000 positions certified in fiscal 2005 to just over 275,000 in fiscal year 2020, clearly indicating the scarcity of farm labor.[35] During the 2020 harvesting season, some farmers even became fully dependent on this program as domestic workers were not available. Moreover, the H-2A visa process is long and time consuming, taking an average 75 days to receive approval.[36] Hence, if more workers are needed on short notice, it is difficult to rely on migrant workers. The cost of bringing workers into the U.S. also is becoming increasingly expensive. Farmers cover virtually all the costs of the migrant worker (transportation, housing, application process etc.), which are expected to further increase over time. Moreover, employers must pay foreign workers the higher of the applicable state or federal minimum wage, the prevailing wage in that region and occupation, as determined by the U.S. Department of Labor or the regional average farm wage. Both federal and regional minimum wages are expected to increase over time. So although migrant workers help to reduce the shortage of domestic labor, employing them is becoming increasingly challenging due to the rising costs and lengthy application cycles (see Figure 14).

If crops are left unharvested due to being unable to source labor, it impacts the overall farm yield. This is particularly the case for crops which have time-sensitive harvest schedules, such as berries and stone fruit, which spoil quickly. The labor scarcity has therefore seen some farmers switching to crops that have less time-sensitive harvest schedules, for example, citrus fruits, or crops that require less labor. Additionally, some farmers are taking their specialty crop farms south to countries like Mexico and Peru, where there is a more stable supply of labor.[37]

Although U.S. and California growers are struggling with labor availably, the issue is not specific to North America. In the past 10 years, imported fresh produce in the EU has increased by 20 percent.[38] This reliance on other markets was amplified by the COVID-19 pandemic when EU farmers struggled to find local workers due to border closures and other restrictions. This is pushing European growers into automation. As an example, a small Italian grape grower with approximately 13 hectares of grapes decided to invest $100,000 in a grape harvester due to unreliable labor during the pandemic. Despite the large capital investment and long payback period, the investment was necessary to ensure that the farm was able to harvest despite the labor shortage.[39] Similar situations occurred in Spain where a small grape grower for cava production invested in automated harvesters which will take him at least five years to pay off.

35 Farm Labor | USDA
36 H-2A Visa Program | USDA
37 Short on Labor, Farmers in US Shift to Mexico | The New York Times (September 2007)
38 European Union Sees Increase Of Fruit and Vegetable Imports | Produce Business (December 2019)
39 Robots Take Over Italy's Vineyards as Wineries Struggle With COVID-19 Worker Shortages | Wall Street Journal (October 2021)

3.3.3 CLIMATE CHANGE

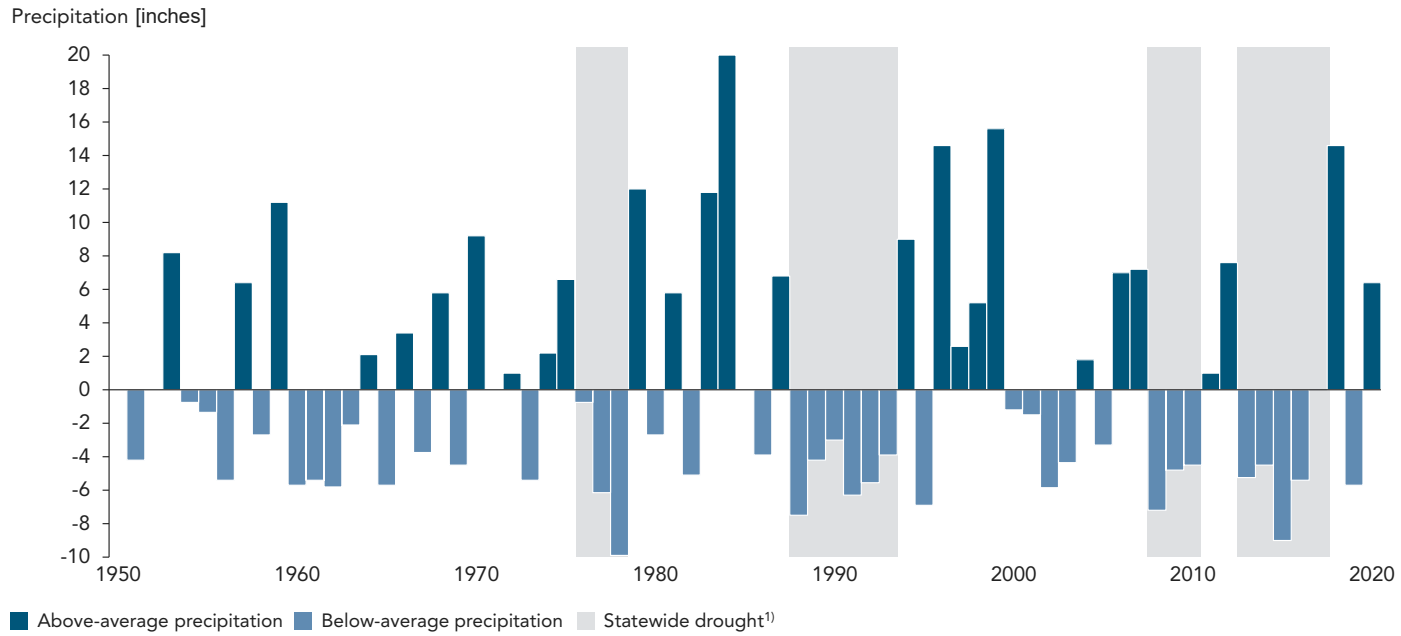
Climate change poses a significant risk for farmers as altered, more unpredictable growing conditions impact quality, yield and future food security. The geographical ranges where crops can be cultivated could shift, temperature and weather patterns could change and growing conditions could worsen, reducing the quality and nutrition of crops.

Water scarcity is also a crucial issue. This will particularly affect specialty crops that rely heavily on high quality water from surface and groundwater resources. Increasing water scarcity might reduce the production of certain crops and drive further substitution of crops that require less water.

California is already feeling the effects. For example, in the past two decades, the state has experienced two serious droughts that many attribute to climate change (see Figure 15). Since California has a high dependence on groundwater, the Sustainable Groundwater Management Act (SGMA) was enacted to balance the level of water in basins. This law will restrict the amount of water available to farmers, negatively impacting crop yield and quality.[40] As a result, farmers will be forced to reduce their total acreage. Experts predict that at least 500,000 acres of agriculture land will be reduced due to water restrictions. The rising frequency of extreme weather conditions will further reduce farmers' ability to forecast yield and ultimately hit profitability and food security.

CALIFORNIA HAS EXPERIENCED TWO SERIOUS DROUGHTS SINCE 2000, WITH THE MOST RECENT LASTING FIVE YEARS

Evolution of annual rainfall in California, 1950-2020 [inches]



1) Droughts occur when two or more successive years are very dry, and reservoirs and groundwater reserves are depleted.

Source: Public Policy Institute of California, Roland Berger

Figure 15 Precipitation trends in California, 1950-2020 [inches]

40 Water Security In The Age of SGMA | Aquaoso Technologies

Falling profitability, labor scarcity and climate change all highlight the major challenges facing farmers and the urgent need for radical change in the agricultural industry. Western Growers is confident that automation can be a catalyst to alleviate increasing pressures on both profitability and labor shortages as well as make the industry more resilient and attract new talent. As harvesting is the most labor-intensive component, making up roughly 80 percent of labor costs[41], advancing harvest automation will be critical to solve the challenges ahead.

Despite the promise of harvest automation, technological solutions are still in their infancy and there are challenges to bring the technology to commercialization. In the next sub-chapters, challenges of harvest automation from growers' and start-ups' perspectives are further elaborated.

41 Farm Labor Survey | USDA

3.4 CHALLENGES OF HARVEST AUTOMATION: GROWER PERSPECTIVE

Harvest automation promises to transform the specialty crop industry. However, with the industry still in its infancy, there are several hurdles for growers to overcome. Specifically, concerns over unproven technologies, financial constraints, lack of available talent, and a lack of collaboration are often voiced.

3.4.1 CONCERN OVER UNPROVEN TECHNOLOGIES

As farmers continue to face economic pressure, investment in, and adoption of, new technologies is slow. While many farmers are open to automation, they are generally risk-averse and want to be convinced of a clear return on investment before adopting new technologies. Based on the survey results, farmers typically expect a payback period of 18-24 months when making a new investment.

However, new solutions do not always offer an accurate yield and/or cost impact due to their limited track record, thereby hampering payback and return on investment calculations. This may make growers hesitant to try new technologies, especially when upfront costs and/or investments are high, as the benefits are unproven.

3.4.2 FINANCIAL CONSTRAINTS AND LACK OF TALENT

Farmers are struggling to fund projects and attract the technical talent needed to develop automation technology. Currently, there are limited harvest automation options that are commercialized for specialty crops, forcing many farmers to build technology in-house. Many growers in California choose to buy generic equipment and customize the technology to their needs.

Farmers need to deploy a large amount of capital at the onset to fund R&D when customizing equipment or developing a new automation technology. Many are unable to justify the expenditure, or cannot afford it, meaning that promising innovations go unfunded or are not funded to completion. For example, a farmer in California recently spent $2 million to develop a specialty crop harvester but ran out of money, leaving the unfinished machine gathering dust in the farm warehouse.

Growers may also lack the knowledge to develop automation technologies in-house, especially when it comes to IT solutions and computer systems. At the same time, they struggle to attract people with the required knowledge. Very few technology workers choose to work in the agriculture industry primarily due to the lower pay compared to tech companies. This difficulty in attracting individuals to work in the agriculture industry is hindering the growth of automation in the sector, as collaboration with technology experts is essential to bridge the needs of farmers and the capabilities of automation.

Despite this, the agriculture industry has come a long way in terms of advancing harvest automation solutions, mainly driven by in-house innovation efforts of large farms. A best-in-class example of in-house innovation can be found at California-based Grimmway Farms, the world's largest producer of carrots. Grimmway used innovation to drive the company's growth, for example, by leveraging technology from Europe, building tailor-made machines and partnering with Western Growers to accelerate automation. A drastic change in seed varieties drove the efficiency of baby carrot production. "If you look at the trajectory of the company, innovation took place early on in the formation of the baby carrot, so that is a textbook example of food product innovation where the customer needs are being met and it changes the texture of the marketplace," says Jeff Morrison, Director of Innovation and Technology at Grimmway.

3.4.3 LACK OF COLLABORATION

In-house innovation efforts can help to improve the automation process across the entire specialty crop industry when successful. But they rely on collaboration between farms, something that is not always easy to achieve. Due to highly competitive pressures in the industry, many growers are wary of sharing information about innovation and technology developments. The lack of collaboration is lengthening the time needed to bring new products to market that could lift the entire industry. This hinders progress and illustrates the need for greater transparency in the industry. While information sharing is still rare, the mindset of growers is slowly starting to shift (see Figure 16).

As a result of these harvest automation challenges, growers are increasingly collaborative with start-ups to bring innovative solutions to the fresh produce market.

>> Interview

Dr. INES HANRAHAN

Executive Director of the Washington Tree Fruit Research Commission

Fostering collaborative environments accelerates technology development and deployment

One of our main goals at the Washington Tree Fruit Research Commission is to bring new technologies to our orchards. It is our belief that we can empower the entire industry to shape their own future through innovation. Likewise, we are big believers in collaboration across industry groups as a strategy to advance and accelerate technology development and implementation.

By fostering vibrant public-private partnerships globally, we enable meaningful partnerships. In our experience, combining research institutions and commercial partners drive more realistic solutions, that enable to sustain farms and keep them profitable.

Based on our historic knowledge as an organization, the key to successful collaboration across industry groups is to identify the right people in the industry. People to whom growers listen and who can function as exemplary figures to share success stories on why industry collaboration is advantageous.

Two specific cases to highlight are the adoption of pheromone mating disruption for codling moth and the success in enabling year-long supply for Honeycrisp apples. In both cases, WTFRC was critical in funding and driving research, creating industry optimism and confidence in the respective technologies, and getting grower buy-in. This approach helped to elevate the technologies in these two areas and laid out realistic parameters for implementation by the growers.

Furthermore, collaboration runs across state and international borders. We are currently working on a project to advance smart orchard technologies, named "Orchard of the Future," bringing together researchers, tech companies and growers in Washington, California and the Netherlands.

Growers in the Netherlands and in Washington state face similar challenges in terms of labor and need for automation, so it makes sense to collaborate on technology development. Rather than spending money on duplicate research efforts, we aim to collaborate to share and build on each region's existing efforts. To that goal, we bring groups of companies and scientists together to develop future orchard practices.

In the same spirit, it is with great enthusiasm and conviction that we join the Global Harvesting Automation Initiative with Western Growers to bring harvest automation to the next level in the fresh produce industry.

Figure 16 Interview with Dr. Ines Hanrahan (Washington Tree Fruit Research Commission) – Collaboration in the orchard industry

3.5 CHALLENGES OF HARVEST AUTOMATION: START-UP PERSPECTIVE

The technology and business challenges of developing innovative harvest solutions such as harvest robots are significant. The discussions with more than 20 harvest automation start-ups unearthed three key problems: scalability, providing real-world solutions that also satisfy investors, and technical complexity.

