TESTING THE RELIABILITY OF CIVIC SCIENCE DATA COLLECTION OF PLANT TRAITS IN A PERENNIAL SUNFLOWER DOMESTICATION EXPERIMENT

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ABSTRACT

Testing The Reliability of Civic Science Data Collection of Plant Traits in a Perennial Sunflower Domestication Experiment

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Civic science has been prevalent in environmental science for many years. The use of volunteers and the community as a helping hand in research continues to link society and science, as well as increases the magnitude and breadth of environmental studies. Assessments of data quality produced by civic science is an important component in validating the accuracy and reliability of the research. In this study, the reliability of civic science was tested by assessing the variation within data gathered from undergraduate Cal Poly students. Using a common garden experimental set up, the health of twelve wildtype silphium genotypes were assessed through six general plant traits: plant height, the number and width of viable seed heads, percent disease and herbivory, and pollinator count. During the lab period of a Cal Poly ecology course, eight groups of students performed the plant health assessments on all twelve genotypes. As an assessment of reliability, the coefficient of variance was calculated for each plant trait and an ANOVA with a Tukey-Kramer HSD test applied to determine any significant variation within groups. Significant variation within groups was found in more complex estimation methods such as estimating disease prevalence and herbivory, while more simple methods of data collection such as counting seed heads or measuring plant height were the most reliably consistent. We conclude that methods of data collection had a significant effect on the reliability of data collection using civic science and that with increased training and improved protocols, civic science can produce reliable data in the environmental sciences and further broaden the involvement of the community in research.

Keywords: Civic Science, Perennial Grain Crops, Agriculture, The Land Institute

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Chapter 1: INTRODUCTION

Climate change is driven by anthropogenic activity forcing greenhouse gases into the atmosphere; the most drastic carbon emitter is fossil fuel burning (Höök and Tang, 2013). Because of the changing climate farmers are forced to cope with intense drought conditions, and the situation is only expected to escalate in the years to come (Fereres and Soriano, 2006). It will be important for farmers to promote efficient use of irrigation water in arid and semi-arid areas for both social and economic sustainability (Shangguan et al., 2002). Drought can cause detrimental effects to plant growth and overall health. If it is severe enough, normal plant functions can be hindered causing changes in physiological and morphological traits (Vurukonda et al., 2016). Farmers should be thinking about alternative crops that can withstand the changing climate, while nations around the world should be considering alternative renewable energy sources. Perennial crops are a promising alternatives for feedstock, oilseed production, biofuel, and other renewable energy technologies because of their extensive root systems and drought resistance (Peni et al., 2020a).

Fossil fuels are the main driver of anthropogenic climate change and are a non-renewable source; renewable biofuels are a promising substitute (Peni et al., 2020a). Fossil fuels are used for power and energy in every sector from industry to home life. They are also very prevalent in the production of synthetic fertilizers for conventional agriculture (Ramírez and Worrell, 2006). Developing perennial crops for agricultural production can reduce the need for synthetic fertilizers, while the same crops have a potential for biofuel production as a renewable energy (Cox et al., 2006; Slepetys et al., 2012; Peni et al., 2020a; Schiffner et al., 2021). The North American native perennial sunflower, *Silphium*, has recently become a plant of interest in the scientific community as a drought tolerant oilseed crop and a potential biofuel source (Peni et al., 2020a). Maize is grown conventionally as a biogas substrate for bioenergy, but Silphium is a perennial alternative that can provide more environmental benefits such as soil protection and drought tolerance (von Cossel et al., 2020). While water shortages driven by climate change are leaving farmers with decimated crops, *Silphium integrifolium* is a strong alternative for farmers due to its large seed size and drought tolerance and *Silphium perfoliatum* is promising as a biogas alternative to fossil fuels (Reinert et al., 2019; Peni et al., 2020a).

Silphium Integrifolium (silflower) is just several years into its domestication process, but significant advances towards desired domesticated traits have been shown (Reinert et al., 2019). Comparisons between silflower and domesticated annual sunflower made apparent silfower yields are far from where they need to be (Schiffner, 2018). Sunflowers have been domesticating for over 4000 years now, but Silflower is expected to advance rapidly due to modern tools like germplasm characterization and trait selection (Schiffner, 2018). The domesticated sunflowers have been compared to its wild relatives, and the native species were found to pull water and nitrogen up from nearly 2 meters deep (Vilela et al., 2018). This demonstrates the potential for Silflower to survive drought and provide a bioremediation role in the ecosystem, such as nutrient cycling and soil stability (Vilela et al., 2018). A similar species under the *Silphium* genus is *perfoliatum* (cup plant). This species is being developed for bioenergy in Germany to replace maize production because of its beneficial ecological functions like soil protection and pollinator feed (von Cossel et al., 2020). Several studies have assessed the benefits of perennial biofuel sources compared to annuals, and *Silphium* continues to prove itself as an effective alternative (Slepetys et al., 2012; Šiaudinis et al., 2012; Figas et al., 2016; von Cossel et al., 2020).

