Stakeholder Mapping of California's Precision Weeding Sector

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ABSTRACT

Precision weeding, a sector of agricultural technology in which drones and/or automated weeders use chemical, mechanical, or thermal means to eradicate weeds, has moved from academic research settings to commercialization. Because of labor shortage pressures, the push to gain competitive advantages, and the environmental impacts of excessive chemical inputs, many California growers have been interested in adopting precision weeding technologies in their operations. Using semi-structured qualitative interviews, this study investigated the viewpoints of three key stakeholder groups involved in the diffusion and adoption of precision weeding technologies: California growers, precision weeding startups, and agricultural technology venture capital firms. With the supplemental viewpoints of large agricultural firms and their corporate venture capital arms and government agencies, this study seeks to understand the compatible motivations between stakeholders, current collaborative models between stakeholders and their limitations, and the user journey for growers adopting precision weeding technology. Through thematic coding and analysis, the textual data was visualized using a chart and cognitive maps. The chart indicated that compatible motivations included addressing current labor issues, reducing costs, and the potential of precision weeding to transform agriculture. Less cited but still popular motivations included having more weeding options, meeting specific field needs, and environmental sustainability. The individual cognitive maps and stakeholder group maps found that the adoption of precision weeding technologies by growers is commonly limited by concerns about startup longevity, the high expenses of precision weeding machinery, and some startups lacking a direct connection to growers.

KEYWORDS

California growers; Precision agriculture; Technology diffusion; Cognitive mapping; Agricultural technology.

INTRODUCTION

In commercial agriculture, weeds threaten effective crop production and thus is conventionally combated by the application of herbicides. By competing with commercial agricultural crops for light, water, and nutrients, weeds threaten crop yields and the financial health of commercial agriculture. In addition, weeds may serve as posts for pests and pathogens, interfering with crop production. The most common weed management strategy is the application of herbicides and pesticides. In 2017, over 400 types of pesticides were used in the United States, amounting to over one billion pounds (Acharya 2020). Pesticide and herbicide use is prevalent in California despite the state having one of the country's strictest environmental protection regulations. In Fresno County in 2017, 32 million pounds of pesticides were used in commercial agriculture, the largest amount out of all California counties (Rodriguez-Delgado 2019). In Tulare County, 19 million pounds were used that same year. (Rodriguez-Delgado 2019).

A differentiating factor of California agriculture compared to nationwide agriculture is its large production of high-value specialty crops, such as vegetables, fruits, and nuts. In 2017, 44% of the state's farm sales came from fruits and nuts, 17% from vegetables and melons, and 14% from nursery and horticultural specialty crops (Martin et al. 2020). Despite the prevalent use of pesticides, weed management for specialty crops still faces significant issues due to the increasing number of herbicide-resistant weeds. Because specialty crops have fragmented markets and development for one type of herbicide can cost up to $300 million, the development of new herbicides is hindered if the market sizes for specialty crops are too small to justify the high development costs (Fennimore and Cutulle 2019). A danger of herbicide-resistant weeds is that they can spread and damage crops more than expected, making a "routine" pest a more serious problem. Persistent weeds emerge from selection pressure favoring weed species that are more tolerant to different management practices. Herbicide-resistant weeds are a result of adaptive evolution, whereby mutations cause the physiology of plants to be more resistant to an herbicide (Hanson et al. 2014). Selection pressure and herbicide resistance are more common in high-intensity commercial agriculture due to the extensive use of herbicides. The first resistant biotype was confirmed by the International Survey of Herbicide Resistant Weeds in 1957, and since then more than 400 unique species-herbicide group combinations have been discovered

(Hanson et al. 2014). Of the 400, the US is home to 165 of these biotypes, more than any other country, and California of 21 (Hanson et al. 2014).

As a result of greater herbicide resistance as well as a push towards organic farming, hand weeding is now a crucial weed management strategy. The greatest constraint California growers have regarding weed management is the expenses and difficulties of manual weeding. The labor rates are impacted by recent California state legislation that increased the minimum wage. Passed in 2016, SB 3 raised the minimum wage to $15.00 per hour in 2022, a 7.1% increase since 2021 (Labor Commissioner's Office 2021). As a result of AB 1066 being passed in 2016, the overtime threshold, defined as the hours of work required before employees receive overtime benefits, in the agricultural industry has decreased to 40-hour weeks and 8-hour workdays in 2022 (Labor Commissioner's Office 2022). Because of these increased labor protections, on-farm labor has increased in cost and for organic crops and high-density planting, hand-weeding can cost more than $300 per acre (Hanson et al. 2014). Labor shortages have also been a long-standing trend in California agriculture as American agriculture increasingly competes with Mexican farms for farm labor (Taylor et al. 2012). This structural shift in the labor pool has caused fewer workers to be available for low-skill, low-wage agricultural jobs. To address labor shortages and high labor costs, precision weeding technologies have emerged.

Precision weeding, selective weeding to replace and/or complement herbicides, has long been an academic interest to combat the difficulties of manual weeding in commercial agriculture. In addition to labor shortages, human labor also is time-consuming and error-prone, eliminating only an average of 65% to 85% of weeds (Slaughter et al. 2008). The world has more than 50,000 weed species and weed detection often uses image segmentation to distinguish the visual features of weeds versus crops (Li et al. 2022). Precision weeding techniques include mechanical, chemical, and thermal/electrical weeding. Existing precision weeding robots are effective for short crops and future R&D may focus on tall crops like sugarcane and maize. While mechanization in the 19th century caused farmers to standardize the way they treated large areas, precision farming seeks to enable site-specific management (Lowenberg‑DeBoer 1996). For example, UAVs can be used for precision weeding by targeting undesirable weeds with herbicides instead of herbicides' traditional application throughout a field. Precision weeding is still an early-stage technology and thus faces challenges when encountering unexpected changes in the environment, for example, wind direction (Dai et al. 2017). Therefore, though much research has been done on prototypes in academia (Raja et al. 2023; Nasiri et al. 2022; Bakker 2009), there is a research gap in the feasibility of precision weeding commercialization.

In this study, I ask the central research question of how do the relationships between stakeholders (California farmers, agtech startups, and venture capital firms) in the precision weeding ecosystem impact the adoption/scalability of the technology? My sub-research questions will answer the following: (1) What, if any, are the compatible motivations between the stakeholders? (2) What are current collaborative models between stakeholders and what are their limitations? (3) What is the user journey for farmers adopting precision weeding technology?. My working hypothesis for the question regarding motivations is that a compatible motivation between all stakeholders is financial, local economic vitality, and environmental and social sustainability. I also expect perceived sources of tension to include a power imbalance/struggle between government agencies and VC firms and corporations. Regarding the farmers' user journey, I expect farmers to become familiar with precision weeding technology primarily through word of mouth, perhaps try out the technology through a pilot program that involves larger corporations, and long-term adoption to be supported by government funding or initiatives. My data collection objective is to use qualitative data from semi-structured interviews to map out the precision weeding ecosystem and its impact on the technology's scalability.

Background

Setting: Agriculture in the Central Valley and Central Coast of California

The study system is the Central Valley and Central Coast of California, two of the most valuable and productive agricultural areas in the United States where there are also extensive chemical inputs. Nine out of ten of the state's top agricultural counties are in these two regions (CDFA 2020). California produces over 400 commodities worth over $49 billion in sales (CDFA 2022). Of that, the Central Valley produces over 250 crops with a value of $17 billion per year (USGS n.d.). The Central Valley alone contributes an estimated 25 percent of the nation's food (USGS n.d.). In the most recent Census of Agriculture in 2017l, the Central Valley had more than 35,000 farms and nearly 6 million harvested acres (USDA 2019). Top commodities across Central Valley counties include almonds, pistachios, table grapes, oranges, wine grapes, walnuts, cotton, and nursery crops (DeLonge 2022). The Central Coast consists of Monterey, Santa Cruz, and San

Benito Counties and produces many row vegetables and berries. In 2017, there were over 400 vegetable farms and nearly 800 fruit and nut farms in these three counties (Olimpi et al. 2019).

A pressing issue for most California farmers is a shortage of labor and high labor costs. The labor rates are impacted by recent California state legislation that increased the minimum wage. In 2016, SB 3 set the 2017 state minimum wage of $10 per hour for employers with 25 employees or less and $10.50 per hour for employers with 27 employees or more (Labor Commissioner's Office 2021). The minimum wage has been mandated to increase yearly and in 2022, it is now $15.00 per hour for employers with 26 or more employees, a 7.1% increase since 2021. As a result of AB 1066 being passed in 2016, the overtime threshold, the hours of work required before overtime benefits are received, in the agricultural industry has decreased. In 2019, the overtime threshold was "decreased from 60 hours per week and 10 hours per day to 55 hours per week and 9.5 hours per day" and in 2022, it is now 40-hour weeks and 8-hour workdays (Labor Commissioner's Office 2022).

As a result of these increased labor protections, on-farm labor has increased in cost. For example, in 2019, UC Davis published the sample costs to produce and harvest romaine hearts in the Central Coast (Tourte et al. 2019). These costs were calculated under the assumption that weeds are managed first with one banded herbicide application, herbicide spraying on all crops over a certain width, after planning (Tessier and Leroux 2010). Then, the beds were hand weeded with the removal of doubles three weeks after thinning and then a second time prior to harvest. The labor rates were impacted by recent California state legislation that increased the minimum wage and decreased the overtime threshold. As a result, this study determined that wages were $24.70 per hour for machine operators and $18.70 for general labor, higher than similar jobs in other industries because of the high overhead of 41 percent. The costs of two hand weeding applications totaled to $299 in labor expenses per acre of romaine hearts, 7.5% of total cultural costs. For a cost study for organic strawberries, hand weeding and runner removal is estimated to be a cumulative of 34.5 hours per acre per month for the 10 months of production season (Bolda et al. 2022).