3.5.1 SCALABILITY

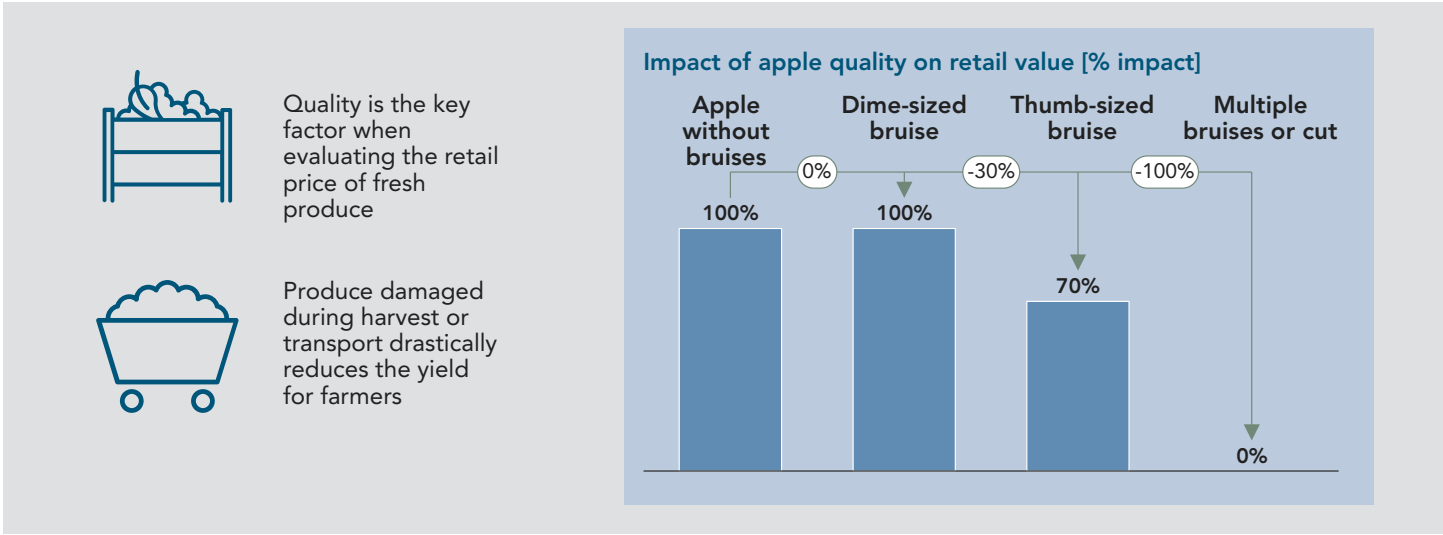
Every specialty crop is harvested differently, depending on the crop-specific agronomics and farming practices. This means each harvest automation solution needs to have a different harvesting mechanism and artificial intelligence (AI) software based on its target plant's features. Single-crop harvest automation solutions are therefore less versatile, resulting in a small addressable market and limited investor interest. This lack of scalability is a key reason why established original equipment manufacturers (OEMs) have not actively invested in this market.

To circumvent the scalability challenge and increase the addressable market, many start-ups are experimenting with automating tasks that are common to a variety of specialty crops. Given the specificities of the harvesting process, most solutions instead focus on pre-harvest (for example, weeding, thinning) and harvest-assist activities. In-market solutions and associated start-ups are discussed in Chapter 5.

3.5.2 PROVIDING REAL-WORLD SOLUTIONS THAT ALSO SATISFY INVESTORS

Automation start-ups must focus on solving the real-world problems of growers and finding the right solutions to the right challenges. To do this, start-ups need to obtain a thorough understanding of grower pain points, and align grower needs with investor pressure for returns. It is crucial for them to engage in initial discovery conversations with growers to understand their key

GROWERS PLACE GREAT IMPORTANCE ON THE QUALITY OF HARVESTED PRODUCE AS IT DIRECTLY IMPACTS THE RETAIL SELLING VALUE, AS SHOWN BY THE IMPACT OF APPLE BRUISES



Source: Expert interviews, Western Growers, Roland Berger

Figure 17 Impact of produce quality on retail price

challenges and tailor automation solutions to them, while keeping grower economics and willingness to pay in mind. For example, growers greatly value the quality of the yield as it directly relates to the selling price (see Figure 17). When quality standards are not met, the value of the crop drastically falls, negatively affecting the farmer's profitability.

Equally crucial is addressing the problem of harvesting speed. For example, humans can pick a strawberry every two seconds, while machines typically take 8-10 seconds.[42] While automation productivity can be lower than human harvest, the ability to supplement the labor force and ensure that crops will be picked make the investment attractive for growers.

Finally, it is important for start-ups to align investor needs with the product that best serves the grower. Many start-ups fund their development and operations through investors who are looking for a return within a short period of time. This does not always align with the long-term goals of growers and the lengthy R&D phase that start-ups require. It is important to look for investors who understand the agriculture industry and are willing to wait for a return, as indicated by multiple start-ups during interviews.

"To date, we have decided not to take any venture capital funding to mitigate misaligning with grower needs. Additionally, we are looking for investors who understand the agriculture space so that the development of the product would not be negatively affected."
– Start-up in pre-venture round

3.5.3 TECHNICAL COMPLEXITY

Due to the specific technical complexities of picking specialty crops, harvesting is one of the most difficult tasks to automate. First, the machinery needs to be equipped to function in unstructured environments (rain, dust, mud etc.) and constantly changing conditions (ambient light, weather, new parasites, different weeds etc.), which can affect image recognition technologies. Durability and adaptability are therefore critical to the success of the machinery.

Next, the machine must be able to actually pick the produce. Harvesting is typically a combination of various complex manipulations which need to be performed in a gentle manner to avoid crop damage. Automation solutions must therefore be able to accommodate the different harvest processes (picking, cutting, pulling etc.) of individual specialty crops. This requires a multifaceted system which often takes several iterations to properly develop. Machines also may need to be tailored to individual farm sizes, configurations, and operations. This complicates standardization and requires flexible and adaptable automation solutions. ■

42 Agricultural Robots, Drones and AI: 2020-2040: Technologies, Markets and Players | IDTechEx

4.0

IMPACT ANALYSIS

4.1 INTRODUCTION AND PURPOSE

The impact analysis aims to provide a comprehensive summary of the status and impact of automation in the specialty crop industry. This report, as the first of the Global Harvest Automation Report series, intends to establish the baseline in terms of current status and impact of harvest automation in the fresh produce industry. It will be updated annually based on grower metrics and future developments in automation.

In this chapter, the status of harvest automation is measured both generally across all specialty crops destined for the fresh market, and specifically for six selected crops – apples, blueberries, strawberries, broccoli, lettuce and almonds. As specialty crops differ widely in terms of automation needs and key performance indicators, an aggregated view across all crops would hamper the accuracy and usefulness of the report. Therefore, the scope is narrowed to provide an in-depth analysis on the selected six. The criteria behind their selection were a combination of U.S. market size and current harvest automation traction. The aim is to extend coverage to more crops in future reports.

The methodology of the impact analysis was defined following interviews with more than 20 growers. It aims to understand the main industry challenges; comprehend grower economics and key performance indicators; grasp status and impact of harvest automation; and familiarize with ongoing harvest automation initiatives (see Appendix, Chapter 7.2). Based on these grower interviews and combined with more than 15 report benchmarks, a set of general key performance indicators was developed to measure the status and impact of automation across all crops. Data was collected through surveys targeted at member growers from Western Growers and partner association members, such as the Washington Tree Fruit Research Commission. The report does not aim to provide an exhaustive view of all possible metrics to measure the status and impact of harvest automation. Rather it was limited to selected metrics tracked through the survey. The report will be updated annually, and future versions will be benchmarked against the baseline established in this report.

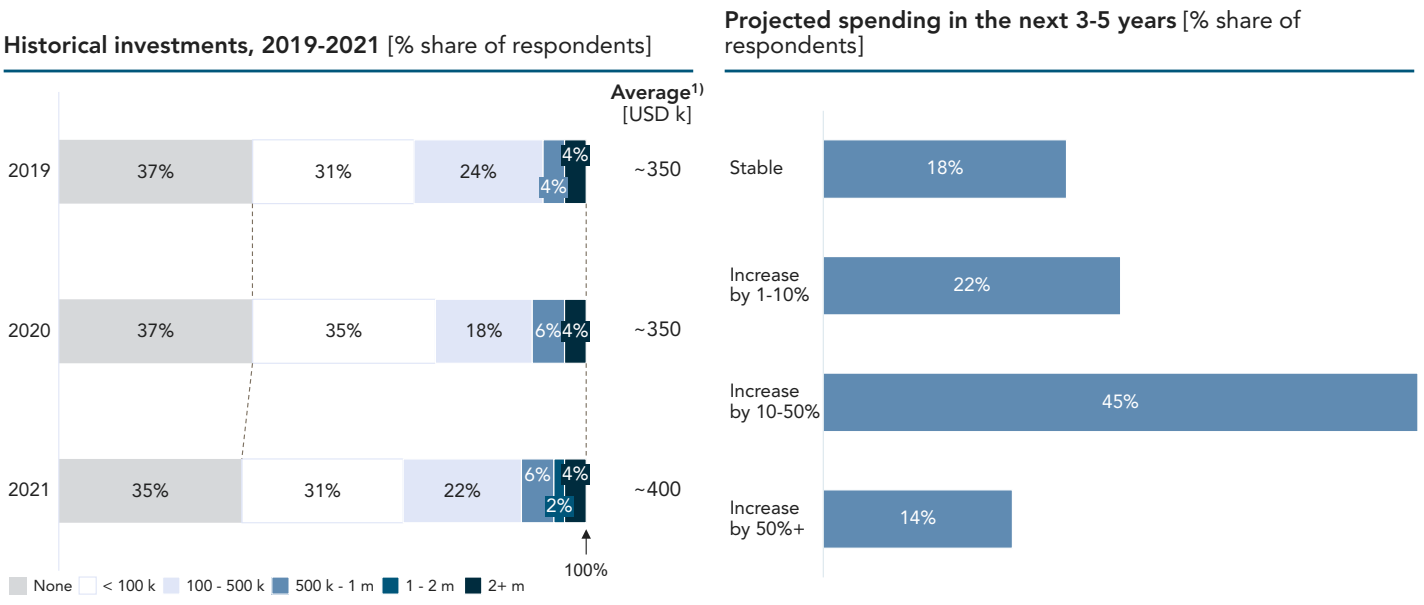
4.2 CURRENT STATUS OF HARVEST AUTOMATION IN SPECIALTY CROPS

4.2.1 GENERAL (ALL SPECIALTY CROPS)

To measure the status of automation across all specialty crops, annual investments in automation were tracked between 2019 and 2021. Currently, around 65 percent of growers are investing in automation and most growers expect investments to increase by 10-50 percent in the next 3-5 years (see Figure 18). Between 2019 and 2021, the average amount spent on automation per grower increased from approximately $350,000 to $400,000 annually. Despite the COVID-19 pandemic causing uncertainty in businesses, automation levels still increased, indicating a need in the market and a willingness among growers to adopt new technology.

The status of automation was also measured at a more granular level across the different harvest-related activities. These have been broken down into three categories: pre-harvesting activities, harvesting activities and harvest assist activities. Pre-harvesting activities are tasks to prepare and protect the crop, and eventually make harvesting more efficient. They include weeding, thinning, pruning and spraying. Harvesting activities include the actual picking, cutting or other collection method of the crop. Finally, harvest assist activities are tasks or tools to support the harvesting process, such as harvesting platforms or ground vehicles. It should be noted that harvesting platforms can sometimes also be used to support pre-harvesting activities. For example, apple harvesting platforms are also used for pruning or thinning.

ON AVERAGE, AROUND 65% OF SURVEYED GROWERS HAVE INVESTED IN HARVEST AUTOMATION SINCE 2019 AND MOST EXPECT THEIR SPENDING TO INCREASE BY 10-50% IN THE NEXT 3-5 YEARS



1) Average calculated using only growers who have automated

Source: Grower survey, Western Growers, Roland Berger

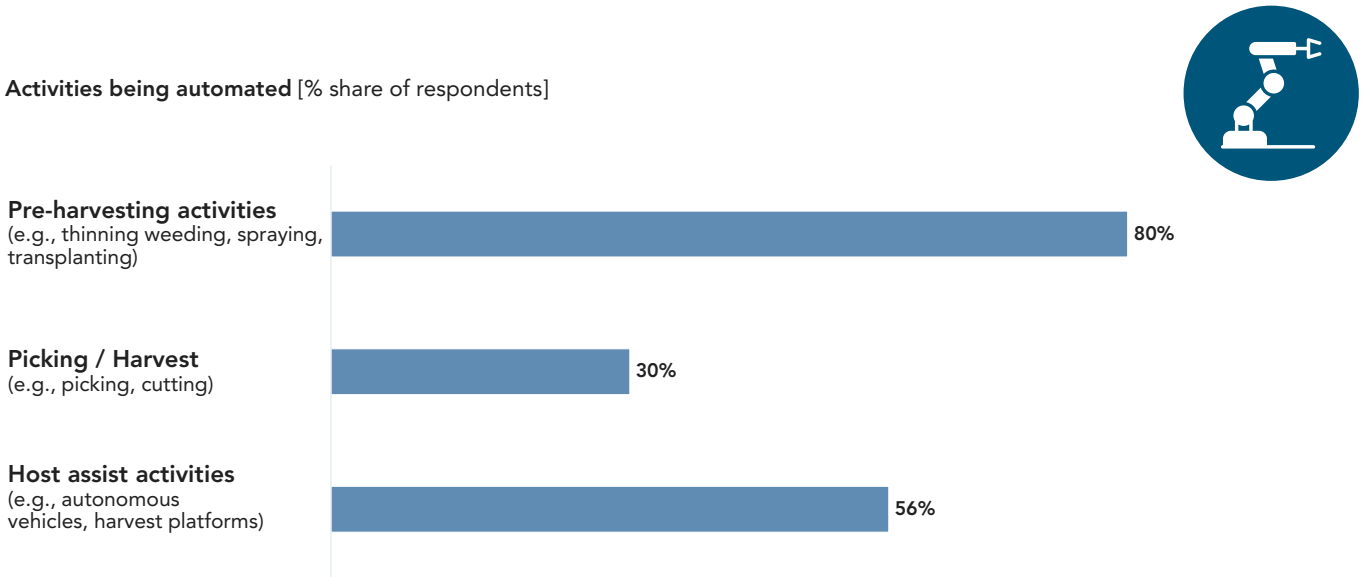
Figure 18 Historic and anticipated investments in automation [percentage share of survey respondents]

In 2021, more than 80 percent of growers indicated that they deployed some form of automation in pre-harvest activities, such as weeding, thinning, spraying, transplanting. Figures for the other categories were lower (see Figure 19). This disparity can be attributed to the complexity of creating a fully automated harvest machine in contrast to the relative ease with which weeding, thinning and assist machines can typically be deployed across a wider crop base, as discussed in Chapter 3. As a result, there are currently few options for growers when they are looking to automate their harvest process, resulting in a low adoption rate. As technologies continues to advance, adoption rates for harvest automation are expected to increase.