The Land Institute is a research institute working on developing alternative agricultural practices, specifically through breeding perennial grain crops. *Silphium* has been a crop of interest to them since 2001. The long-term goals for Silfower, is to replace, at least partially, annual oilseed crops like canola, soy, and sunflower. Another angle the Land Institute is incorporating into their research is civic science: expansion of a study through community collaboration to incorporate environmental education and culture. By incorporating people across the nation, the importance of perennial crops will be understood and supported by the public ("Civic Science - The Land Institute,"). This project at the student experimental farm will assess the reliability and predictability of civic science incorporation into *Silphium* research.

To better understand civic science and its important role in advancing plant breeding research at The Land Institute, an evaluation of undergraduate students' abilities to collect reliable data will be assessed on the common garden experiment of the wild crop varieties of *Silphium* at the Student Experimental Farm on Cal Poly's campus. The data will include qualitative and quantitative plant health assessments such as plant height, disease prevalence, and productivity. Several research questions will be addressed:

1. How reliable is civic science Silphium data?

2. How does reliability differ by measurement type? Which types of measurement exhibit less/ more reliability?
3. What may explain differences in reliability?
4. How can measurements be modified (data type, methodology/ protocol, instruction/ training) to improve reliability?

The accuracy of civic science data can be explained through two components: reliability and validity (Steinke et al., 2017). This paper focuses on how reliable civic science is among a group of students assessing plant traits of Silphium. Reliable data must be repeatable and consistent across groups and over time, whereas the validity of data is in reference to how closely the data aligns to the actual value or the standardize results (Steinke et al., 2017). The objective of this study is to determine how well civic science can be incorporated into plant research in the hopes of improving protocols and the reliability of civic science data.

Chapter 2: LITERATURE REVIEW

Climate change is accelerating from our extensive use of fossil fuels, leading to less water availability throughout agricultural systems (Campos et al., 2004; Höök and Tang, 2013). In order to address increasing drought conditions, perennial crops in agriculture have been studied as potential alternatives to current annual cash crops (Schiffner, 2018). There are immense benefits from cultivating perennial crops such as soil protection, ecosystem cycling, organism habitat, and higher drought tolerance (Pimentel et al., 2012). Drought tolerance has been studied across many different crops with the view to better understand and mitigate stress due to limited water resources (Passioura, 1996; Campos et al., 2004; Tuberosa and Salvi, 2006; Verulkar and Verma, 2014). Silphium is a perennial sunflower native to North America currently being developed as a potential oilseed and biofuel crop (Cox et al., 2006; Šiaudinis et al., 2012; Schiffner, 2018).

2.1 Agriculture's impacts on Climate

Conventional agriculture is responsible for 24% of the world's greenhouse gas emissions (US EPA, 2016). Agricultural soils should be a carbon sink instead of a carbon source, however the way the United States has been farming only releases stored carbon from the ground. In Europe, it is estimated that croplands are the largest biological source of carbon lost to the atmosphere each year (Smith, 2004). The potential for carbon storage in soils ranges from 90-120Mt C in Europe each year. Sustainable practices such as no-till, perennial crops, and fertilizer management are all potential mitigators for greenhouse gas emission from agricultural croplands (Smith, 2004).

2.1.a Industrial Revolution of Agriculture

There is an undeniable link between agricultural history and environmental history (Warde, 2009). Heavy tillage in the native US plains sparked huge dust storms in the 1930s, better known as the dust bowl. Several environmental regulations were put into place to better preserve the agricultural land (Romm, 2011). However, World War 1 sparked the intrigue for synthetic fertilizers. Farmers realized how much better crops grew with nitrogen, potassium, and phosphorous inputs. No one at the time was concerned that this development could have a long list on environmental consequences (Warde, 2009). Intense fertilizer use causes nutrient runoff into sources of drinking water and eventually the ocean. High nutrient levels in water can produce hypoxic zones and cause highly polluted undrinkable water (Ramírez and Worrell, 2006).