Precision Weeding Stakeholders

Arguably, the most important stakeholder in the precision weeding ecosystem is the growers as they are the ones using the technologies in their day-to-day operations. In 2019, California 69,9000 farms with an average farm size of 348 acres (CDFA 2020). This average farm size is smaller than the national average of 445 acres (USDA 2022). In 2017, Californian farmers had an average age of 59.2 years and less than 6 percent of all California producers, defined as farmers and ranchers, were aged 24 or younger (Kranz 2019). Most farms–74 percent–were owned by individuals, families, or partnerships. Although 10 percent of farms were owned by corporations, less than 2 percent were owned by non-family corporations (Kranz 2019). Most farms are operated by California's 700,000 seasonal farmworkers (Minkoff-Zern and Getz 2011).

Precision weeding startups have increased in popularity in the past few decades and have a positive growth trajectory, with the sector expecting to grow by $268.75 million with a CAGR of 18.41% from 2022 to 2026 (MarketReport 2022). On-farm research and pilot farms allow for research to be more effective and quicker to be implemented on a farm level (Aarts et al. 2014). Precision weeding startups may be complementary to existing R&D efforts at larger corporations or seeking to disrupt current technologies or business models. As a result, new competition from startups can erode monopoly power (Graff et al. 2021). Venture capital investment in startups has accelerated in the past decade, with "twenty times more capital… invested in new agtech ventures in 2021 than 2012 (Asthana et al. 2022)." The average seed round for digital and precision agriculture startups is $3.8 million and the average funding increases to $117 million for Series D and later funding stages (Asthana et al. 2022). Up to 2006, global investments in agtech startups remained less than $200 million per year but then steadily grew until investments began exceeding $3 billion every year in 2010 (Graff et al. 2021). VC markets are largely driven by expected returns on investments, macroeconomic health, industry characteristics, and company performance (Gompers and Lerner 2004). VC investments may also be catalyzed by exit outcomes (i.e., IPOs and M&As) such as Monsanto's acquisition of the Climate Corporation in 2013 and John Deere's Acquisition of Blue River Technology in 2017 (Graff et al. 2021). A study that used a database of over 1,500 startups with financial transaction history from 1997 to 2007 found that 10 percent exited through an IPO, 47 percent exited through M&A, 10 percent exited through another buyout, and only 4.4 percent are likely still in business (Graff et al. 2021). These figures demonstrate the volatility of VC-backed startups and the startups' neverending battle to acquire additional funding and exit.

Other California Agriculture Stakeholders

Government agencies are incentivized to be involved in the agricultural industry, especially in California, because it is such a big part of the economy. California regulates pesticide use through the California Department of Food and Agriculture and the California Department of Pesticide Regulation. In the 19th and 20th centuries, the government played a larger role in agricultural research and development through supporting agricultural research stations and academia as well as supporting philanthropic foundations (Graff et al. 2021). Governments work with other private stakeholders through public-private collaborations. Governments are involved in the agtech industry by providing funding and resources through public-private collaborations and steering market demand through policy. Outside of direct research and development financing, governments also serve as allies in cleantech startup innovation (Doblinger et al. 2019). However, startups face higher risks than larger companies when forming alliances because of their resource constraints and thus are often hesitant to enter alliances with governments. The benefits of alliances for technology development are numerous as they can catalyze startup innovation–as measured by patenting activity–and serve as signals to private investors as a result of knowledge spillover (Doblinger et al. 2019).

An example showcasing the value of private-public partnerships includes four examples from the Netherlands that found that collaborations are policy instruments that catalyze innovation system feedback loops (Hermans et al. 2019). They typically involve governments, startups, and universities whereby resource mobilization and knowledge development feed into entrepreneurial activities and market development (Hermans et al. 2019). Governments play a large role in the mobilization phase in particular because they select participants and set the criteria for funding (Hermans et al. 2019). The innovation systems framework can be applied to many regional public-private efforts in the US and demonstrates the crucial role of government agencies in supporting sustainable agriculture technology. Particularly with regards to precision weeding, the Governor's Office of Business and Economic Development (GO-Biz) has tax credit and sales tax exemption programs for the agriculture and agtech sectors. In the U.S., the USDA, other federal agencies and state governments all administer public agricultural R&D funding (Smith and Blaustein-Rejto 2022). The USDA is the major funding administrator, and in 2019, this department used programs and R&D agencies, such as the National Institute of Food and Agriculture (NIFA) and the Agricultural Research Service (ARS; USDA's in-house scientific research), to administer over $2.7 billion (Smith and Blaustein-Rejto 2022). State governments play a significant role alongside federal agencies, funding 21% of total public agriculture-related R&D in 2019 (Smith and Blaustein-Rejto 2022).

The Big Four are global agricultural companies that dominate the chemical and seed markets: BASF, Bayer, Corteva, and Syngentra. They started out as the "Big Six" in the 1990s and early 2000s. Mega-mergers such as the Bayer/Monsanto merger, Syngenta being acquired by ChemChina in 2015, and Dupont and Dow's merger in 2015 concentrated the current future control of agrifood innovation (Lianos 2017). A consequence of increasingly concentrated markets is perhaps a decrease in innovation. Most R&D and innovation are driven by close rivals and companies wanting to maintain their market position. Additionally, though some may argue that "firms in concentrated industries may be more likely to invest in research because they can appropriate more of the returns from an innovation," net returns to an innovation may be lower considering they will take sales away from existing products and services (MacDonald 2017). The size of R&D teams and budgets may also impact the amount of Big Ag companies work on innovating: economies of scale may apply up to a certain budget however, at a certain point, larger R&D teams will be less effective because of their similar approaches and decreased competition/sense of urgency (MacDonald 2017).

These innovation concerns are on the radar of US antitrust enforcement agencies. For example, in 2016, the US DOJ cited innovation reduction in their challenge of John Deere's acquisition of Precision Planting, LLC. Because the two parties were both producing high-speed planters and the DOJ was concerned that the elimination of the rivalry would increase prices for farmers (MacDonald 2017). Larger agricultural corporations were also involved in precision weeding investments such as Taylor Farms' investment in FarmWise in 2022 and John Deere's acquisition of Blue River Technologies in 2017.

Precision agriculture and precision weeding

Precision agriculture refers to technological advancements that increase the efficiency of on-farm management through data collection, measurements, and responding to field and crop variability. Precision agriculture can be used for many on-farm functions, including harvesting, yield management, irrigation, soil and crop health detection, and weeding (Baerdemaeker, Munack et al. 2001). Precision weeding can be conducted autonomously or with human guidance. For both, weed control involves plant detection and classification–by their shape, color, and other visual characteristics–and the control method, which is currently most commonly mechanical removal or selective spraying (Komi et al. 2007). Other control methods include thermal treatments, freezing treatments, and electrical discharges. Selective spraying herbicides in low dosages can reduce the amount of chemical inputs by 70 to 90 percent compared to broadcast herbicide applications (Raja et al. 2023). Autonomous weed control also includes using motion sensors for navigation and positioning and be conducted using either mapping or real-time approaches (Komi et al. 2007). The mapping approach first uses techniques, such as GPS mapping, to produce weed maps which are later targeted with machinery. On the other hand, the real-life approach requires instant responses between the detection and the control method, reducing time and costs.

Research Frameworks

Existing innovation frameworks and theories

There are many existing theories and frameworks surrounding innovation and the process of going from invention and R&D to commercialization. E. M. Rogers' Diffusion of Innovation theory from 1963 is one of the earliest frameworks in innovation study and has been used in many fields such as political science, economics, education, and public health (Sahin 2006). An innovation, which can be an idea, practice, or project, must be considered new by the adopters, and can only become widely accepted by reducing its uncertainty by informing individuals of its consequences. These consequences can be either advantageous or not, such as costs and resource expenses, or the effectiveness and compatibility of the innovation (Dearing and Cox 2018). The diffusion of innovations is also dependent upon communication channels because diffusion is a social process between individuals and can be categorized as localite channels or cosmopolite channels. Diffusion takes place within a social system which has interrelated parts that have a common goal. Leveraging communication channels and the social system, the innovation-decision process goes from knowledge to persuasion to decision to implementation to confirmation (Sahin 2006). Adopters can be classified based on innovativeness on a normal distribution curve as innovators, early adopters, the early majority, the late majority, and laggards.

Technology transfer can happen via both market and non-market interactions, which include input-output relationships (i.e., one party supplies while one party buys), problem-solving collaborative networks, and informal networks. These networks can overlap and their relative importance is dependent upon local dynamics and considerations (Carlsson et al. 2002). The approach of national innovation systems emerged in the late 1980s which broadened input/output analyses from the 1940s and 1950s to include not only companies but also R&D activities and technology (Nelson 1993). This expanded the scope of stakeholders to include universities, research institutes, and government agencies. Techno-economic competence is required to identify and exploit business opportunities. Selective capability is required to engage in entrepreneurial activity and identify technological opportunities. Organizational ability involves combining existing knowledge and skills to organize internal resources and economic activities. The functional ability allows for "the efficient execution of various functions within the system to implement technologies and utilize them effectively in the market." Learning ability enables organizations to identify and correct mistakes, a skill required for long-term success (Carlsson and Eliasson 1994).