In terms of preference, growers mainly automate through established manufacturers (as answered by around 65 percent of survey respondents) followed by internal resources (about 30 percent). However, roughly 20 percent of surveyed growers indicated that they have trialed and worked with start-ups in the past. Many growers rely on recognized OEM brands due to already established relationships, with solutions often sourced through local or regional dealer networks. However, as automation becomes more advanced and fewer manufacturers have specialized solutions for specialty crops, there will be a shift towards start-up companies that can provide innovative solutions that address growing needs in the market. In future reports, grower preference for automation will be consistently tracked and measured across multiple levels, including start-ups, OEMs, custom manufacturers and agtech integrators.

Growers also indicated a preference to assess each harvest automation opportunity on a case-by-case basis. Interviews with growers have shown that the decision between making a direct purchase or using a contract/ subscription model will strongly depend on the farm size and economics.

PRE-HARVEST AUTOMATION IS THE MOST DEVELOPED TYPE ACROSS ALL CROPS, WITH HARVEST ACTIVITIES THE LEAST DEVELOPED



Source: Grower survey, Western Growers, Roland Berger

Figure 19 Automation activities [percentage share of survey respondents]

4.2.2 SPECIFIC CROPS

For the six selected crops, the status and evolution of automation across various harvest and harvest-related activities was measured in terms of the share of acres per crop using some form of automation. The metric was tracked from 2019 to 2021, along with the expected evolution in the next 3-5 years.

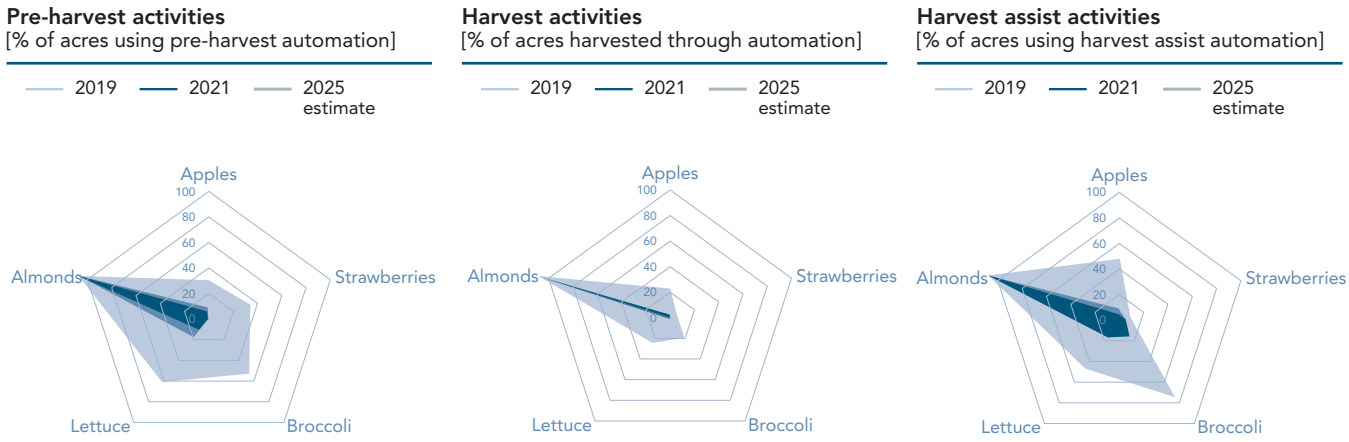
Apart from almonds, the farming of which is highly mechanized across all harvest-related activities, few of the six have gained traction in harvest automation to date (see Figure 20). Lettuce is the furthest advanced for pre-harvesting activities, reaching, on average, about 20 percent of acres using automation in 2021. For harvest assist activities, broccoli and lettuce recorded average figures of about 15 percent. Important to highlight is the advancement of harvest assist activities for apple growers thanks to harvest assist platforms. Indeed, large apple growers indicated that 20-50 percent of acres were harvested using harvest assist platforms between 2019-2021. The overall average across all apple growers was significantly lower as smaller growers reported little automation to date.

Although largely still limited today, growers have high expectations for automation in the future, with pre-harvest and harvest assist activities predicted to reach 30-50 percent automation by 2025, on average. Growers agree that automating actual harvesting will require longer lead times to reach a commercially viable solution. Aside from almonds, averages for harvest automation by 2025 across the selected crops are at around 20 percent, except for strawberries (5 percent on average) due to manipulation complexity.

Figure 20 visualizes current and expected status across harvest and harvest-related activities, and across crops.

Below we look at the automation status and best practices in harvest automation initiatives for three of the most advanced of the six crops.

EXCEPT FOR ALMONDS, FEW CROPS HAVE GAINED TRACTION IN HARVEST AUTOMATION TO DATE – PRE-HARVEST AND HARVEST ASSIST ACTIVITIES SHOW THE MOST FUTURE PROMISE



Source: Grower survey, Western Growers, Roland Berger

Figure 20 Status of automation across harvest and harvest-related activities and selected crops [average percentage share of acres using automation, based on survey respondents]

Almonds: Almonds are currently the most heavily mechanized of the six, with virtually 100 percent of pre-harvest, harvest and harvest assist activities being mechanized. For the past four decades, almonds have been harvested using shaker and sweeper machines. Rather than requiring a labor force to manually knock down almonds and possibly damage the tree, shaker machines gently loosen the almonds while sweeper machines collect the fallen nuts.

To further improve the efficiency of the process, an integrated shaker-sweeper machine is currently under development. Other technologies in the research phase include systems to help with post-harvest maintenance of the trees, such as making sure trees are free of almonds to reduce pests.

Apples: Automation in apple harvesting is most prevalent for harvest assist activities. To date, best practice in apple harvesting is the use of harvest platforms. These have revolutionized the process for tree fruit crops. Before, pickers needed to climb up and down ladders to pick fruits, which was time consuming and unsafe. The emergence of harvest assist platforms, where pickers stand on a raised, moving platform, eliminates the need for ladders and significantly improves worker safety. The solution can be used for other orchard fruits as well.

According to an orchard operations manager with about 2,000 acres under management, the use of harvest automation platforms has enabled labor savings of 20-30 percent. With local labor increasingly difficult to find, these savings help to ensure food security. However, harvest assist platforms are not the perfect solution for everyone. The cost for smaller farmers is prohibitive, with most small growers indicating in our survey that they had zero to only very limited harvest assist automation to date.

Other apple harvest-related and harvesting activities are less advanced due to the high manipulation complexity of picking the fruit. However, many different automation technologies are currently being trialed in orchards, including vacuum arms, robotic gripper arms and drone pickers. Our survey showed that growers expect automation to further progress in the next 3-5 years, reaching around 30 percent of acres using pre-harvesting automation and about 20 percent of acres picked through autonomous solutions.

Lettuce: Pre-harvest automation is the most widely used technology in lettuce farming compared to harvest and harvest assist automation. On average, growers indicated that around 20 percent of acres currently use some form of pre-harvest automation, such as thinning, weeding, spraying, or transplanting. The figures for harvest and harvest assist usage are much lower, at 1 percent and 14 percent respectively. Automated thinning machines that use vision systems can properly space lettuce plants by removing unwanted crop. This improves the quality of yield and ease of harvest for laborers. Weeding, spraying and transplanting technologies also focuses on one aspect of the cultivation process.

4.3 IMPACT OF HARVEST AUTOMATION

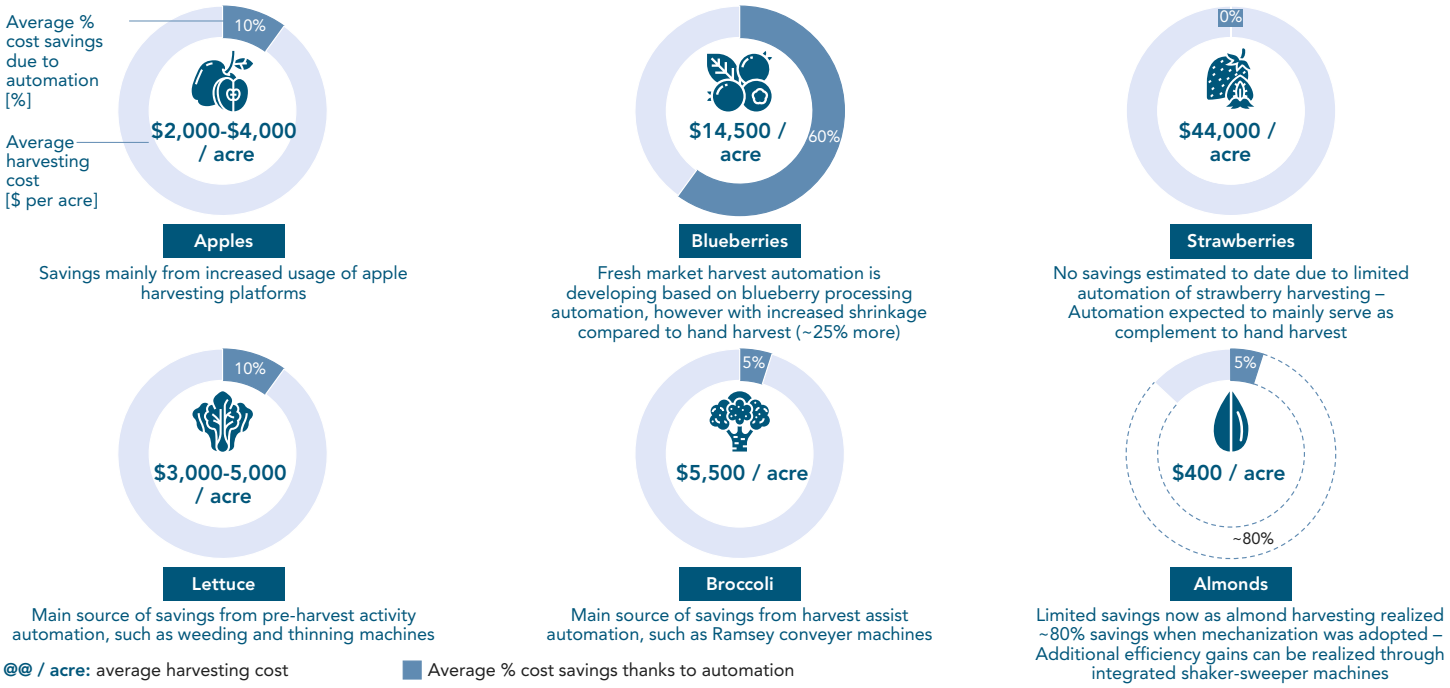
The impact of automation is measured by looking at the change in harvest cost, quality of yield and impact on food security.

Currently, savings on harvest cost are limited due to the immaturity of automation technology (see Figure 21). Two exceptions should be highlighted. First, blueberries show high cost savings potential, however this is accompanied by a significantly higher shrinkage rate compared to hand harvest. Second, for almonds, most efficiency gains and savings have already been realized over the past years due to the high level of mechanization. As the greatest opportunity for cost reduction is in harvest automation, further savings could be realized as more automation solutions come to market.

However, growers often indicate that cost savings are not the primary reason to turn to automation. Securing sufficient food supply for a growing population and reducing food wastage in the field are other key reasons that many growers turn to technology. Automation has also been critical to both supplementing labor and improving worker efficiency, an important growth catalyst for farmers.

Finally, the quality of crop harvested through automation is an important consideration for growers of fresh produce. It is expected to be a major factor in investment decisions once more harvest technologies reach commercialization.

TO DATE, SAVINGS ON HARVEST COST THROUGH AUTOMATION ARE SMALL DUE TO LIMITED ADVANCEMENT – BLUEBERRIES AS EXCEPTION, ALBEIT WITH INCREASED SHRINKAGE OF ~25%, AND ALMONDS WITH ALREADY HIGH LEVEL OF MECHANIZATION



Source: Grower survey, Western Growers, USDA, UC Davis, Roland Berger

Figure 21 Impact of automation on harvesting costs for selected crops [$ per acre; percentage cost impact]

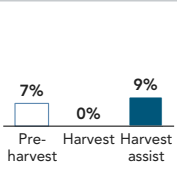
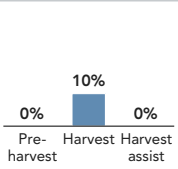
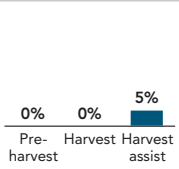
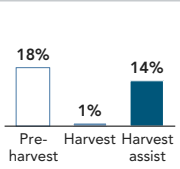
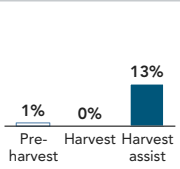
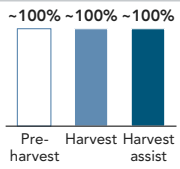
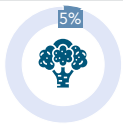
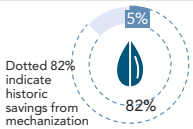
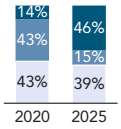
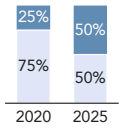
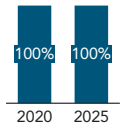
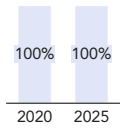
Below we look in more detail at the impact of harvest automation for a selection of crops (see also Figure 22).