2.2 Climate Change Impacts on Agriculture

Global temperatures are expected to rise between 0.5 and 3 degrees Celsius by the year 2077. With these changes we expect to see more extreme heat events more often (Cowling et al., 2019). Unfortunately, food systems contribute 21 to 37 percent of greenhouse gas emissions, and 78 to 86 percent of those emissions are from agricultural practices (Dale, 2020). Additionally, nitrogen based fertilizer, heavily used in industrial agricultural, production contributes to over 20 percent of greenhouse gas emission in the food system sector (Dale, 2020).

2.2.a Drought stress on the food system

Abiotic stresses, such as drought, are important factors to consider when addressing the changing climate and our food system resilience (Fahad et al., 2017). Drought is expected to significantly lower yields, specifically in corn, as the global temperatures rise and water availability decreases (Campos et al., 2004). There are plant physiological consequences from drought stress that negatively affect the yield and growth of a plant (Fahad et al., 2017). Learning the specific physiological, biochemical, and ecological changes of a crop in response to drought will help farmers to better prepare for a changing climate (Fahad et al., 2017).

2.2.b Reliance on fossil fuels

Fossil fuel burning is the driving force for CO2 emissions which continues to warm our climate (Höök and Tang, 2013). Mankind is heavily reliant on burning fossil fuels for electricity and power. Climate models have demonstrated that greenhouse gas emissions could only reach their current potency through human influence, proving our detrimental role in climate change (Höök and Tang, 2013). Renewable energy like wind, solar, and bio energies are the most promising mitigation to lowering our dependence on fossil fuels (Luderer et al., 2014). Bioenergy is a versatile renewable energy that uses biomass from recently living organic matter and processing it into fuels, heat, and electricity (Luderer et al., 2014). For the time being, renewable energy sources are more expensive than burning fossil fuels, but development of crops for biomass production and full life cycle utilization on fiber crops will help mitigate the cost (Slepetys et al., 2012).

2.2.c The Role of Fossil Fuels and Synthetic Fertilizers

In the last 50 years, synthetic fertilizer use has grown dramatically and the energy cost is embedded deep into the agricultural system lifecycle (Ramírez and Worrell, 2006). In an analysis of the energy cycle for fertilizer production globally, 72% was used for nitrogen fertilizers and 10% for phosphorus, and the other 18% was used for complex mixes and potassium fertilizer inputs (Ramírez and Worrell, 2006). The paper found an overall increase of energy efficiency over the period 1961 to 2001. Incentive energy consumption to make fertilizers means intense fossil fuel use (Bomford, 2010). The United States food system consumes approximately 10 quadrillion Btu (British Thermal Unit of heat) from fossil fuels every year (Bomford, 2010). This can include anything from making fertilizers to packaging and distributing food. Conventional agriculture relies heavily on synthetic fertilizers and fossil fuels, a fundamental shift in the way agriculture is produced can have a dramatic effect on the environment (Smith, 2004; Ramírez and Worrell, 2006; Nunes et al., 2020).

2.3 Agroecological solutions to a Changing Climate

Agroecology is the science of sustainable agriculture. Sustainability in agriculture is reliant on ecological principles applied in a system that best mimics nature while also allowing for high yields and profitable markets (Kremen et al., 2012). Science will be an important part in transitioning the world’s food system into something sustainable. A good relationship between farmers, scientists, and consumers is of the utmost importance.

2.3.a Agroecological Systems

Agroecology strives to incorporate ecological functions into agricultural systems, and in whole produce a sustainable organic system (Dale, 2020). A successful agroecological system should mimic natural ecosystems as close as possible to naturally fertilize crops and biologically control pests, while producing a viable profit (Dale, 2020). The Mediterranean climates, like the Central Coast, have been especially impacted by climate change, but agroecological solutions can offer a holistic approach to recovery the environment (Aguilera et al., 2020). An important goal for ecological farmers is to eliminate the potential for greenhouse gas emissions through reliance on fossil fuel derived synthetic fertilizers, however, access to non-synthetic fertilizers continues to prove challenging to these farmers (Dale, 2020). Similar challenges arise with pesticide and herbicide alternatives (Dale, 2020). There are incredible amounts of knowledge and labor that go into sustainable farming, and the transition proves to be one of the most daunting phases for famer's to accomplish (Dale, 2020).