Local Ecosystems: The Role Of Geographical Clustering

Private actors, government agencies, and the agtech startups optimize their interactions with one another through the curation and development of local ecosystems. A study focused on institutional factors that impact startup formation uncovered the relative importance of knowledge networks, policies, and resources (Sunny and Shu 2019). Through identifying metropolitan clusters, determining congressional support using scores from the League of Conservative Voters, and social norms estimated at the state and country levels, the researchers found significant relationships between most county-level variables but they were much less significant between states, implying the importance of local ecosystems (Sunny and Shu 2019). Pro-startup government policies and social support had positive correlations with local firm formation (Sunny and Shu 2019). The results of this study also are an example of the institution theory, which suggests that public policy influences firm formation and performance through incentives.

The study also suggests the theory of agglomeration, which states that increased consumer demand and interfirm relationships overshadow competition for resources, explaining why firms usually develop in clusters. Giudici et al. (2019) conducted an analysis of startup clustering in Italy, providing a concrete example of the institution theory and the theory of agglomeration. Using a data set of almost 400 cleantech startups extracted from Italy's official database, it was found that factors that impact the creation of cleantech startups include the availability of scientific and technological knowledge and personal experiences with the adverse impacts of climate change. Localized factors such as university knowledge, particularly in the natural sciences, and the history of environmental disasters in provinces were positively correlated with the likelihood of cleantech startup formation (Giudici et al. 2019). Both of these papers illustrate the value of local ecosystems that are supported by government policies and funding.

In California in particular, research-derived innovation is shown through the role of research universities in intellectual property and technology transfer. The UC system has Offices of Technology Transfer and close to 5,000 active patents (Gordon et al. 2020). Additionally, the UC Cooperative Extension (UCCE) is a mechanism whereby UC campus-based specialists collaborate with farm advisors and research stations throughout the state. The UCCE enables Extension professionals to work with UC faculty on applied research as well as provide expertise to other stakeholders like government, nonprofits, agribusiness, and farmers (Gordon et al. 2020).

Existing Research on Farmer User Journeys

The success of the precision weeding sector is dependent on whether farmers are willing to adopt it into their current weed management processes. The adoption of new technology is heavily impacted by farmer perceptions and characteristics. In a study examining the role of farmer perceptions on the adoption of traditional versus improved rice varieties in Odisha, India, researchers found management considerations such as labor and chemical input use were highly valued by the farmers (Kshirsagar et al. 2002). In addition, farmers also highly valued financial considerations such as economic returns and capital investment sizes. Characteristics that may impact whether Californian farmers adopt new technologies are their ages and social networks (Bandiera and Rasul 2006). Though adoption rates are also positively correlated with older age, more experience, and the affordability to take risks, younger farmers may experience the lower cognitive cost of switching and thus be more likely to adopt new technologies (Bandiera and Rasul 2006).

Social networks also impact the probability of adoption. An inverted U-shaped relationship is illustrated in which the probability of adoption is low when only a few people in the network have adopted or almost all have adopted, but high when about half of the people in the network have adopted (Bandiera and Rasul 2006). Thus, word-of-mouth could be the key factor in farmers becoming aware of precision weeding technology, considering its adoption, and making or not making the decision to adopt.

Precision agriculture technologies are often used in tandem. Therefore, precision weeding technology adoption rates could be higher for farmers who also use technologies such as GPS mapping and guidance systems (Schimmelpfennig 2016). There is research on how farmers make choices but not on how this applies to the precision weeding sector. The farmers' user journey could be different depending on the startup's business model (e.g., weeding-as-a-service versus a farmer having to buy/lease the technology). Considering California's large production of specialty crops compared to other American states, specialty crop growers typically have less developed formal information networks compared to farmers of major commodities like wheat, and they rely more heavily on informal information.

METHODS

Data Collection

To collect textual data for my three subquestions, I used the data collection method of semi-structured qualitative interviews. Though the number of qualitative interviews required to draw legitimate conclusions is contentious, I followed a guideline that six to seven interviews achieve a data saturation of less than five percent new information threshold (Guest et al. 2006). Guest et al. conducted 30 interviews, in which the first six interviews and the subsequent six interviews uncovered 70 percent and 19 percent of themes and ideas, respectively (2006). Therefore, to obtain more than 90 percent data saturation, I conducted 16 interviews. Of the 16 interviews, I conducted interviews with four Californian farmers, five venture capital firms/accelerators, four precision weeding startups, two Big Ag corporations and corporate venture capital arms, and one government agency. A small sample size was effective in revealing the core categories of these lived experiences (Bernard 2018). To ensure the validity of the data collected, I certified that the interviewees had experience within the precision weeding sector and hold mid to high-level roles in their respective organizations. The outreach process was through networking at an in-person conference, cold emailing and Linkedin messaging, and speaking with 'connectors'' such as UC Cooperative Extension Specialists.

Due to logistical constraints, the interviews were conducted over video calls. Prior to the interview, I obtained informed consent via a form through WeSignature or verbally, allowing for voice recordings and transcriptions of the interviews. A caveat is that two of the interviewees' informed consent forms did not allow for voice recordings due to their companies' legal directives but did allow for the interviews' content and quotes to be used in this thesis. I ran the voice recordings through the software Fireflies.ai (Fireflies.ai 2022) to obtain transcripts, which were manually proofread following the interviews. The number of questions asked was based on data and thematic saturation, a criterion used for discontinuing data collection and analysis (Saunders et al. 2018). To guarantee qualitative rigor, in this case, defined by the points at which no new themes are generated from the interviews, I asked three open-ended questions for each sub-research question, adding up to a total of nine questions in addition to basic biographical questions. A constraint in this study is that potential subjects may not be inclined to be interviewed if there are too many questions. Therefore, I chose to streamline and cull some of the questions for feasibility.

Data Analysis

For interview coding, the first step of thematic analysis, I ran the interview transcripts through the software ATLAS.ti (ATLAS.ti 2023). After I became familiar with the data, I developed a thematic framework and indexed the data against the said framework (Goldsmith 2021). This framework approach enabled comprehensive indexing and comparative analysis between the interviewees, allowing for the mapping of patterns.

I used an open coding method within the framework of grounded theory in which the textual data is used to uncover the responses of actors to changing conditions and the subsequent consequences (Corbin and Strauss 1990). A procedural characteristic of grounded theory is that data analysis must occur at the same time as data collection; the coding and analysis of the first interview should incorporate details of all potential relevant information into the design of the following interviews (Corbin and Strauss 1990). Because my research question is about cross-organization perspectives and the complexity of stakeholder relationships, I used structured yet non-mathematical methods for multi-level stakeholder maps. First, I created individual stakeholder maps from the individual interviews (micro level). Then, I combined the individual cognitive maps for each stakeholder group (macro level). To combine individual stakeholder maps to create stakeholder group maps, I overlaid similar themes, added links between themes that individual interviewees contributed, ensured that the strategic map maintained the individual maps' themes, and identified clustering in the stakeholder group maps (Pidd 1997).

RESULTS

Interviewee Demographics

The three core stakeholder groups in my study were (1) California growers, (2) agtech venture capitalists, and (3) venture capital-backed, precision weeding startups. Additional supplemental interviews were conducted with large agricultural companies and their corporate venture arms and government agencies. Each of the interviewees was assigned an alphanumeric identifier. Most of the interviewees–14 out of 16–hold managerial/senior positions (Table 1).

Table 1. Interviewee characteristics.

Category	Alphanumeric Identifier	Role
Venture Capital	V1	Executive
Venture Capital	V2	Director
Venture Capital	V3	Vice President
Venture Capital	V4	Executive
Venture Capital	V5	Analyst
Startup	S1	Director
Startup	S2	Head
Startup	S3	Executive
Startup	S4	Executive

Category	Alphanumeric Identifier	Role
Grower	Gr1	Executive
Grower	Gr2	Manager
Grower	Gr3	Vice President
Grower	Gr4	Vice President
Ag Corporation/CVC	C1	Engineer
Ag Corporation/CVC	C2	Senior Director
Government	Go1	Manager

Compatible Motivations

Answering the first subquestion of compatible motivations, I found the frequencies of eleven indexed motivations (Figure 1). This subquestion is more nuanced compared to the other two because the questions the interviewees answered differed based on their stakeholder group. The listed motivations are for why precision weeding technologies should be within the future of weed management: why startups are working, why growers are adopting, why VCs and CVCs are investing, and why government agencies are supporting precision weeding technologies.

The most common motivator was labor concerns, which was cited by 75 percent, or 12 out of 16, interviewees (Figure 1). Three stakeholders out of the 16 added additional details about the labor pressures of organic farming in California, five stakeholders spoke about the competitive labor market, three stakeholders mentioned the hiring budget difficulties because of California's increasing minimum wage, and two stakeholders addressed the role of precision weeding technologies in increasing the efficiency of labor. The interviewee Gr3 said that "As you lose your herbicide, you got [sic] to rely more on hand labor [and] mechanical labor." While they did not think that precision weeding technologies will ever completely replace hand labor, they speculate that growers will be able "to do a lot of heavy lifting with these newer mechanical weeders."

Following labor concerns, the second-most common motivator was cost, which was cited by 56 percent, or 9 out of 16, interviewees (Figure 1). Five out of sixteen interviewees noted precision weeding's potential to 'transform agriculture' and provide positive 'returns on investments' as motivations for support. Within the category of 'transform agriculture,' five interviewees, primarily startups, addressed precision weeding's potential to add value and increase farm profitability through sensors, additional data collection, advanced computation abilities, and automation.