Apples: There are three key reasons that apple growers are adopting automation. First, automation enables the labor force to pick the apples on time and reduce wastage. With an automated platform, workers can work more efficiently than when carrying a ladder from tree to tree. Second, it improves worker safety as workers don't have to move up and down ladders. Lastly, growers are able to realize savings after automating. Apple growers that have higher degrees of automation or more automated activities save more. On average, growers who have automated more than one activity or have automated more than 0-10 percent of their acreage save around 10-15 percent on harvesting costs compared to growers who have little to no automation. Farms with limited automation (for example, 0-10 percent automation of one activity) do not report any savings. As such, there may be a potential correlation between farm size and level of savings. This will be further investigated in future reports once traction is further increased across all apple orchards.

Blueberries: Historically, blueberries harvested through automation were frozen or used in juices because the process damaged the appearance of the fruit, reducing its fresh market price. However, harvest automation for the fresh market has recently started to develop, using technology adapted from processing automation. While this has expedited the development process, the quality of the total yield is reduced.

Today, only about 10 percent of fresh market blueberries are harvested using automation. When harvesting, a machine will shake the blueberry bush and capture all the berries that fall off, regardless of ripeness or quality.

A SUMMARY OF THE STATUS AND IMPACT OF SELECTED SPECIALTY CROPS HELPS TO HIGHLIGHT AUTOMATION TARGETS

	Apples	Blueberries	Strawberries	Lettuce	Broccoli	Almonds
Cash receipts, 2020 [$ bn and % of US specialty crop market]	**2.9 bn** ~6%	**0.9 bn** ~2%	**2.2 bn** ~5%	**3.0 bn** ~6%	**0.9 bn** ~2%	**5.6 bn** ~11%
Average harvesting cost, 2021 [$ / acre][1)2)]	2,000-4,000	14,500	44,000	3,000-5,000	5,500	400
Average acres using harvest automation, 2021 [% acres using some form of automation per harvesting activity]						
Current cost savings through automation, 2021 [%] Savings						
Average shrinkage due to automation, 2021 [%]	Limited decreased shrinkage (<5%)	Significant increased shrinkage (~25%)	n.a.	Limited increased shrinkage (1-2%)	n.a.	No impact on shrinkage
Unharvested acres of crops due to labor shortage, 2020-2025 [%] 0% 0-10% 10-20%		n.a.	n.a.			

1) Average calculated based on survey results, UC Davis, and USDA data; 2) Harvesting costs includes all costs associated with the harvesting of the crop, i.e., labor costs, equipment costs, fuel costs, as well as overhead costs, e.g., H2A worker house, certifications

Source: Grower survey, Western Growers, USDA, Roland Berger

Figure 22 Summary of status and impact of harvest automation for selected crops

Afterwards, the harvested berries need to be sorted to remove the unripe or damaged berries. In the sorting process around a quarter of the yield is lost compared to human harvest. However, labor cost is reduced by about 60 percent. Overall, harvest automation helps to bridge the labor shortage gap and reduces the number of unharvested crops, especially in regions with short harvesting periods.

Strawberries: The main automation goal for strawberry growers is ensuring that berries can be picked on time. Most available solutions are still in a pilot phase and are not yet ready for commercialization. Many currently have a slower picking speed and lower picking rate compared to human harvesters and lack integrated solutions that include packing of the fruit.

As a result, many autonomous harvesting systems are used to complement human harvesters rather than serve as standalone solutions, either to pack the fruit and/or pick the remaining berries left in the field. As more growers adopt such complementary solutions, the current structure of piece rate pay may need to be revised to incentivize employees and attract sufficient labor.

The impact of autonomous solutions on the quality of the berries is undetermined due to the limited sample size. However, studies have indicated that every additional touch leads to increased shrinkage. Human harvesters only touch the berries once – when picking them and then placing them directly into the clamshell. But with no integrated packing solutions yet available, automated solutions may require multiple touches to pick and pack the berries, potentially leading to increased shrinkage.

Lettuce: In contrast to strawberry growers, large growers of lettuces do expect significant harvest cost reductions through automation. When making investment decisions, growers look at whether the investment helps to secure future operations and the return on investment. As many growers are wary about the availability of labor in the next 3-5 years, automation that helps supplement the current labor force is attractive as it protects future operations from external labor changes. Additionally, growers look for large savings on harvest costs (50+ percent) when evaluating investment opportunities. Although there is little automation in lettuce harvesting at the moment, some products are expected to go to market in the next 3-5 years. The extremely laborious lettuce harvesting process presents a particularly good opportunity for savings.

Almonds: With mechanization well established, almond farming demonstrates the savings automation can realize. For example, in 1960, the cost of harvesting an acre of almonds was around $240 (about $2,250 in 2021 dollars).[43] In 1980, as almond harvesting became increasingly mechanized, the cost fell to about $120 per acre (around $400 today), which is comparable to the average cost in 2021 of $400. Overall, mechanization resulted in around 80 percent savings, a figure that demonstrates the benefits achievable through mechanization or automation.[44]

Figure 22 aims to summarize the impact of automation on harvesting cost, quality and food security to date for a selection of crops.

4.4 ENABLERS TO ACCELERATE HARVEST AUTOMATION ON FARMS

Industry associations such as Western Growers can help facilitate elements to accelerate harvest automation in the fresh produce industry. These enablers can be grouped into five categories (see Figure 23).

First, non-harvest technologies such as genetic innovations and new farming practices have the potential to drive a fundamental shift in mechanization and automation in the fresh produce sector. Indeed, parallels can be drawn with the emergence of combines to harvest broad acre crops decades ago, something that also coincided with new farming practices, novel farming systems and genetic innovations.

Genetic innovation, such as through seed innovation and/or new breeding variants, can adjust and emphasize traits that facilitate the harvesting process, either for human or robotic harvesting, while also delivering the same or even better end-products to the consumer. For example, so-called high-rise broccoli, bred to grow a longer stem for easier harvesting, has increased productivity, benefiting the entire value chain. Seed companies are able to receive premium pricing given patent protection, while the harvesting crew benefits from less taxing labor and increased productivity, resulting in increased pay per hour in case of a piece-rate system. With standard broccoli, an average of 380-420 boxes can be harvested per hour, while with high-rise broccoli 600-700 boxes can be harvested in the same period. The grower also benefits from increased productivity per hour, and the end-consumer gets the same, or sometimes even superior, product for the same price (see Figure 24).

TO ACCELERATE HARVEST AUTOMATION ON FARMS, WESTERN GROWERS CAN OFFER SUPPORT IN FIVE KEY AREAS, INCLUDING GENETIC INNOVATION, NEW FARMING PRACTICES AND INCREASED INDUSTRY COLLABORATION

Enablers	Short description	Potential role(s) for Western Growers
Genetic innovation	Experimenting with genetic innovation to facilitate harvest automation, e.g., high-rise broccoli	• Increase **collaboration with seed companies** (e.g., Bayer) and universities (e.g., WA State University, UC Davis) to tailor genetic innovation to automation • **Connect growers and seed companies** to understand grower needs, e.g., round table discussions
New farming operations	In line with historical broad acre transformation, new farming practices and systems can facilitate harvest automation for fresh produce, e.g., 2D trellis for apples	• Perform **research** around "future farming practices" with automation purposes in mind, e.g., vineyard of the future project from the Table Grape Commission – Set up project team to conduct research and hold interviews with growers – Assess impact on farm practices, e.g., yield, planting, harvesting • Collaborate with **Smart Farms project**
Industry collaboration	Increased industry collaboration to share best practices around harvest automation	• **Connect growers** to share success stories, e.g., appoint grower champions • Increase **cross-association collaboration** to share best practices and pool resources regarding automation beyond WA Tree Fruit Research Commission, e.g., Smart Farms, CA Strawberry Commission, CA Fresh Fruit Commission • Collaborate with the **new AI institute of UC Merced** to tackle agriculture challenges
Policy change and transparency	Policy updates and regulatory transparency can provide clarity regarding technology development	• **Lobby** for policy updates and increased regulatory transparency to embrace new technologies • **Coordinate funding opportunities** for next generation agriculture workers, e.g., innovation funding
Next gen ag workforce	Changing public opinion of agriculture and addressing next generation workforce could facilitate new technology adoption	• Change overall **perception of the agriculture industry** and **make next generation excited** about ag and AgTech , e.g., upskilling of workforce, sustainability of farming practices, food security, mindful of resources • Work with **education institutions** and growers to help define the curriculum based on grower and industry needs (e.g., 2-year, 4-year programs)

Source: Western Growers, Roland Berger

Figure 23 Enablers to accelerate harvest automation on farms, with potential roles for Western Growers

Second, new farming operations and practices can enable easier harvesting. As an example, two-dimensional trellis growing techniques for apples force the trees to grow in two rather than three dimensions, facilitating the harvesting process for both humans and robots.

Third, increased industry collaboration to share best practices in harvest automation can advance technology deployment. For example, Western Growers aims to increase industry collaboration across various partner associations to pool resources and share automation insights. Collaboration should not necessarily be limited to the same crops, as learnings can be extended and leveraged across different crops.

Fourth, policy changes and increased regulatory transparency can enable start-ups and technology developers to focus on future-proof solutions. For example, the EU has widely adopted tabletop strawberry growing practices due to changing regulations, spurred by government funding, while large-scale tabletop strawberry growing is still rare in the U.S. Autonomous solutions are being developed in the U.S. for both tabletops and in-soil strawberry growing. Regulatory direction and transparency could steer start-ups in the right direction for technology development.

Finally, Western Grower has a leading role to play in changing the public perception of agriculture and making the next generation excited about agriculture and agtech solutions. After all, the transformation of the agriculture industry will require new skills to match emerging technological innovations, sustainable farming practices, and mindful usage of available resources to ensure food security for a growing population. To that extent, Western Growers aims to work together with universities and education institutions to build customized programs that prepare future generations to tackle the main challenges of the agriculture industry. Development of such programs will require close collaboration with growers to understand pain points and future workforce needs. ■

>> Interview

JENNY MALONEY

Global-Americas Strategic Accounts Manager at Bayer

Genetic seed innovation to facilitate harvest automation of specialty crops

At Bayer, we are always looking for opportunities to create products that benefit growers and align with consumer preferences. Our high-rise broccoli is one example of the innovative projects that were designed with machine harvesting in mind.

High-rise broccoli produces taller stems that are more uniform, have higher consistency in terms of maturity and present with fewer leaves compared to normal broccoli. More uniform maturity and higher quality crowns enable growers to reduce the number of passes needed to harvest the crop, and fewer leaves reduce the amount of thinning that growers need to carry out. As a result, human harvesters, and eventually machines, are able to increase the harvesting speed and quality while experiencing less worker strain.

Along with grower benefits, consumer testing showed superior taste and tender stems of high-rise broccoli, which align with consumer preferences.

As most of our projects have a long lead time, we are working on products now that can help farmers of the future meet consumer demands. As automation continues to progress, Bayer is committed to developing products that enable the adoption of advancements in technology.

Figure 24 Interview with Jenny Maloney (Bayer) – Genetic seed innovation and high-rise broccoli


BURRO

5.0

MARKET TRACTION ANALYSIS

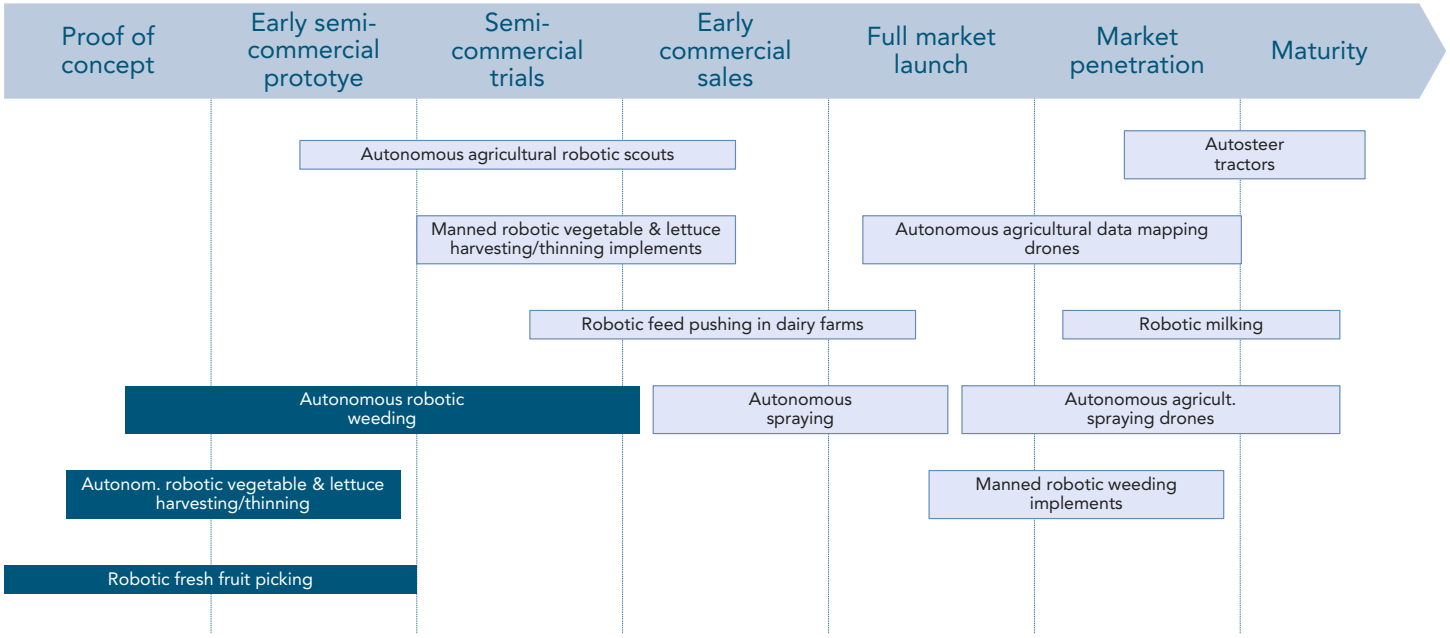
5.1 INTRODUCTION AND PURPOSE

The aim of the market traction analysis is two-fold. First, it aims to create increased transparency about harvest automation start-ups across different crops and harvest-related activities. Second, it aims to identify innovation leaders in the harvest automation space, based on various market traction metrics. These include total funding raised to date, the number of paying customers and the number of robots in service.