3.3.b Drought Tolerant Crops

Climate change is forcing farmers to be more water conscious in their irrigation methods to avoid yield disturbances and crop failure. Food security is depended on accurate predictions in weather and crop success. Learning the physiology of a plant's response to drought will help farmers and plant scientists to better prepare and plan for future water loss (Campos et al., 2004). Campos et al., explored quantitative trait locus (QTL) analysis to better predict phenotypic performance of maize under drought stress since it is one of the most important crops in food production today. Conventional selection breeding of maize plants with desirable traits was found to improve yield tolerance to drought, although there was still a decrease in yield compared to well-watered maize plants. They advocate for genetics and genomics use in plant breeding for a fuller analysis of maize responses to drought stress and in turn, providing better breeding techniques for maize (Campos et al., 2004). Researchers are always looking for more ways to improve the drought tolerance of crops. In a study by Tauschke et al., mycorrhizal fungi was applied to crops to evaluate a potentially higher water use efficiency than those without (Tauschke et al., 2008). Mycorrhizal fungi were overall beneficial in plant health and water use efficiency, providing a potential inoculant for farmers to use to improve the crop's water efficiency. Addressing the morphological and physiological traits of a plant's response to deficit water can help to predict future behavior in plant species and potential shifts in plant communities (Tucker, 2010)

2.4 Perennial Crops in Agriculture

Perennial plants have a root system that persists throughout the year whereas annuals are seasonal plants that die out each year. Annuals require more labor and care since they need to be recultivated each growing season, and they make up almost 70% of the worlds croplands (Pimentel et al., 2012). There are some perennial systems in practice commercially, they mostly include orchards or alfalfa. In general, perennial plants do not produce as high of yields precisely because they survive longer than one season. Annual crops produce seed fast and in abundance to keep their genetic line going after their one growing season. This has been a challenge for breeding perennial crops for commercial agriculture, a goal of the Land Institute. Increasing plant yield while preserving the desired traits of perennial crops will an important question to answer on our way to a sustainable future in agriculture.

2.4.a Soil health and tillage

Soil is the medium in which plants grow and the habitat in which organisms seek refuge. Sustainable agriculture is built off the foundation of maintaining and building soil health (Congreves et al., 2015). Soil health is not defined by one specific quality; it is determined through many characteristics that combined can sustain plants, animals and humans (Congreves et al., 2015; Nunes et al., 2020). The characteristics of soil health are dependent on management practices and are extremely influenced by agriculture (Congreves et al., 2015). Soil quality is a reference to the soils ability to perform its ecological functions such as soil carbon sequestration, which is the soils ability to bring carbon down from the atmosphere into the soil through plant roots and organic matter to be stored for long periods of time (Congreves et al., 2015). Soil organisms are responsible for providing soil functions like decomposition and sequestration (Nunes et al., 2020). Tillage affects soil microorganism communities in ways that changes soil carbon storage negatively (Nunes et al., 2020). In a meta-analysis of 302 studies, transitioning to a no-till management practice has proven to increase soil health overall by increasing both soil organic carbon content and microbial activity, improving soil functions at deep depths, and increasing labile carbon and nitrogen (important plant nutrients) contents in the top soil (Nunes et al., 2020).

2.4.b Soil erosion

Soil is considered a non-renewable resource based on the rates of erosion compared to the rates of formation. It is the medium for the plant growth and supplies the necessary nutrients. Tillage is the leading cause of soil erosion, which is primarily used to cultivate annual food crops (Pimentel et al., 2012). The majority of food crops are annuals requiring new cultivation and disturbance every year; researchers are constantly thinking about a solution to the growing population's food security while maintaining soil health and minimizing disturbance. Soil erosion is caused by high soil disturbance, typically due to intense tillage. While annuals only survive their specific growing season, perennials die off and grow back each year leaving their root system intact and preserving the soil structure and health. Perennial crops have shown to provide general soil health benefits like soil stability and improved structure, as well as increased biodiversity compared to annuals (Cosentino et al., 2015)

2.5 Important Crops in Today's Agricultural Systems

The United States hold some of the most production croplands in the world. The US produces food and fuel that is distributed across the globe. Maize is the most extensively grown crop in the United States, it is used for food, fodder, and fuel. Similarly important crops are oilseeds such as sunflowers, soybeans, canola, cottonseed, peanuts… etc. ("USDA ERS - Oil Crops Sector at a Glance,").