The motivators of 'more weeding options,' 'meeting specific field conditions/needs,' and 'environmental sustainability' was brought up by a quarter of interviewees (Figure 1). According to growers Gr3 and Gr4, the motivator of having additional weeding options through precision weeding technologies is partially a result of increased pesticide regulation in California which may cause growers to lose access to certain types of pesticides. The government stakeholder was concerned about "glyphosate-resistant varieties out there…these weeds are mutating and they're resistant…then these new formulations come out…these spray-resistant weeds are mutating and getting worse and worse. I would love to see anything that can do targeted spraying or manual weeding come out to the front." Other interviewees added that weeds eventually adapt to weed management tools and thus effective regimes vary both temporally and in terms of products used. Precision weeding technologies are also seen to meet specific field conditions or needs such as varying soil conditions, banding, and thinning. The umbrella of environmental sustainability includes the benefits of (1) fewer inputs and chemicals, which was cited by seven interviewees, (2) animal and human health outcomes, cited by three interviewees, (3) soil conservation, cited by one interviewee, and (4) following the guidelines of the United Nations' Sustainable Development Goals, which was also cited by one interviewee.

The motivation for aesthetics was evoked by three out of four of the growers and refers to the negative impact of weeds on the aesthetic or cosmetic value of the fields (Figure 1). Interviewee Gr2 added that "growers like their fields to look nice and so [weeds] are also removed for aesthetic reasons" and interviewee Gr3 added that weeding is also a preventative measure so that harvesters do not accidentally harvest weeds in addition to the crops.

Though there was a general consensus across all stakeholder groups about the importance of labor concerns, other motivators were more polarized (Figure 1). For the most part, only growers expressed concerns about weeds harboring diseases, pests, and viruses, weeds competing with crops for resources, and the aesthetic value of weeding. In addition, only growers mentioned under the motivator of "more weeding options" that precision weeding adoption was partly driven by concerns that increased regulation in California could cause growers to lose access to herbicides. Aligning with the main goals of VCs, the interviewees of this stakeholder group were all motivated by return on investment (ROI).

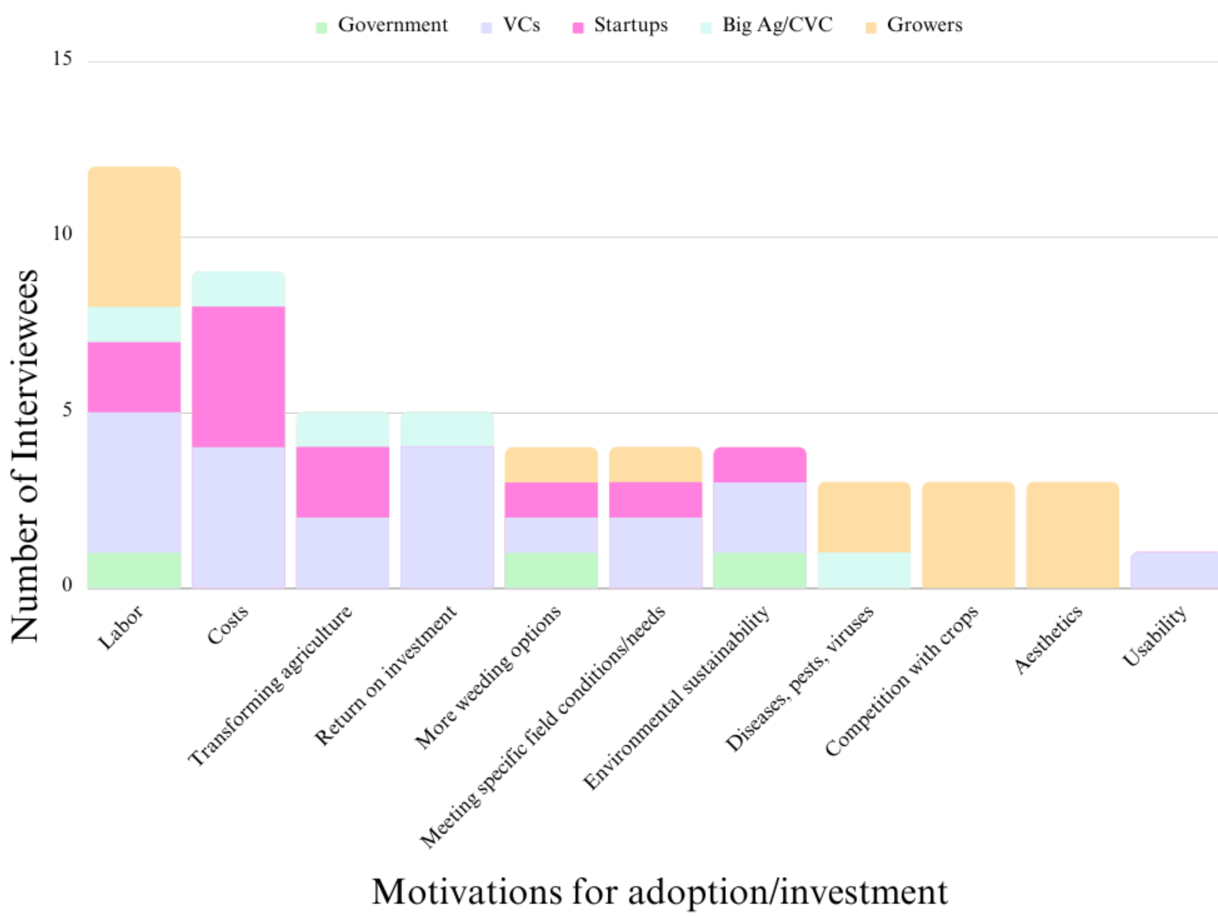

Figure 1. Frequency of motivations. The most common motivations for supporting precision weeding were its potential to increase labor efficiency and reduce costs. Only growers were motivated by eliminating weeds that compete with crops and the aesthetic value of a "clean" field.

How Stakeholders Collaborate

To answer the second subquestion regarding collaborative models between stakeholders, the comprehensive indexing of themes revealed that the average number of constructs for all interviewees was 60. Excluding labels and descriptors, the startup stakeholder group produced an average of 59 constructs, growers had 58 constructs, and VCs had 63 constructs.

Growers identified blockers to adoption such as competition between growers, old-school mentalities, and a lack of connection between startups and growers (Figure 2a). Because precision weeding needs the bandwagon effect for growers to want to try new technologies, competition between growers can hinder the bandwagon effect because growers may not wish to share their competitive advantages with their neighbors. This stakeholder group also asserted that many growers view working with startups as a high-risk endeavor, citing the high capital expenditures of most precision weeding machinery and the history of unsuccessful agtech startups. Because of the perceived risk, the multiple farm managers who work at one company may disagree with one another and prevent adoption. Startups also added that concerns about startup longevity are especially intensified because most traditional agricultural companies, such as John Deere, have been around for decades or centuries (Figure 2b).

Furthermore, growers perceived old-school mentalities and a potential lack of on-paper education as a blocker to the adoption of precision weeding technologies (Figure 2a). For example, some may view new technologies as not a necessity and the mark of "true" growers as putting in the hard work twelve hours a day, seven days a week. In addition, because many startups compare their products' efficiencies and costs to hand crews, some growers fear automation replacing their jobs. Though many growers want to own their own equipment, they may not want to hire specialized staff to run the equipment.

Startups and VCs also mentioned and expanded upon the growers' urge to own their own equipment, coming into conflict with the weeding-as-a-service business model that some startups have ventured into. interviewee V2 also added that "eventually farmers need to own the equipment [because of] timing. As your operations become larger, timing becomes absolutely critical. As you grow different crops in variable environments, you need the machine. You may be in a field and discover, I need the machine right now and you phoned the service guy and he's got three farms ahead of you." Other startups have turned to the weeding-as-a-service business model to abate prohibitive capital costs and to ensure the machinery out on the fields are up-to-date with the startups' latest developments (Figure 2b). S3 illustrated this point by saying "the first generation spray that we've built is like the iPhone 1, and technology is changing so fast that I know in three months I'm going to have iPhone 3 coming out." S3 also added that startup-centric reasons for the service model include allowing the startups to have constant access to new data and the ability to relay failure points quickly to the R&D teams. In addition, weed-as-a-service provides a more intimate experience between the startups and the growers, and enables the startups to conduct in-depth customer discovery for their current products and future ideas.

The startup interviewees brought up the limitation that some startups lack connections to growers (Figure 2b). Many proposed that startups need to hire employees who have worked in the agricultural industry and have local connections, while some also brought up that startups could develop strategic alliances with a committee of growers. Another startup limitation was the long timelines for hardware research and development, raising concerns about financial runways and funding. Some startups asserted collaboration between startups could alleviate runway fears as many startups have complementary products; consolidation will save time and effort.

According to VCs, startup-university and grower-university relationships are often difficult to navigate and are not always advantageous (Figure 2c). For example, sometimes with startup-university partnerships, patent battles may emerge, particularly if the startup's distinguishing technology directly spun out of university-sponsored research. In terms of how growers interact with universities, university research topics and trial designs are usually limited in scope and not perfectly aligned with the goals of the growers.