While the scope of the analysis is global, most start-ups initiate operations in developed regions as growers there experience higher labor costs and more extensive labor shortages than in developing regions. Consequently, willingness to pay in developed regions will generally be higher as pain points are amplified. In addition, as most start-ups are still in the early development stage and technology still needs to move down the cost curve, developed regions will generally become economically feasible first. This focus typically leads to more viable early-stage business cases, and hence facilitates access to funding from agtech investors, such as S2G Ventures and Finistere.

The methodology of this analysis was defined following discussions with more than 20 start-ups. It aims to better understand the main challenges from a start-up perspective, thoroughly comprehend market structure and define report objectives and comparable market traction metrics (see Appendix, Chapter 7.2). Data was gathered through surveys targeted at harvest automation start-ups active in the fresh produce industry. It will be updated annually to track market dynamics and evaluate in-market progress. The report does not aim to provide an exhaustive view of harvest automation start-ups, as only start-ups that have completed the survey are featured in this version of the report.

HARVEST AUTOMATION FOR FRESH PRODUCE IS STILL LARGELY IN THE DEVELOPMENT STAGE, ALTHOUGH AUTONOMOUS WEEDING ROBOTICS ARE SLIGHTLY MORE ADVANCED GIVEN HIGHER SCALABILITY ACROSS CROPS



Source: IDTech, FIRA, Roland Berger

Figure 25 Market and technology readiness level by agricultural activity (IDTechEx, 2021)

5.2
CURRENT STATUS OF HARVEST AUTOMATION START-UPS

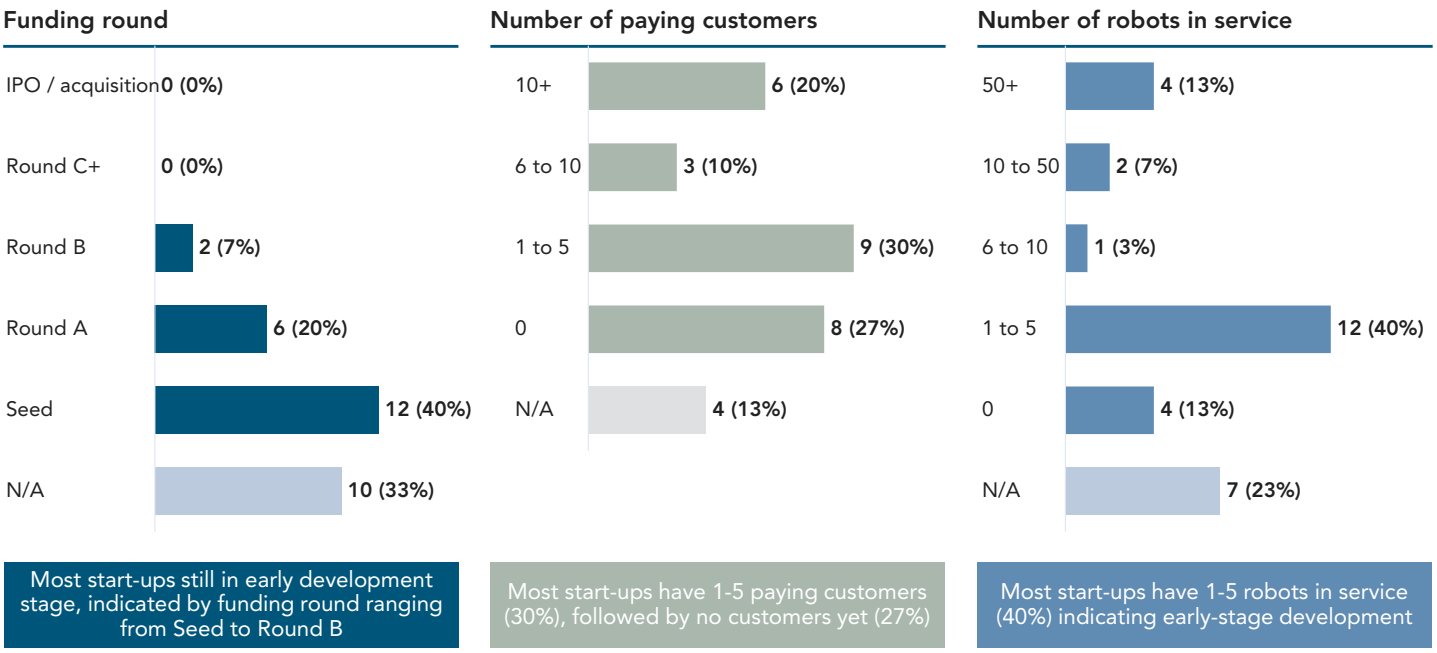
Today, most fresh produce is harvested by hand due to human dexterity, efficiency and precision. The transition towards intelligent mechanization, and eventually automation, will happen gradually as technology continues to develop.

Harvesting robotics will be enabled by two main technologies: vision technologies and complex AI systems. Vision technology will enable robots to identify, classify and become familiar with specialty crops. Additionally, complex AI systems will be able to localize crops for picking, identify the maturity and health status of a plant and decide whether to pick it.

Harvest robots for fresh produce are today still in proof of concept, early semi-commercial prototype and semi-commercial trial stage (see Figure 25). Pre-harvesting automation, such as autonomous robotic weeding, is slightly more advanced compared to fruit and vegetable picking due to its higher scalability across crops, unlocking a larger addressable market.

The survey responses confirm early-stage development for harvest automation in terms of funding round, number of paying customers and number of robots in service (see Figure 26). Approximately 40 percent of start-ups indicated they were at the seed funding stage while another 33 percent were in pre-venture rounds. The remaining roughly 25 percent of start-ups recently completed Round A or Round B funding. No start-ups reported completion of a C+ funding round. Most (approx. 75 percent) have fewer than five paying customers, and a similar proportion have fewer than five robots in service.

SURVEY RESULTS SHOW THAT MOST HARVEST AUTOMATION START-UPS ARE AT THE EARLY DEVELOPMENT STAGE, WITH MOST ONLY COMPLETED SEED FUNDING, HAVE A SMALL NUMBER OF CUSTOMERS AND SMALL NUMBER OF ROBOTS IN SERVICE



Source: Start-up survey, Western Growers, Roland Berger

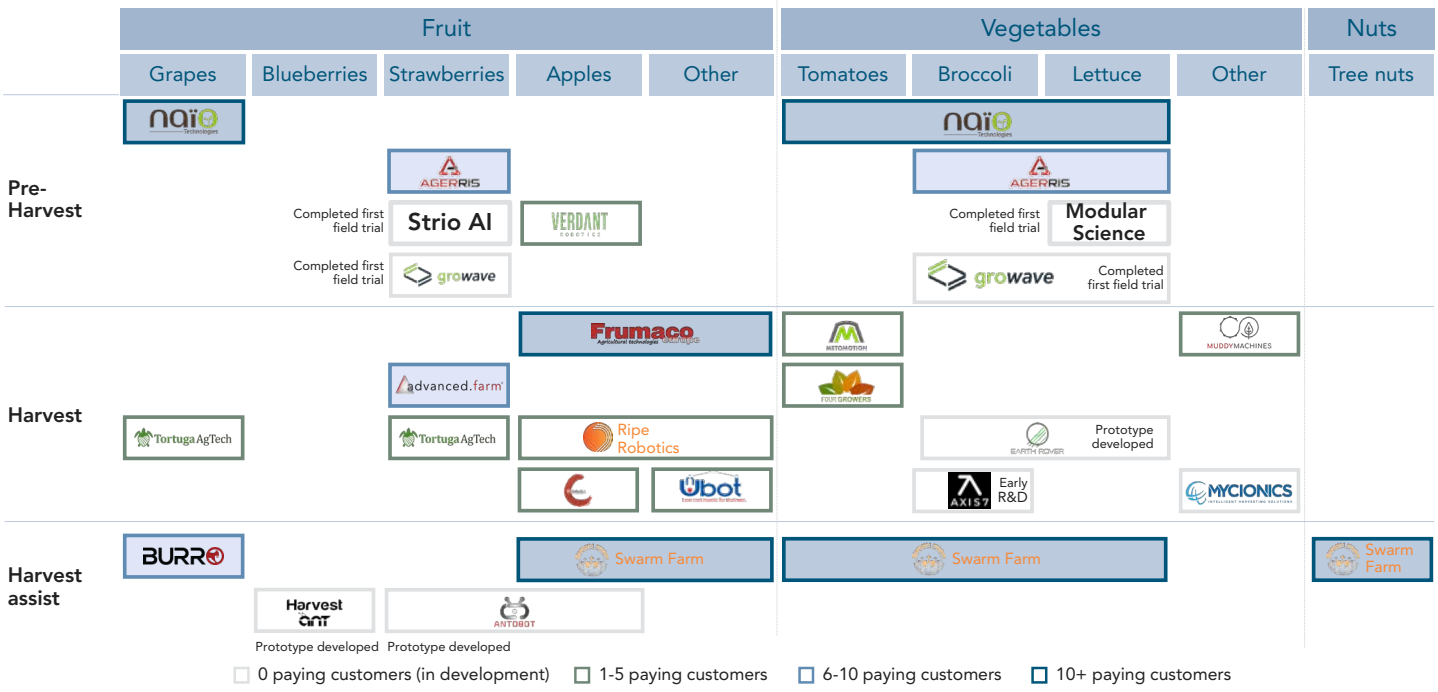
Figure 26 Start-up overview by funding round, paying customers and number of robots in operation [number of respondents; percentage share of total]

5.3
MARKET TRACTION OF HARVEST AUTOMATION START-UPS

To create transparency across harvest automation start-ups and identify innovation leaders, start-ups involved in the survey were mapped according to three distinct dimensions (see Figure 27). The horizontal axis defines the crop type, categorized as fruits, vegetables or nuts. The vertical axis outlines the harvest or harvest-related activity that the start-up is automating. These are defined as pre-harvesting activities (weeding, thinning, pruning etc.), harvesting activities (picking, cutting etc.) and harvest assist activities (for example, autonomous ground vehicles). The third dimension measures the market traction of start-ups based on the number of paying customers to date.

It's clear from the graphic that many start-ups are still in the early development stage, with only a limited number of paying customers. Start-ups active in pre-harvesting and harvest assist activities appear to be gaining most market traction, measured in number of paying customers, as the technology is typically more scalable across various crops. Except in pre-harvesting activities, few start-ups appear to develop solutions that are compatible across crop categories, namely fruits, vegetables and nuts.

MOST MARKET-READY AUTOMATION START-UPS IN THE SPECIALTY CROP SECTOR FOCUS ON COMPARATIVELY EASIER HARVEST ASSIST AND PRE-HARVEST ACTIVITIES – YET SEVERAL HARVEST-FOCUSED START-UPS WITH AN INITIAL CUSTOMER BASE



Source: Start-up survey, Western Growers, Roland Berger

Figure 27 Market traction analysis – Mapping of harvest automation start-ups by crop type, activity and number of paying customers [based on survey responses]

5.3.1 START-UP PERFORMANCE

Below are some examples of start-ups and their technologies that have created a stir in the agriculture industry, across the different harvest (and non-harvest) activities.

Pre-harvest activities: Naïo Technologies has gained significant market traction in this field, with 10+ paying customers and around 230 robots in operation. Naïo offers autonomous weeding and farming assist robots to enable smart and sustainable farming, mainly focused on vegetable and grape growers (see Figure 28).

Harvest assist activities: Burro is an innovation leader in harvest assist platforms, offering plug-and-play collaborative robots for outdoor, heavyweight logistical support. To date, the company has around 90 robots in service and supplies several customers. Its platform is

>> Company profile

NAÏO TECHNOLOGIES

Offering? Naïo Technologies offers autonomous weeding and farming assistant robots to enable smart and sustainable farming, with a focus on high-value crops in Europe and North America. Currently, Naïo offers three robots, Oz (for professional vegetable growers), Dino (for large vegetable growers) & Ted (for winegrowers). These have enabled them to log over 60,000 hours of operations.

Business model? The company has two main business models: sales of robots and robotics as a service in the US. The latter enables ROI for growers within a day.

Impact? Evaluations of Naïo's Dino platform by UC Davis showed ~20% savings in weeding time compared to standard weeding practices. The robots can remove ~90% of weeds in the field, resulting in up to ~50% savings.