The startup and VC relationship was also described in-depth by both stakeholder groups (Figures 3b and 3c). For both parties, interviewees were in agreement that portfolio support from VCs to startups includes hiring and marketing support, business acumen and advice, connections to lawyers, accountants, and other startup founders, advancing governance to create stable and mature companies (by for example, participating in the startup's board of directors), and financial advising. VCs also mentioned hands-on, agriculture-related support such as matching startups with farmers for field trials, building a farmer advisory board, and helping with plot designs and trialing systems. Beyond portfolio support, VC ecosystems also vary in scale from local, regional, national, and international. When VCs evaluate which startups to fund, the criteria depends on the stage of the startup. For example, during the seed stage, VCs judge startups based on their technology, team, and the extent to which the startup has a believable market opportunity. Moving towards the Series A funding round, VCs begin to care about unit economics, proof of traction through contracts and letters of intent, and revenue. At the Series B stage, VCs continue to value revenue metrics and begin to look for established customer pipelines, go-to-market strategies, and proof of high growth companies.

All three stakeholder groups had varying opinions of the role of government in the precision weeding ecosystem. Under existing conditions, growers viewed the government as offering little support and being out-of-touch with grower needs. Because specialty crops are a small percentage of America's total agricultural production because of large commodity crops like rice, soy, and corn, government intervention for specialty crops would not provide as positive of a return on investment. While the government is slow, some of the growers did commend effective government funding for irrigation. However, in the future, because hand labor for weeding is arduous, some growers have hope for increased government support for precision weeding for the positive social implications. Startups viewed government involvement as limited to grants and the USDA's agronomy advice. Though pushed by local politicians, particularly in Salinas Valley, R&D tax credits remain trivial. In addition, startups and VCs saw the role of regulatory agencies such as CalOSHA and the Department of Pesticide Regulation.

In connection to the government, all three stakeholder groups mentioned government funding for land grant university research and the UC Extension system. Some startups mentioned that they want to become more involved with universities to influence the curriculum and develop two-year technical degrees to combat workforce constraints in agricultural technology. However, some interviewees such as V2 voiced that the Extension has lost grower influence and that now, Extension Advisors may not be the farmer's first call or key advisor anymore. Similarly, growers felt that though Advisors are helpful in educating and advising, a lack of funding and relatively low salaries have prevented the UCCE from gaining more influence over grower behavior and precision weeding adoption.

The government interviewee, G1, was the only one to bring up frameworks related to diversity, equity, and inclusion. For example, a certain percentage of their portfolio must be allocated towards strengthening minority-owned businesses, small businesses, and businesses from underserved communities. G1 found great satisfaction in achieving and exceeding DEI goals: "[i]t really is satisfying when a small institution gets an award competing with these ones that have huge support and even grant writers."

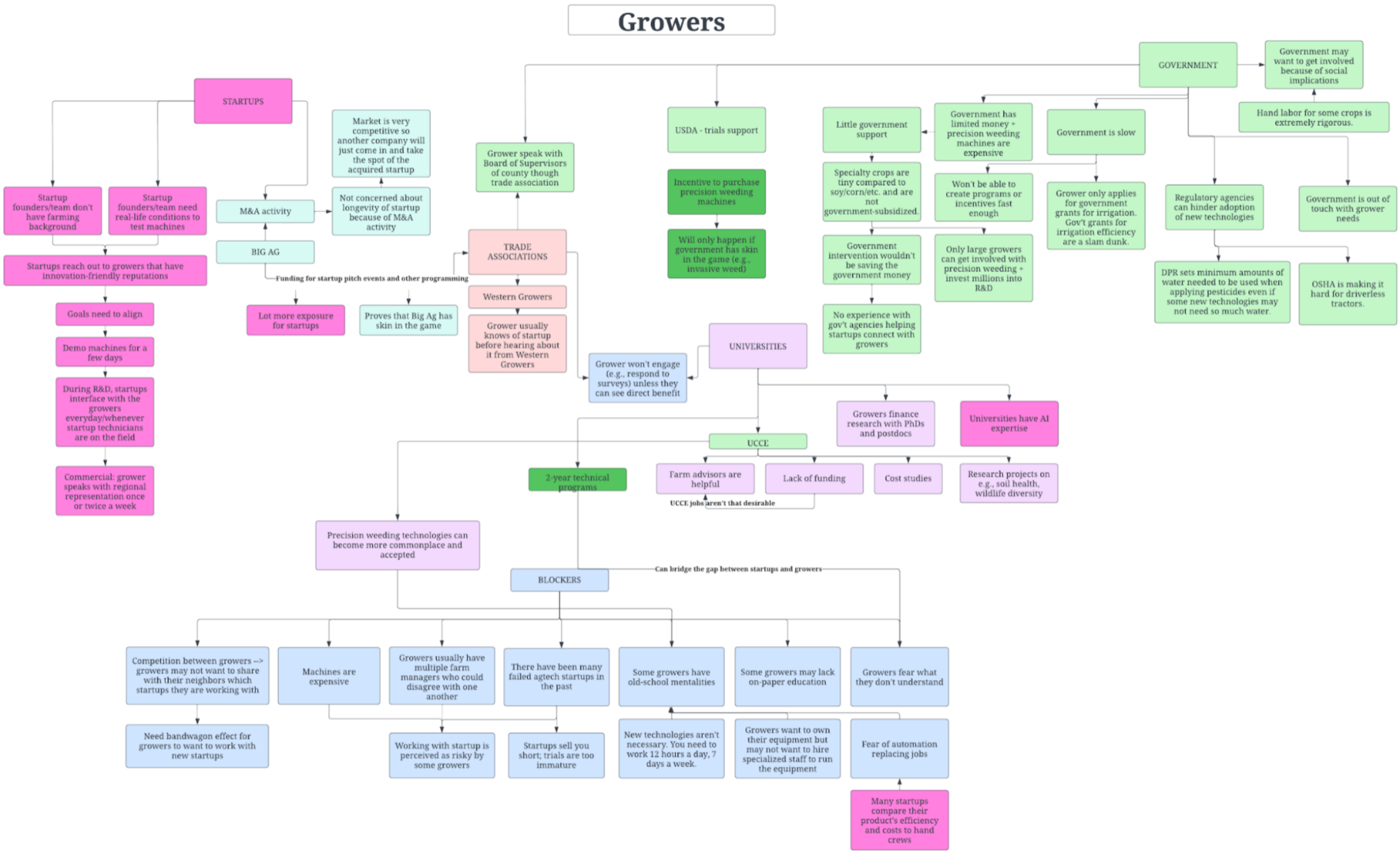

Figure 2a. Grower stakeholder group cognitive map.

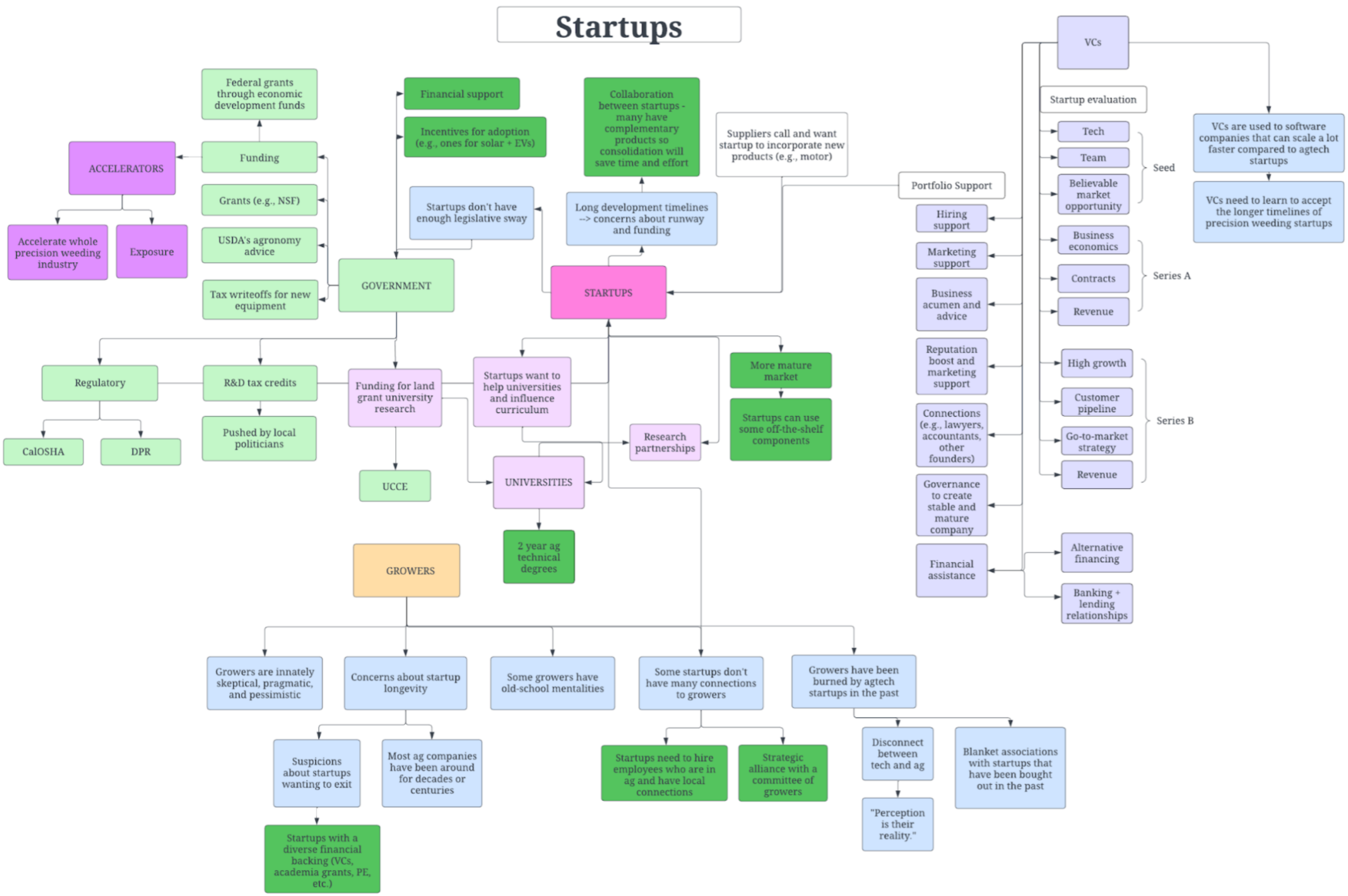

Figure 2b. Startup stakeholder group cognitive map.

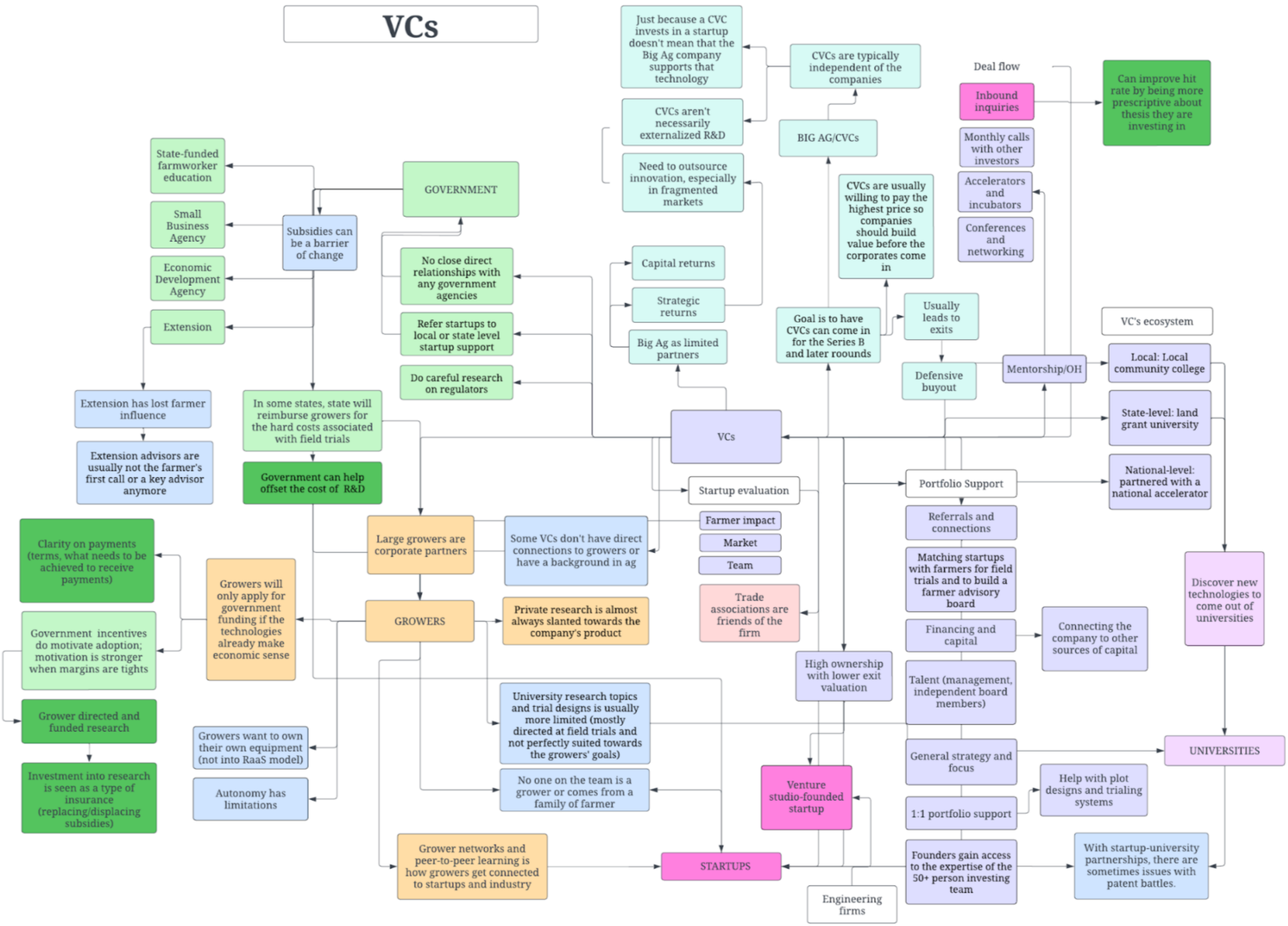

Figure 2c. VC stakeholder group cognitive map.

Grower User Journey

To visualize the results to the third subquestion, I mapped interviewee responses onto a user experience template. After I overlaid the results for growers, I found that the most common touchpoints in the growers' awareness phase were social media, in-person networking through conferences and conventions, and collaborations with universities.

Growers perceived startups to be concerned about their lack of connection to the agricultural community, risk of wasting time with unideal pilots, and ensuring the grower has the right field conditions for what the startup needs feedback for (Figure 3a). On the other hand, startups perceived their concerns to be the dual marketing of value propositions towards growers as well as their investors, supply chain issues that may limit their technical execution of commercializing manufacturing, and large growers having bureaucratic issues that prevent demonstrations and pilot projects from converting them to recurring customers (Figure 3b).

During the pilot phase, growers perceived themselves to be concerned about the risk of crop damage, support staff, startup longevity, and startup quality and capabilities (Figure 3a). During the piloting and purchasing phases, startups perceived growers' concerns to be the price model, logistics, weeding quality, and the startup quality and capabilities (Figure 3b). While many startups were concerned about matching customer expectations because imitating human dexterity and vision is technically challenging, one grower explicitly did not have concerns in the piloting phase because they have realistic expectations: "I don't expect it to be like a John Deere tractor that's just going to come out and be perfect and do everything that's expected. I get it with technology companies that when it's going to come out, it may suck."

Most of the areas of improvement brought up were in the consideration/piloting phase. Growers felt that points of improvement in their user journey included the prioritization of larger growers over smaller growers: smaller growers should have firsthand access to the new technologies larger growers have (Figure 3a). In addition, smaller growers may value other pain points, such as food safety, over precision weeding (Figure 3a). Startups felt that improvements could be made with educating growers about misperceptions about a lack of equipment availability. Some startups were also concerned about the ability of dealers to devalue equipment. Because the primary piece of equipment, such as a tractor, is the attractor, the additional implements, such as precision weeding add-ons, could devalue the equipment (Figure 3b).

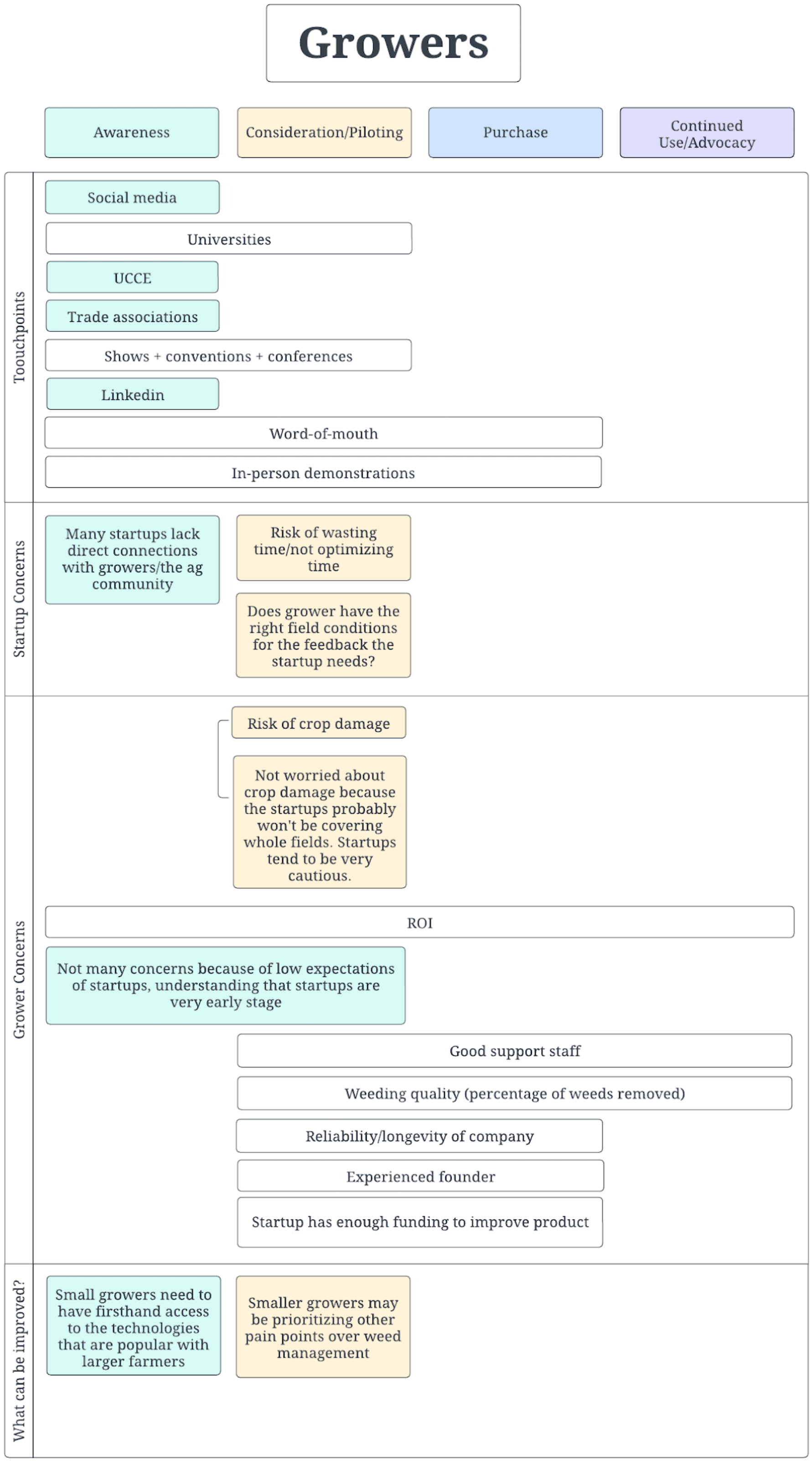

Figure 3a. User journey of adoption of precision weeding technologies according to growers.