Growth path? Looking ahead, Naïo aims to further expand geographically and across crops. In the short-term, autonomous weeding solutions for sugar beets and cereals will be launched. The next 3 years will bring geographical expansions across other US states, Australia and South America.

Website? https://www.naio-technologies.com/en/home/

Contact details? contact@naio-technologies.com

Picture of Naïo Technologies' large-scale vegetable weeding robot, Dino

Figure 28 Naïo Technologies company profile

crop agnostic and can be deployed in all settings where people need to carry heavy weight produce over long distances (see Figure 29).

Harvest automation: Many start-ups are experimenting with technologies to automate the harvesting of specialty crops indicated by the large number of start-ups in Figure 27. However, technologies are not as far advanced as pre-harvesting and harvest assist activities, and efforts appear to be concentrated around a small selection of crops. Start-ups typically focus on developing automation solutions for one or two crops only as each is harvested differently. This is in contrast to pre-harvesting activities, where Figure 27 illustrates that, for example, Naïo Technologies, Swarm Farm Robotics, Agerris and Growave operate across a variety of crops. In addition, most harvest automation interest seems to be concentrated on a selection of crops, mainly apples (or tree fruit in general), strawberries, tomatoes, and leafy greens.

Different automation technologies are typically being developed for different crops. For apples, different AI-driven technologies such as vacuum arms (Ripe Robotics), robotic arms (Fresh Fruit Robotics) and drone picking (Tevel Technologies) are currently being tested in orchard environments.

For strawberries, Advanced Farm and Tortuga appear to be gaining market traction for strawberry picking. Advanced Farm recently completed its Series B investment round, raising $25 million to further grow strawberry harvesting and adapt the technology to apple harvesting (see Figure 30). Tortuga recently completed a $20 million Series A round to further scale its strawberry picking solution and develop its picking technology for table grapes (see Figure 31). Important to note that both companies focus on different growing practices for strawberries, namely Advanced Farm on in-soil strawberries and Tortuga on tabletop strawberries.

>> Company profile

BURRO

Offering? Burro offers plug-and-play collaborative robots for outdoor, heavy-weight logistical support that are crop agnostic. Today's focus is mainly on supporting grape production. Its platform collects data through cameras while going through the fields.

Business model? Autonomous robots can be purchased by the growers. The minimum required to support one harvesting crew is six units.

Impact? One Burro unit typically supports 6-8 people per day and enables the harvesting team to produce 30%+ more fruit per day.

Growth path? First priorities are to extend the offering beyond grapes. Burro's platform can support any situation in which people are working and carry heavy weights, such as berries and nurseries. Furthermore, Burro aims to partner with other technology companies that can use the autonomous platform to scale and/or advance their technology. Burro aims to be a modular, multipurpose platform and become a preferred supplier for autonomous solutions, e.g., by mounting a robotic arm on the platform.

Website? https://burro.ai/

Contact details? sales@burro.ai

Picture of Burro's integration in the grape harvesting process

Figure 29 Burro company profile

>> Company profile

ADVANCED FARM

Offering? advanced.farm has developed an autonomous strawberry harvester that picks red, ripe fruit from in-soil strawberry beds using custom-designed robots and gentle, food-grade grippers. Its machines currently work alongside manual harvest crews on strawberry farms in California.

Business model? Today, customers can order fleets of multiple machines under a traditional tractor lease model (monthly payments over the course of a season).

Impact? One machine can harvest up to 100 pounds per hour and one person can operate five machines simultaneously. As a result, growers can reduce labor requirements by ~30%.

Growth path? advanced.farm continues to grow its strawberry harvesting fleet in California and will also introduce post-harvest automation solutions for strawberries in 2022. Beyond strawberries, R&D is underway to adapt the technology for harvesting apples. A first prototype will be ready for the 2022 harvesting season, developed in close collaboration with the WA Tree Fruit Research Commission.

Website? https://www.advanced.farm/

Contact details? info@advanced.farm

Picture of advanced.farm TX Robotic Strawberry Harvester

Figure 30 Advanced Farm company profile

>> Company profile

TORTUGA AGTECH

Offering? Tortuga AgTech offers harvesting robots for tabletop strawberries (glasshouse or outdoor tunnel) with integrated AI software that enable other harvest-related services, such as data-driven forecasting, UV treatment, trimming, and other services. The start-up is also launching a table grape harvesting robot in 2022.

Business model? Tortuga currently offers its harvesting robots through a robots-as-a-service model, getting paid by the kilo for the produce that its robots pick. The additional services are charged on a monthly or per-hectare basis.

Impact? Tortuga is picking strawberries at commercial quality and at cost-competitive rates compared to human harvesters. The robots ensure crops can be picked in an increasingly tightening labor landscape.

Growth path? Main strategic priorities for next year are to further scale strawberry robots and to further develop the harvesting technology for table grapes. By the end of 2022, Tortuga will have 160 robots deployed commercially across both crops.

Website? https://www.tortugaagtech.com/

Contact details? info@tortugaagtech.com

Picture of Tortuga's strawberry harvesting crew picking at night

Figure 31 Tortuga company profile

>> Company profile

EARTH ROVER

Offering? Earth Rover is a four-year-old start-up, with a novel approach to selective broccoli harvesting. Its patent-pending machine is designed to first cut and lift up the whole plant and then separate the head from the plant body in a separate second stage. Pollybell Farms, the largest organic grower in the UK, is a co-development partner of Earth Rover.

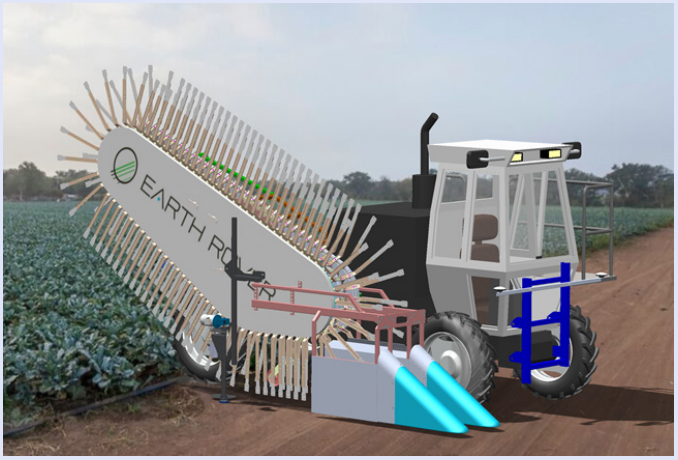
Business model? Still in development phase, recently completed first workshop prototype with field trials planned for 2022 season starting July. Looking to partner/license to specialist harvest machinery companies.

Impact? As well as increasing the speed of harvesting broccoli, Earth Rover aims to valorize the broccoli stems and leaves which would otherwise be wasted. This unlocks an additional revenue stream for the farmer, hence increasing overall farm yield.

Growth path? Primary focus is on broccoli, with aim to adapt the technology to be compatible for Romaine lettuce harvesting. Next to harvesting, Earth Rover has also developed a patent-pending light weeding technology.

Website? https://www.earthrover.farm/

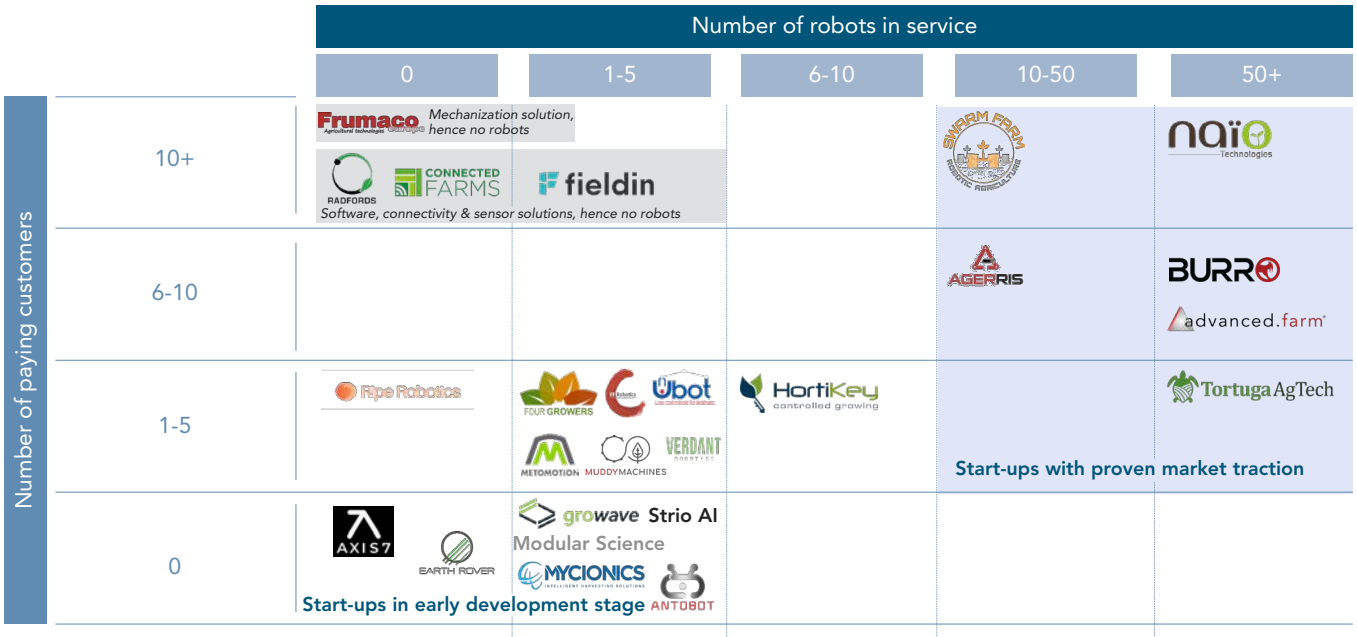
Contact details? david.whitewood@earthrover.farm



Picture of Earth Rover's single row prototype selective broccoli harvester

Figure 32 Earth Rover company profile

MOST START-UPS ARE STILL IN RAMP-UP PHASE, SERVICING 1–5 CUSTOMERS AND OPERATING 1–5 ROBOTS – FEW START-UPS GAINED MARKET TRACTION



Note: The following start-ups were not plotted on the matrix due to insufficient data: ABC, Citrus Vending, ConnectOne Club, Harvest Ant and SoilTech Wireless

Source: Start-up survey, Western Growers, Roland Berger

Figure 33 Visualization of start-ups by number of paying customers and robots in service (incl. harvest automation and software, analytics, and intelligent hardware start-ups) [based on survey responses]

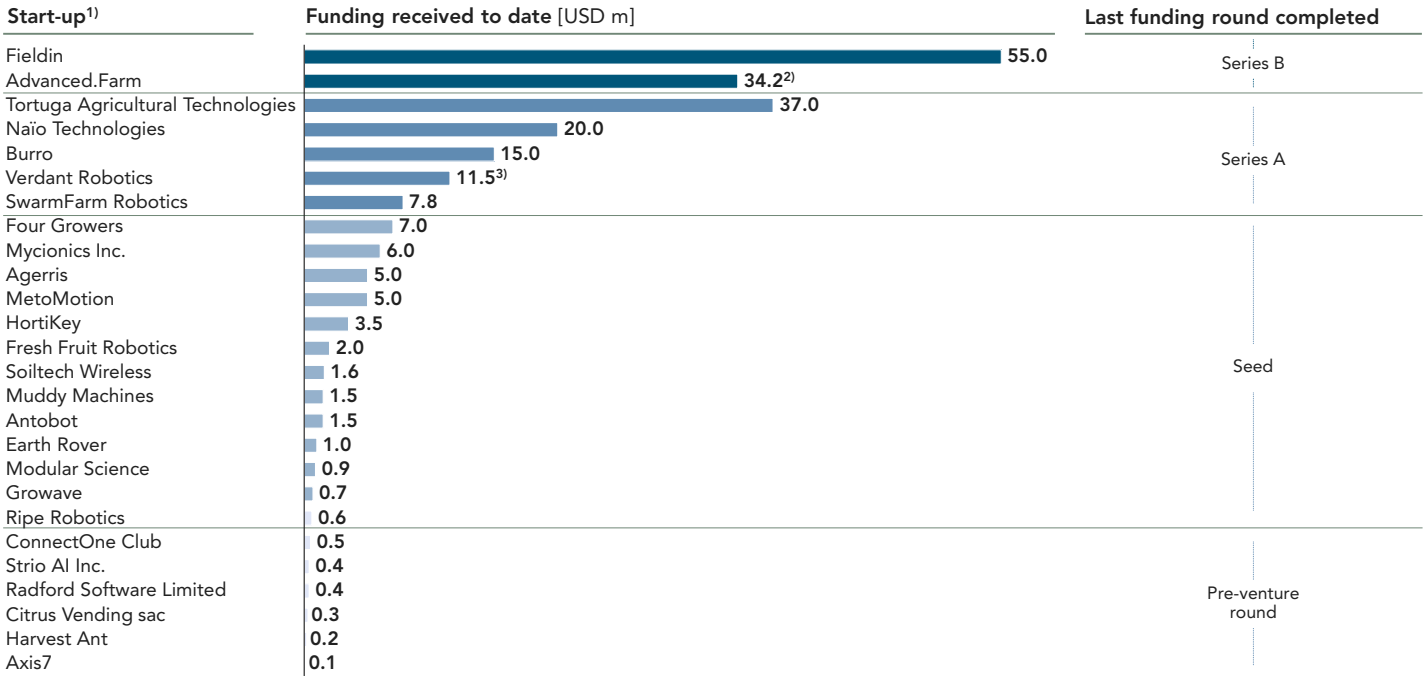
Harvest automation add-ons: Automation start-ups also are trying to optimize farm economics through other innovative solutions. As an example, Earth Rover's harvest solution aims to valorize broccoli stems, which would otherwise be discarded during the harvesting process (see Figure 32).