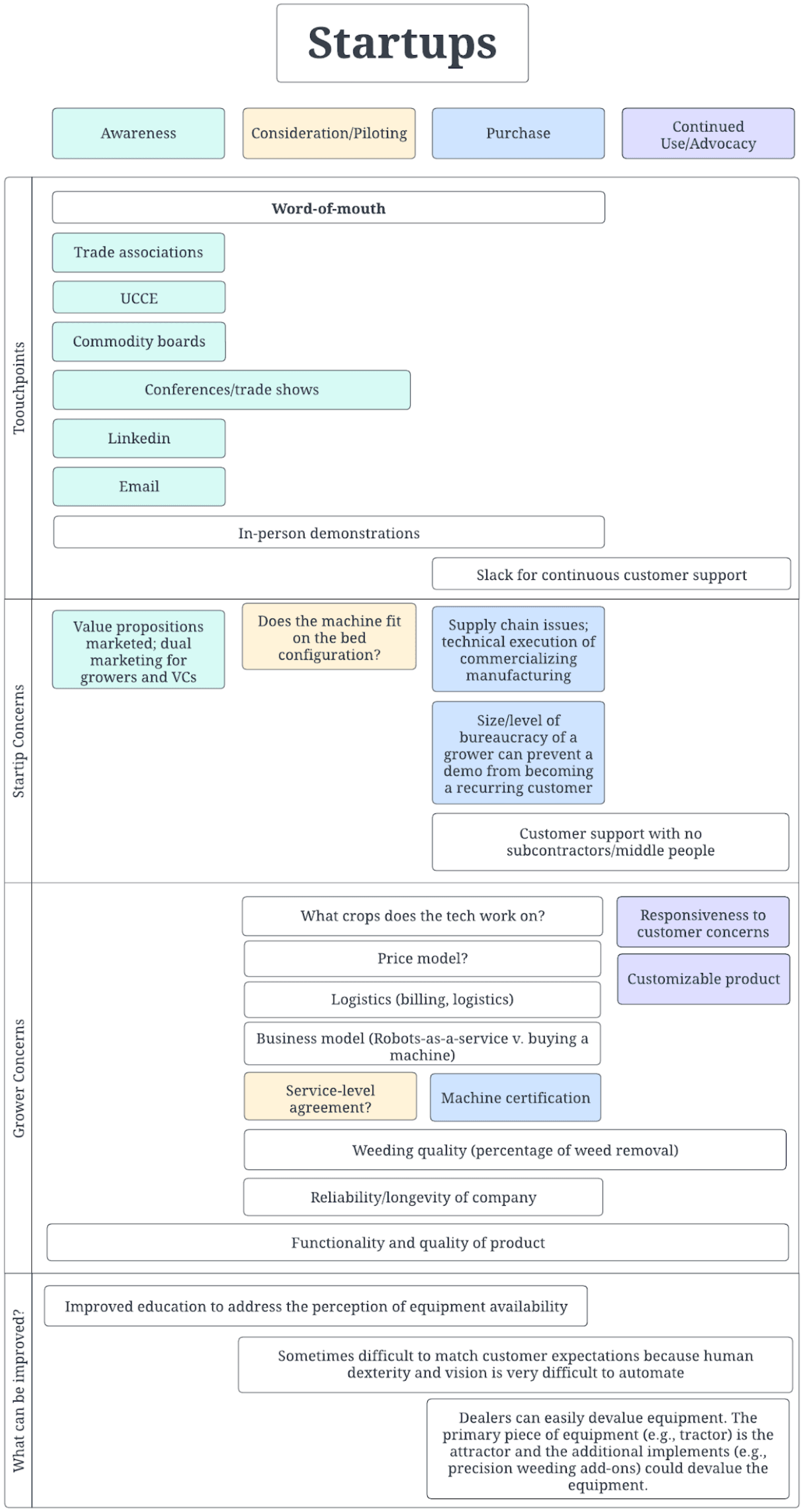

Fig 3b. User journey of adoption of precision weeding technologies according to startups.

DISCUSSION

The key results of this thesis uncovered (1) the motivations behind adopting precision weeding technologies, (2) the financial, R&D, and social exchanges and collaborations between the stakeholders, (3) and the user journey for growers using the products and/or services of precision weeding startups. The key results included the varied motivations between the stakeholders and thus varied understandings of precision weeding's value, the controversial role of government in accelerating precision weeding technologies, and the user journey of growers adopting precision weeding technologies.

Compatible Motivations

The most common motivations for precision weeding technology adoption were labor concerns, environmental sustainability, costs, and return on investments. Growers were the most vocal and detailed about the shortage of labor motivating their interest in precision weeders. Because of the increase in minimum wage and AB 1066 qualifying farmworkers for overtime pay, growers and producers are growingly concerned about labor regulations (Quandt 2023). These increased labor expenses push producers to increase on-farm efficiency and mechanization, particularly on vegetable and organic farms. California growers' issues with labor scarcity and thus increased labor costs was a long-standing trend that also contributed to early mechanization during the 20th century. Because California had a high number of specialty crops and niche growing conditions, there was the advent of new gasoline tractors and mechanical pickers and harvesters (Olmstead and Rhode 2017).

Labor expenses in California agriculture are also especially pertinent because of the strong organic sector. In 2019, data from the California Department of Food and Agriculture's State Organic Program found that California's organic sector is growing: organic acreage has increased from 1.8 million acres in 2014 to 2.6 million acres in 2019, and in 2019, organic products in the state sold for more than $10.4 billion ("California Agricultural Organic Report"). Additionally, California's organic production makes up 40 percent of all organics in the U.S., indicating the state's importance as the trailblazer of organic agriculture ("California Agricultural Organic Report"). This increase in organic production has arguably been fueled by support from the State Organic Program, a regulatory and educational department within the CDFA which has, for example, implemented cost share programs for USDA certification, and consumer preference for organics (Klonsky 2010). Multiple studies have demonstrated consumers' willingness to pay premiums for organics, with the market demand influencing grower decision making (Yue and Tong 2009). From a logistical viewpoint, organic farms employ more workers per acre. A survey of organic farms revealed that farms that have less than half of their land in organic production have fewer direct-hire workers per acre, 0.58, in comparison to farms with more than half, 0.84 (Strochlic et al. 2008). Similarly, another study found that compared to conventional farms, organic farms have more workers per acre and also a higher proportion of full-time employees to seasonal contractors (Finley et al. 2018).

All venture capitalists interviewed were motivated by environmental sustainability while none of the growers mentioned it. This venture capital emphasis on environmental concerns such as soil quality, water quality and quantity, and unsustainable cultural practices spur agtech investments. Investors not only valued financial returns but were also motivated by social impact and environmental returns (Dutia 2014). Similarly, precision weeding startups often tout themselves as examples of social entrepreneurship and list sustainability as a motivator on marketing and branding materials. On Crunchbase, a company that provides business information on over two million companies, I used the 'Search Companies' function to narrow down the industry to 'Agtech' and filtered the results using the description keywords 'weed,' 'weeds,' and 'weeding,' I then compiled the top fifteen precision weeding results and found that eight include environmental stewardship details like soil health and decreasing herbicide usage in their websites' mission statements or company background pages. An additional three companies used vague terms like 'sustainability' or 'environmentalism,' indicating the roles of startup personal belief and marketing strategy. Because of the venture capital emphasis on environmental concerns, startups may align themselves similarly to raise funding.

Climate-smart agricultural practices increase grower resilience toward and mitigate the negative impacts of climate change (FAO 2010). CSA includes technologies, practices, and policies for nutrient, soil, and water management through on-farm mechanization, such as precision weeding. Grower adoption of CSA practices are "positively influenced by farm size, educational attainment and by a farmer's interest in conservation, but negatively related to a farmer's age (Ruto and Garrod 2009)." Non-financial factors can also nudge growers towards adopting on-farm mechanization. However, studies have also shown that smaller farmers were more concerned about environmental and social sustainability while larger farms were more focused on financial advantages as well as the legal liability concerns and equipment safety (Spykman et al. 2021). The different opinions and motivations of smaller and larger farms were not explored in this thesis.

How Stakeholders Collaborate

Considering the varying views of government conveyed by the interviewees, the political identities of the interviewees may influence their views on the effectiveness and ideal roles of government. All growers expressed a distrust in government and a common sentiment across stakeholders was that the state government reacts too slowly to be effective and the vast majority of politicians do not understand the reality of California agriculture. A study using ANES survey data found a shift from democratic identification to independent and conservative ideologies. Growers also expressed an increased distrust of government, a trend that is consistent with the general population (Kaufman 2016). California growers in Yolo County were more concerned about climate change policy risks, such as economic and regulatory changes, as opposed to the physical climate change risks like temperature and water concerns (Niles et al. 2013). In addition, in Imperial County, the most impactful work-related stressor for farmers and ranchers were unpredictable factors like government regulations (Keeney et al. 2022). Though growers felt that the government did not understand the realities of agriculture, many actively advocated and were involved in agricultural leadership efforts (Quandt 2023).