Non-harvest automation: Start-ups also are developing solutions to serve the broader agriculture industry. Indeed, several start-ups that are not focusing on harvest automation completed the survey, mainly with a software, sensor, connectivity and/or analytics offering. There are several examples. FieldIn offers a smart spray and harvest management tool, based on a combination of sensors, analytics and software. HortiKey perform plant analytics to enable precision farming. ConnectOne Club and Radford Software offer software services, while Connected Farms provides connectivity layers for start-ups. Finally, Soiltech Wireless provides intelligent hardware for soil data collection and analysis.

In addition to the three dimensions, the start-ups were also mapped based on other factors. First, the number of paying customers was plotted against the number of robots in service to help to further visualize their market traction (see Figure 33). Harvest automation start-ups with most traction are portrayed in the upper right quadrant.

Second, start-ups were ranked based on total funding raised (Figure 34). It shows most start-ups are still in pre-venture or seed funding rounds. Start-ups with proven track records in the number of paying customers and the number of robots are typically further advanced in the funding process. Hence, most start-ups featured in the upper right quadrant of Figure 33 have typically recently completed Round A or Round B funding. In addition to venture capital funding, more than 50 percent of the start-ups that participated in the survey reported that they have received a government grant.

START-UPS WITH THE HIGHEST MARKET TRACTION HAVE TYPICALLY ALSO RAISED THE MOST FUNDING



1) Following start-ups not included as funding reported as 0: ABC, Connected Farms, Frumaco & UBOT; 2) Funding from Crunchbase; 3) Funding from press release

Source: Start-up survey, Crunchbase, Roland Berger

Figure 34 Start-up ranking by funding round and total funding raised [based on survey responses]

5.4 ENABLERS TO ACCELERATE TECHNOLOGY AND MARKET DEVELOPMENT

Industry associations such as Western Growers can help to accelerate technology development and enable early-stage start-ups to gain market traction. These enablers can be grouped into five categories (see Figure 35).

First, opportunities to connect start-ups with growers and provide access to farmland for prototype testing and field trials is of crucial importance. The results and data collected through trials carried out under real conditions is invaluable to help start-ups to improve their technology and growers to assess the added value of the new solutions. Today, many start-ups are partnering with growers to test technology on their land and crops but establishing the right partnership can be time consuming. To facilitate connections, Western Growers aims to support start-ups in their commercialization strategy and acts as a match-making platform between start-ups and growers. In addition, Western Growers will continue to organize events, such as field days and networking events, for start-ups and growers.

Second, access to funding provides start-ups with the necessary resources to further develop their technology. Venture capital funding is a common way of raising money. VC funds will evaluate start-ups based on the quality and composition of the team, the addressable

TO ACCELERATE TECHNOLOGY AND MARKET DEVELOPMENT, WESTERN GROWERS CAN OFFER SUPPORT IN FIVE KEY AREAS, INCLUDING ACCESS TO GROWER NETWORK AND FARMLAND, FUNDING AND SUPPLEMENTING TECHNOLOGY

Enablers	Short description	Potential role(s) for Western Growers
Access to growers and farmland	Getting access to and connecting with farmers is crucial to test technology under real conditions and tailor solutions to growers' needs	• Support start-ups in **commercialization strategy** (match-making platform) • **Connect growers and start-ups**, e.g., field days, networking events • Provide access to **farmland for field trials,** potentially in collaboration • **Educate** growers about automation options and advantages
Facilitate access to funding	Funding provides start-ups with the necessary resources to develop technology, e.g., conduct research and development, expand operations	• **Establish private-public partnerships (PPP)** for R&D and commercialization funding, e.g., joint research project for broccoli harvester • **Expand investor partnerships**, potentially beyond VC, e.g., government funds
Access to supplementing technology	Building a Tech Stack could enable faster technology development, cost reduction and shorter time to market	• Continue to develop **Technology Stack** to reduce the cost of start-ups to scale • Establish **open-source collaborative approach**, e.g., image library, AI
Increased transparency regarding regulations	Regulatory transparency ensures technologies and solutions are compliant and future proof	• **Lobby** for policy updates and transparency to embrace new technologies, e.g., growing practices for specialty crops • Coordinate **R&D grants** for new technologies and innovations
Data transparency in terms of quality and cost	Data transparency is key to ensure start-ups can tackle and solve the right problems for growers	• Develop **online repository** of industry quality standards and grower data benchmark per specialty crop, e.g., through field case studies

Source: Western Growers, Roland Berger

Figure 35 Enablers to accelerate technology and market development, with potential roles for Western Growers

market size, the problem the start-up is trying to solve and the technological maturity of the technology. As well as VC funding, government and research grants are also a common funding source for new innovations and technologies. Western Growers has a long-standing partnership with S2G Ventures and together, the two organized the annual AgSharks pitch competition to bring investors and start-ups together (see Figure 36). Going forward, Western Growers aims to establish public-private partnerships for R&D and commercialization funding.

Third, providing start-ups with access to complementary technologies, or building a technology stack, could enable faster technology development. Today, most start-ups begin their technology development from scratch, thereby increasing the lead time for the solution to be brought to market. If existing technology could be leveraged and further built on, it could significantly accelerate market deployment. Based on our survey responses, around 50 percent of participating start-ups indicated that they were highly interested in partnering with another start-up or technology company to accelerate their development. The highest level of interest for industry collaboration was shown in image libraries (47 percent of respondents), robot middleware (42 percent) and mobile platforms (37 percent). In response to this demand, the Western

>> Interview

AUDRE KAPACINSKAS

Vice President at S2G Ventures

Developing an agriculture ecosystem to remove silos and accelerate technology adoption

S2G Ventures is a venture fund that invests across the food and agriculture supply chain to reflect the changing preferences of consumers. For the last several decades, food supply chains have been largely siloed, with consumers having limited visibility into the production process. Our investment thesis focuses on the consumer driving change across the value chain by demanding more transparency, sustainability, functionality and variety from their food.

Over the past decade, more companies than ever are developing products to align with consumer demands and emerging technologies provide the means to do so. These new technologies (robotics, specialized sensors, image analytics etc.) provide growers, packers, shippers and others the opportunity to measure sustainability, unlock new revenue streams, and ultimately adapt to the evolving expectations across the food supply chain. As new technologies become available and novel data is generated at scale, food producers can better connect with consumers.

At S2G, we are very deliberate about how we deploy capital. We typically invest $0.5 to $40 million per deal. We are active investors and typically participate in follow-on financing rounds as companies grow. Right now, we are excited to see emerging innovation in the specialty crop space and increasing collaboration between start-ups and growers.

As venture investors evaluating investment opportunities, we like to see technologies that are being developed that deliver value to the end user (e.g., grower), are interoperable and can be extended across multiple crops to ensure a large enough total addressable market. At the end of the day, we want to invest in companies that work with growers to understand their needs and deliver value – either through cost savings or new revenue opportunities.

At S2G we strive to be a value-added partner to the businesses we invest in; for our investments to be successful, we believe we need to provide more than just capital. We have developed a Platform Team that serves as the growth engine for our firm and our portfolio companies. We invest across the value chain and our goal is to connect emerging technologies with operating companies to accelerate technology adoption across the entire industry. With more stakeholder participation and education about emerging technologies, we hope businesses can find solutions to the challenges they are experiencing – whether that is water availability, food safety, sustainable farming practices or others.

As the food and ag industry continues to evolve, S2G is excited to connect with both growers and start-ups and take an active role to help bridge the gap between technology available today and the innovation capabilities of the future.

Figure 36 Interview with Audre Kapacinskas (S2G Ventures) – Accelerating technology development

Growers Center for Innovation and Technology is already building a Technology Stack to de-risk the technology component (see Figure 37).

Fourth, increased transparency regarding industry standards and regulations could help make technology compliant and future-proof. Additionally, visibility regarding regulations allows start-ups to develop sustainable, climate-friendly solutions. Western Growers will keep advocating for increased regulatory transparency and policy updates to embrace new technologies for the future of agriculture.

Finally, data transparency in terms of quality and cost is crucial to ensure start-ups are solving the right problems and to clarify the goals that start-ups need to reach before commercializing their solutions. Initially, industry associations like Western Growers and the Washington Tree Fruit Research Commission could develop an online repository with industry quality guidelines per crop. In a later phase, associations could set up testing centers to assess the quality of crop picked by start-ups and benchmark this with industry standards. As soon as start-ups reach a certain quality level, they could receive certification. This could provide an important signal to growers and investors about the technology readiness of start-ups. ■

>> Interview

WALT DUFLOCK

Vice President of Innovation, Western Growers

Building a common tech stack to reduce the launch and scale costs for start-ups

Western Growers' tech stack will consist of six elements to enable technology development, as shown in the table on the right, centered around software and hardware solutions.

Currently, there are four key priorities for the tech stack workstream:

- Secure public and private funding to support individual elements (goal of $20-25 m for research and commercialization)
- Align with existing start-ups who will leverage the components
- Spread awareness of the tech stack with a focus on research and educational institutions that have a proven history of AgTech R&D
- Define processes and timing for each proposed element

The tech stack will be open source and will be available via the Western Growers' and its partner associations' websites. Access to and use of the tech stack does not require membership of Western Growers Center of Innovation and Technology (WGCIT). However, joining the center enables start-ups to meet other individuals working on similar problems and can facilitate access to a larger grower network.

Roadmap element	Common Modular Architecture (CMA) approach	Estimated impact / savings per start-up
Image library	Shared image databased with tags (across all crops)	$500 k; 9 months
AI / ML	Shared AI (Artificial Intelligence) and ML (Machine Learning) source code repository	$1-2 m; 50% of development time
Sensors and controller	Open-source controller (all crops and standard sensors / equipment)	$2 m+; 75% of development time
Software architecture	Open-source AgOS (leverage Linux and / or ROS)	$1-2 m; 50% of development time
Robot arm / end effector	Integration specification and open documentation	$1 m+; 30% of development time
Mobility / integration	Integration options for existing tractors / ag equipment	$3-5 m; 30-50% of development time

Figure 37 Interview with Walt Duflock (Western Growers) – Western Growers' tech stack development

6.0

CONCLUSION

6.0 CONCLUSION

Since the launch of the Global Harvest Automation Initiative in Tulare in February 2021, Western Growers has rolled out several projects to achieve its ambition to automate 50 percent of harvest across the U.S. fresh produce industry within 10 years. Exactly one year after the launch of the initiative, Western Growers – with the support of Roland Berger – is publishing the first version of the Global Harvest Automation Report. This final chapter summarizes the principal findings of the study, key actions for Western Growers to accelerate harvest automation adoption and key considerations for next report versions.

Today's agriculture industry is facing a multitude of challenges, hampering food security for a growing population. Harvest automation is among the most promising solutions to alleviate pressures on the fresh produce industry. However, the market and technology are still in an early development stage

Farming is under pressure due to several key challenges, including a growing world population, farm labor shortages, ageing farmer populations, increasingly stringent regulatory environments, changing consumer preferences, and climate change. As many of these challenges affect the cost of production and yield of crops, growers are struggling to remain profitable and sustain their farming operations. Labor, in particular, is a key component in harvesting specialty crops, and the widening labor gap is putting growers of fresh produce under increasing pressure. Use of harvest automation technologies in the fresh produce industry is among the most promising solutions to accommodate ongoing industry challenges for specialty crop growers.

Current adoption of automation in harvest and harvest-related activities is low, but significant advancements are expected in the next 3-5 years. Regarding harvest automation, growers expect an average of around 20 percent of acres automated across all crops by 2025. Expectations are higher for pre-harvest and harvest assist automation, with most growers forecasting an average of 30-60 percent of acres using some form of automation by 2025. In line with current automation advancement, impact on cost, quality and food security has so far been limited. However, most growers indicate that they will turn to automation to bridge the labor shortage gap and ensure crops can be picked on time, rather than to save money.

Multiple start-ups are developing harvest automation solutions, with most market traction to date in pre-harvest (weeding, thinning, etc.) and harvest assist activities (harvesting platforms, autonomous ground vehicles, etc.). Overall, most start-ups that participated in our survey are still in development stage, indicated by the limited number of start-ups having completed round A or round B funding (around 25 percent of total respondents) and no start-ups having reported completion of a C+ funding round. Furthermore, some 75 percent of participating start-ups have fewer than five paying customers, and a similar proportion have fewer than five robots in service.

Western Growers has a unique role to play in accelerating harvest automation across the fresh produce industry.

Western Growers can play a unique role in bringing together the entire agriculture community. Efforts will be concentrated around three main initiatives:

1. **Drive collaboration with non-harvest technologies that support harvest automation**

   Non-harvest technologies such as genetic innovations, new farming practices, increased industry collaboration and regulatory transparency can accelerate harvest automation for the fresh produce industry. Western Growers is committed to further increase collaboration with seed companies (such as Bayer) and universities (for example, WA State University, UC Davis) to tailor genetic innovations to automation. Next, in collaboration with other associations, Western Growers will drive research initiatives around future farming practices that could facilitate adoption of automation. Beyond research initiatives, Western Growers is a strong believer in increased industry collaboration to share best practices and pool resources regarding harvest

automation. It aims to further connect member growers to share success stories, foster cross-association collaboration beyond the Washington Tree Fruit Research Commission and expand collaboration with research institutions such as the new AI institute from UC Merced and industry groups like the Bayer Horticulture Advisory Council.

2. **Facilitate access to funding for R&D and commercialization of new technologies**

   As funding is key to support research and accelerate commercialization of new technologies, Western Growers is committed to coordinating funding opportunities from various sources. First, increased transparency and coordination of publicly available funding sources could make more funds available for research and development. This includes potential funding arising from the new USDA-EU agriculture platform, announced in November 2021 and designed to increase international collaboration.[45] Second, Western Growers aims to establish public-private partnerships to have more funds available for research and commercialization of innovations. As example, Washington Tree Fruit Research Commission provided the initiative with $200,000 over the next 3 years, including access to subject matter experts.

3. **Support start-up development in the harvest automation space**

   Western Growers will continue to support the development of harvest automation start-ups by reducing the scaling cost of start-ups through a dedicated tech stack development, and by supporting commercialization efforts. First and foremost, Western Growers is committed to facilitate access to the grower network, for example, through field days and networking events for growers and start-ups. In addition, Western Growers will develop a match-making platform to support start-ups in their commercialization strategy. Second, Western Growers will continue to develop its tech stack to reduce the cost for start-ups to launch and scale. The roadmap will focus on both software and hardware development, with an open-source collaborative approach as a central objective. Third, Western Growers is committed to bringing increased transparency in terms of regulations, grower data and industry quality standards to steer start-ups in the right direction for technology development.

Beyond harvest automation, Western Growers is dedicated to changing the overall perception of the agriculture industry and preparing the next generation for future agriculture labor needs and opportunities in agtech. Western Growers will therefore work with educational institutions and growers to help define the educational curriculum and train the next generation of agriculture workforce.

This report will be updated on an annual basis to consistently track, measure and report on the industry progress of harvest automation in the fresh produce industry

This first version of the Global Harvest Automation Report defines the baseline for the status and impact of harvest automation in the fresh produce industry. The objective of future reports is to measure the aggregate impact of harvest automation compared to the baseline to consistently track advancement of the entire specialty crop industry.

This report covered around 30 percent of the U.S. specialty crop market value. The aim for future versions is to enlarge the focus to eventually cover most of the U.S. specialty crops. Another objective is to gradually widen the geographical spread of the report to leverage global best practices and advance harvest automation across the fresh produce industry on a global scale.

Finally, the aim is to widen both grower and start-up coverage to increasingly segment and draw greater insights across different farm sizes, crops and geographies, and further map evolutions of the start-up landscape. ■

45 U.S., EU Launch Collaboration Platform on Agriculture | USDA press release (November 2021)

WE WELCOME YOUR QUESTIONS, COMMENTS AND SUGGESTIONS

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This report has been developed by Western Growers and Roland Berger. It is based on:

- publicly available information;
- interviews with key market stakeholders such as growers, start-ups, industry associations, researchers, and investors;
- certain assumptions, general assessments, projections and experience derived from Roland Berger's consulting activities.

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Western Growers, founded in 1926, represents local and regional family farmers growing fresh produce in Arizona, California, Colorado and New Mexico. Our members and their workers provide over half the nation's fresh fruits, vegetables and tree nuts, including nearly half of America's fresh organic produce. Some members also farm throughout the U.S. and in other countries so people have year-round access to nutritious food. For generations, we have provided variety and healthy choices to consumers.

Roland Berger is the only management consultancy of European heritage with a strong international footprint. As an independent firm, solely owned by our Partners, we operate 50 offices in all major markets. Our 2,400 employees offer a unique combination of an analytical approach and an empathic attitude. Driven by our values of entrepreneurship, excellence and empathy, we at Roland Berger are convinced that the world needs a new sustainable paradigm that takes the entire value cycle into account. Working in diverse teams across all relevant industries and business functions, we provide the best expertise to meet the profound challenges of today and tomorrow.

7.0

APPENDIX

7.1
IMPACT ANALYSIS METHODOLOGY

The methodology of the impact analysis consisted of five main phases, starting from onboarding discussions with growers, benchmarking exercise, survey design and validation, data collection, and focus group validation.

First, 20+ discussions with growers were conducted to understand the main challenges, status & impact of harvest automation, and ongoing harvest automation initiatives. The data collected was used to determine the automation requirements of growers and provide guidance on the historic investments and future milestones for specialty crop automation.

In parallel, a benchmarking phase was initiated with 15+ external reports on impact analysis. These were reviewed to obtain an exhaustive view on the different methods of quantifying, measuring and reporting technology impact across various industries. The main takeaway from this process was to determine the key performance indicators of the test group and measure the impact on the specific metrics. Measuring the same key performance indicators will help maintain consistency when assessing impact across multiple stakeholders.

After the interview and benchmarking phase, key performance indicators were developed and a survey was created to measure the change of the metrics over time. It was tested with a select number of growers. After incorporating feedback from them, the survey was sent out to a long list of growers consisting of Western Growers members and partner association members, including WA Tree Fruit Research Commission, California Table Grape Group Commission, California Fresh Fruit Association, California Strawberry Commission, Imperial Valley Vegetable Growers, and California Citrus Mutual.

After data was collected, various focus groups were held for the selected specialty crops under focus. This process helped to validate the data collected from the survey as well as filling information gaps.

7.2
MARKET TRACTION ANALYSIS METHODOLOGY

Methodology of the market traction analysis consisted of four main phases, starting from onboarding discussions with start-ups, a benchmarking exercise, survey design and validation, and data gathering.

First, 10+ discussions with start-ups were held to understand the main challenges from a start-up perspective, comprehend industry needs and define objective and comparable market traction metrics. Best practices regarding data gathering from start-ups were also discussed, with a survey emerging as the most feasible solution.

In parallel, a benchmarking phase was initiated where 15+ external reports and articles were reviewed to obtain an exhaustive view on methods of identifying, evaluating and ranking start-ups. The main takeaway from this process was identifying that start-ups were rarely ranked on metrics aside from the amount of funding received. Rather than a formal ranking, start-ups are often mapped based on publicly available information, primarily along two categories, namely financial metric (for example, funding round) and/or company activities (for example, value chain coverage).

Based on the onboarding interviews with start-ups and insights from the benchmarking exercise, a preliminary set of survey questions was designed. The survey was tested with a select number of start-ups. After incorporating their feedback, the survey was sent out to a long list of start-ups and was advertised through LinkedIn. Data collected through the survey was validated by industry experts and by publicly available information, for example, cross checks of total funding raised using Crunchbase datasets.

This report does not aim to provide an exhaustive view of harvest automation start-ups, as only start-ups that have completed the survey are featured in this version of the report. The report will be updated annually to track market dynamics and evaluate in-market progress. ■

7.3
HARVEST AUTOMATION START-UP PROFILES

Advanced.Farm

Autonomous navigation tractors with grippers and vision that are collaborative with human harvesters for in-soil strawberry picking

- California (US) / 2018
- Strawberries
- $34 m / Round B
- 6-10 customers / 50+ robots

info@advanced.farm | https://advanced.farm/

Burro

People-scale collaborative robots for outdoor, heavy-weight transportation and logistical support

- Philadelphia (US) / 2017
- Grapes
- $15 m / Round A
- 6-10 customers / 50+ robots

charlie@burro.ai | https://burro.ai/

Agerris

Solar-electric mobile robot with real time AI and intelligent tools for weeding, spraying, and selective outdoor harvesting

- Australia / 2019
- Blueberries, broccoli, lettuce
- $5 m / Seed
- 6-10 customers / 10-50 robots

enquiries@agerris.com | https://agerris.com/

Connected Farms Limited

Mobile broadband connectivity to enable digital agriculture, AgRobots, and automation

- New Zealand & Australia / 2019
- Crop agnostic
- N/A
- 10+ customers / 0 robots

info@connectedfarms.com.au | https://connectedfarms.com.au/

Antobot

Robot control unit and AI software for automated scouting, logistics, weeding, and spraying

- United Kingdom / 2019
- Apples, strawberries
- $1.5 m / Seed
- 1-5 robots

N/A | https://antobot.ai/

ConnectOne Club

Digital business networks and technology platform for farmer associations to build a secure and collaborative environment with their community

- Australia / 2018
- Crop agnostic
- $0.5 m
- N/A

Contact@ConnectOneClub.com | https://connectoneclub.com/

Axis7

Applied AI harvesting robot for broccoli

- New Zealand / 2020
- Broccoli
- $0.05 m
- N/A

josh@axis7.nz | https://axis7.nz/

Earth Rover

Selective broccoli harvester and patent-pending light weeding technology for broccoli and lettuce

- United Kingdom / 2017
- Broccoli, lettuce
- $1 m / Seed
- N/A

info@earthrover.cc | https://earthrover.farm/

Fieldin

Smart farming platform application that collects, analyzes, and makes decisions based on collected field data

- California (US) / 2013
- Apples, lettuce, almonds
- $55 m / Round B
- 10+ customers / 1-5 robots

sales.au@fieldintech.com | https://fieldin.com/

Growave

Herbicide-free weed management and pathogen control using automated microwave technology

- Australia / 2020
- Strawberries, broccoli, lettuce
- $0.7 m / Seed
- 1-5 robots

N/A | https://growave.ag/

Four Growers

Autonomous greenhouse tomato harvester that integrates directly into high tech greenhouses

- Pennsylvania (US) / 2018
- Tomatoes
- $7 m / Seed
- 1-5 customers / 1-5 robots

info@fourgrowers.co | https://fourgrowers.co/

Harvest Ant

Human IoT hardware and smart tags for harvest traceability and labor management when picking and transporting fruit

- Australia / 2020
- Blueberries
- $0.2 m
- N/A

N/A | N/A

Fresh Fruit Robotics

Robotic tree fruit platform harvester imitating human-hand picking with robotic grippers for apple harvesting

- Israel / 2013
- Apples
- $2 m / Seed
- 1-5 customers / 1-5 robots

avikahani@ffrobotics.com | https://ffrobotics.com/

HortiKey

Digital platform for fruit assessment with integrated AI software and Machine Learning prediction models

- Netherlands / 2016
- Tomatoes
- $3.5 m / Seed
- 1-5 customers / 6-10 robots

N/A | https://hortikey.nl/

FRUMACO

Mechanized shake and catch system for apple harvesting (OE4 harvester)

- Germany / 2007
- Apples
- N/A
- 10+ customers

hello@frumaco.de | https://frumaco.de/

MetoMotion

Platform that provides yield estimation, stress detection, and harvest automation for greenhouse tomatoes

- Israel / 2016
- Tomatoes
- $5 m / Seed
- 1-5 customers / 1-5 robots

info@metomotion.com | https://metomotion.com/

Modular Science

Modular machines that help farmers improve soil health and reduce the use of pesticides, fertilizers, water, and fuel

- California (US) / 2014
- Lettuce
- $0.9 m / Seed
- 1-5 robots

info@modularscience.com | https://modularscience.com/

Radford Software Limited

Fresh produce management system software for enhanced visibility and control throughout the agriculture value chain

- New Zealand / 1988
- Crop agnostic
- $0.4 m
- 10+ customers

info@radfords.co.nz | https://radfords.global/home

Muddy Machines

Field robots for precision harvesting and yield prediction of asparagus

- United Kingdom / 2020
- Asparagus
- $1.5 m / Seed
- 1-5 customers / 1-5 robots

hello@muddymachines.com | https://muddymachines.com/

Ripe Robotics

Automated apple and citrus harvester using suction systems and integrated AI software

- Australia / 2019
- Apples
- $0.6 m / Seed
- 1-5 customers / 1-5 robots

contact@riperobotics.com | https://riperobotics.com/

Mycionics

Autonomous harvesting system for trimming, picking, and packing of indoor mushroom farms

- Canada / 2017
- Mushrooms
- $6 m / Seed
- 1-5 robots

info@mycionics.com | https://mycionics.com/

Soiltech Wireless

Wireless device and centralized platform to monitor soil health in fields

- Idaho (US) / 2019
- Crop agnostic
- $1.6 m / Seed
- N/A

N/A | https://soiltechwireless.com/

Naïo Technologies

Three distinct autonomous robots that focus on weeding, seeding, mowing, and planting using integrated AI software

- California (US) / 2011
- Vegetables, grapes
- $20 m / Round A
- 10+ customers / 50+ robots

contact@naio-technologies.com | https://naio-technologies.com/

Strio AI

Robotic runner cutting with vision and sensors for strawberry pruning

- Massachusetts (US) / 2020
- Strawberries
- $0.4 m
- 1-5 robots

N/A | https://strio.ai/

SwarmFarm Robotics

Base autonomous platform to mount third party attachments for weeding, spraying, and mowing

- Australia / 2014
- Crop agnostic
- $7.8 m / Round A
- 10+ customers / 10-50 robots

N/A

https://swarmfarm.com/

UBOT

Autonomous citrus harvester using AI deep learning and soft touch grippers

- Australia / 2015
- Citrus
- $0.04 m
- 1-5 customers / 1-5 robots

patrick.edwards@ubot.com.au

https://ubotcitrus.com/

Tortuga

Harvesting robot for tabletop strawberries that can perform cultivation tasks and data / forecasting services

- Colorado (US) / 2016
- Strawberries
- $37 m / Round A
- 1-5 customers / 50+ robots

info@tortuga.ag

https://tortugaagtech.com/

Verdant Robotics

Autonomous robots focused on crop spraying and thinning, with first robots focusing on automated chemical spraying and apple thinning

- California (US) / 2019
- Crop agnostic
- $11.5 m / Round A
- 1-5 customers / 1-5 robots

info@verdantrobotics.com

https://verdantrobotics.com/

Source: Western Growers, Roland Berger

Figure 35 Enablers to accelerate technology and market development, with potential roles for Western Growers

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