Another theme that emerged from the second subresearch question is that the ideal role of government should be more hands-off because companies should find success in the free market and not rely on external sources. Some did bring up the benefits of clearly-defined funding opportunities to reduce the friction of growers seeking government funding. A study using financial datasets of over 32,000 companies found that subsidies were only effective for short-term innovation while tax credits were favorable on both short and long terms (Zhang and Guan 2018). Subsidies are direct fiscal measures where the government is the project decision maker whereas tax credits are indirect fiscal measures whereby companies can choose their own projects and the direction/purpose of the innovation activity (Zhang and Guan 2018).

Grower User Journey

The third sub-research question regarding the user journey of growers adopting precision weeding technologies examined grower and startup concerns and touchpoints from awareness to continued use and advocacy. Both startups and growers emphasized in-person networks as the most important touchpoint and vehicle by which growers learn about new technologies. The influence of peer-to-peer networks brings up the question of perceived social risks as studies have shown that farmers are concerned about reduced access to peer-to-peer networks as a result of the social risk perceptions of believing in climate change (Petersen-Rockney 2022). Though many farmers were actually implementing climate adaptation-supporting farm management practices, such as water-effective irrigation, many remained sensitive about framing climate change and their adaptive actions as environmental and justified them with co-benefits, such as economic efficiency (Petersen-Rockney 2022). Additionally, in a pollination management study in Michigan, researchers uncovered several large advice networks in which growers can reach other growers and their partners in a maximum of two to three hops and that 26 percent of all communication mapped was from grower-to-grower (Garbach and Morgan 2017).

Synthesis: Stakeholder interactions' impact on precision weeding scalability

Addressing the central research question of how interactions between stakeholders influence the scalability of precision weeding technologies, the most common constraints brought up by interviewees include VCs and startups not having connections to growers or a background in agriculture, the lack of funding and decreasing influence of Extension advisors on growers, and grower skepticism of startup longevity and effectiveness.

Interviewees from all stakeholder groups brought up the grower preference for equipment ownership, going against service-based business models. Some precision weeding startups are using or have tried in the past to employ the weeding-as-a-service, recurring revenue model, whereby customers pay the startups for each instance of the service of weeding. Owning equipment is preferred because of their lack of use limitations, especially accounting for the time sensitivity of some agriculture operations. Additionally, government loans and incentives, such as USDA Farm Service Agency Direct Farm Ownership Loans, help growers enter into long-term leases or purchase their own equipment. Because of this strong equipment-owning preference, grower skepticism towards a weeding-as-a-service business model can hinder the growth of precision weeding startups. However, literature shows that recurring revenue models, as opposed to the direct sales model, have the advantages of significantly lower capital costs and lower payments compared to traditional loan structures, especially considering that weeding equipment remains idle for the majority of the year (BIS Research 2019). Furthermore, subscription models give growers access to the newest and latest technologies, sharply decreasing the replacement cycle periods (BIS Research 2019). These two revenue models are also not binary: recurring revenue models can derisk the use of new precision weeding innovations, with an initial subscription service proving the value of the technology, before growers transition to potentially purchasing the equipment at the end of the contracting period (Gil et al. 2022).

Interviewees brought up the role of UCCE Specialists in both researching and developing weed management strategies as well as educating growers on precision weeding technologies. The University of California's Agricultural and Natural Resource (UC ANR) programs are largely funded by the state and work to extend grower, producer, and academia-led innovations. The Cooperative Extension System is a network of campus and community experts who work with farmers and industry for applied research. 150 full-time Cooperative Extension Advisors, who are also sometimes called County Agents or Specialists, have local jurisdictions ("An Analysis" 2022). By working at a county-wide or regional scale, Specialists are the traditional links between research institutions and local communities (Gornish et al. 2018). While the US had previously dominated globally in public agricultural R&D funding, since 2000, this public investment has decreased by a third, impacting the Cooperative Extension because it is jointly funded by the USDA, the UC land-grant universities, and state and local governments (Smith and Blaustein-Rejto 2022). However, county-based research and extension programs continue to influence growers as shown by interviewee responses to collaborative models, both in California and other states. A study examining network-smart extension strategies found that 62.7% of all respondents, viticulture growers in the Central Coast, Lodi and Napa Valley, found the information resource of 'UC Cooperative Extension Farm Advisor' to be 'very helpful' (Hoffman et al. 2015). In a pollination management study in Michigan, a quarter of the grower networks were from the state's Extension, far outweighing the representation from other public and private stakeholders like commercial suppliers, government agencies, and commodity groups (Garbach and Morgan 2017).

Limitations

The experimental design purposely was exclusively semi-guided qualitative interviews as opposed to a mix between interviews and surveys because I wanted to examine in-depth perspectives and experiences. A limitation inherent in this experimental design was a lack of breadth, as the stakeholders I interviewed did not thoroughly represent the entirety of California's precision weeding ecosystem. Future research could expand beyond my interview approach to include willingness-to-pay surveys to ascertain grower attitudes towards precision weeding. Another limitation I faced with the interviews is that the agtech investing space, particularly for investors who have interests in California agriculture, is quite small. Because 'all VCs know each other,' some venture capitalists I interviewed or reached out to interview had concerns about anonymity and/or having diverse-enough viewpoints. Additionally, government outreach proved difficult with many potential interviewees cancelling after learning about the informed consent conditions. However, this limitation was not a significant hindrance as my three core stakeholder groups did not include the government. This does raise a potential future research direction that more directly examines agriculture-related government endeavors and public-private collaborations. A limitation in an aspect of my data collection method was concerns regarding interview standardization. Though I followed a guide of pre-prepared questions for each subquestion, some interviewees cut the interview short while some were very generous with their time. The shortest interview was twenty-three minutes while the longest one was over an hour and a half. Therefore, in my results, I only featured the stakeholder group maps, not individual maps.

Broader Implications

Precision weeding technologies respond to grower needs with conventional weed management. Resulting from labor pressures, the rising costs of chemical inputs, and market and government pushes towards environmental sustainability, California growers are pursuing alternative techniques such as buying machinery from new precision weeding startups. However, the adoption of precision weeding technologies is at times hindered by negative perceptions of startups and new technologies from growers. The cognitive mapping presented in this paper can be applied to other emerging agtech technologies and ecosystems. Because the majority of venture capital firms that invest in precision weeding also invest in other agtech startups or hardware/deeptech startups of any industry, the interactions between agtech startups and venture capital firms may remain similar. However, future research may find varied interactions between the startups and growers. Growers have concerns beyond weed management and the adoption of irrigation innovations, for example, is likely motivated by different factors compared to the results I found for precision weeding.

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APPENDIX A: Interview Questions

Subquestion 1: What, if any, are the compatible motivations (e.g., sustainability, competitive advantage, profit, social impact) between the stakeholders?

California Growers	**VCs + CVCs**	**Startups**	**Gov't**
• What are your main concerns when it comes to weed management? • How do precision weeding services fit into your current or future weed management plans? • What are your team's short-term and long-term goals? Which metrics do you use to constitute success?	• What's your investment thesis? • What frameworks/approaches do you take when evaluating precision weeding startups to invest in/partner with? • What are your team's short-term and long-term goals? Which metrics do you use to constitute success?	• What are your main value propositions? ○ How is the messaging for said value props different when talking to VCs versus growers? • What are your team's short-term and long-term goals? Which metrics do you use to constitute success?	• How are you/your department involved with the precision weeding sector? • What, if any, other agencies/groups do you work with? • What are your team's short-term and long-term goals? Which metrics do you use to constitute success?

Subquestion 2: What are the current collaborative models and what are their limitations?

California Growers	**VCs + CVCs**	**Startups**	**Gov't**

● Describe your relationship with the listed stakeholders. What interactions do you have with them? ● What are the main barriers to achieving your objectives as [agency/company]? ● What, if any, changes to existing infrastructure/ processes would make it easier to work with the other stakeholders?	● Describe your relationship with the listed stakeholders. What interactions do you have with them? ● What are the main barriers to achieving your objectives as [agency/company]? ● What, if any, changes to existing infrastructure/ processes would make it easier to work with the other stakeholders?	● Describe your relationship with the listed stakeholders. What interactions do you have with them? ● What are the main barriers to achieving your objectives as [agency/company]? ● What, if any, changes to existing infrastructure/ processes would make it easier to work with the other stakeholders?	● Describe your relationship with the listed stakeholders. What interactions do you have with them? ● What are the main barriers to achieving your objectives as [agency/company]? ● What, if any, changes to existing infrastructure/ processes would make it easier to work with the other stakeholders?

Subquestion 3: What is the user journey for farmers adopting precision weeding technologies?

California Growers	**Startups**
● When was the last time you adopted and implemented new technology in your workflow? ● How do you learn about new ag technologies? ● [If they're into precision weeding] What was the process of working w/ [startup]? What were your main considerations? What were you initially skeptical about?	● How do you get growers into your marketing pipeline? ● What aspects of your value proposition most appeal to growers? ● What's the main blocker when converting a potential client? ● What was the outreach and conversion process with growers you're currently working with? Can you walk me through that process?

Figure A. Interview questions.