2.5.a Crops used for oil seed

In the United States approximately 40 million hectares was harvested for oilseed in 2014 according to FAOSTAT (Schiffner, 2018). Growing populations have increased the need to maximize food production, as a result highly profitable oilseed crops are commonly grown in a industrial system that utilize heavy machinery and synthetic fertilizers which are known to degrade soil health, release greenhouse gasses, and create a heavy reliance on chemical inputs (Johnston et al., 2002; Adeleke and Babalola, 2020; Dale, 2020). Chemical inputs like synthetic fertilizers produced through fossil fuel burning, result in the highest release of greenhouse gas emissions in the food production system (Ramírez and Worrell, 2006; Dale, 2020). In attempt to mitigate this problem, perennial crops have been considered as a replacement to annuals since they require less inputs due to their long-established root systems while also promoting biodiversity for pest resistance and soil protection (Pimentel et al., 2012).

2.5.b Crops used for bioenergy

Exploration of renewable fuel sources have led European countries to turn to herbaceous plants for possible biomass utilization (Šiaudinis et al., 2012). The use of natural gas and fossil fuels have been declining in Germany leading to the experimentation of renewable sources. Most agricultural systems use synthetic fertilizer produced through fossil fuel utilization. This remains an unstable market for agriculture and detrimental to the health of our environment (von Cossel et al., 2020). An important crop used for biofuel is hemp (Jankauskienė and Gruzdevienė, 2012). There are many ways to utilize hemp as a biofuel crop:

burning, oil, and even converting cellulose to alcohol (Jankauskienė and Gruzdevienė, 2012). Burning hemp with coal can reduce emissions and offset the coal used to produce electricity and other power sources (Jankauskienė and Gruzdevienė, 2012). There is argument for perennial biofuel crops over annuals due to their high energy potential, and lower cultivation costs (Šiaudinis et al., 2012). Currently, maize is widely used for biogas substrates, but this has been a cause for debate over efficient land use and environmental protection (von Cossel et al., 2020). Cup plant is a potential replacement for maize biogas, but further cost analysis for the long term will be necessary (Šiaudinis et al., 2012). S. *perfoliatum* has been tested for different uses around the world including fodder, biogas, and a renewable energy source.

2.6 Perennial Alternatives to Important Crops in the Food System

Perennial crops have proven to be a good alternative to annual crops based on their extensive ecological and environmental services (Pimentel et al., 2012; Cosentino et al., 2015). Their extensive root systems have proven their hardiness to a changing climate whether in the short term or over decades. The greatest challenge we face with perennial crops will be to produce genotypes that are as productive as their annual relatives (DeHaan et al., 2005; Cox et al., 2006; Van Tassel et al., 2013; Schiffner, 2018).

2.6.a Silphium Integrifolium

Silphium Integrifolium (Silflower) is a perennial sunflower in the Asterceae family native to North America. It has been considered for a potential perennial oilseed crop intended to replace or substitute for annual sunflower production

(Vilela et al., 2018). It also produces high quality livestock forage from the pre-flowered biomass (Vilela et al., 2018). Seed yield was shown to decrease when biomass was harvested in the same year, but there is potential for an alternating oilseed and forage year rotation (Vilela et al., 2018). Compared to an annual oilseed domesticated sunflower, Silflower's yield are low; however, paired with optimal conditions and germplasm improvements, there is potential to match the yields of a traditional sunflower (Schiffner, 2018). The Land Institute has been breeding lines of *Silphium Integrofolium* in hope of domesticating a reliable line for oilseed. While evaluating a species for a domesticated crop purpose, there are factors to consider for highest success such as total biomass and seed yield, cultivation costs, plant health, and resistance to climate fluctuations (Schiffner, 2018).

2.5.b Silphium perfoliatum

Silphium perfoliatum (cup plant) is native to North America, resides in the same family as silfower, and has become increasingly interesting to researchers as a potential alternative to annual biofuel crops. It has shown to be drought and frost resistant, making it suitable for use in Europe (Peni et al., 2020b). To limit the use of fossil fuels, organic material like plant matter has become an interesting renewable alternative. Cup plant is cultivated at 44% in Germany, if raised to 70% cultivation in the future, methane production will decrease by 742 095 m^3 compared to maize production (von Cossel et al., 2020). The ideal plants for biofuel are easy to grow and offer high yields with low labor costs (Peni et al., 2020b). Maize silage is currently used for biogas, but it requires annual cultivation and heavy inputs (Peni et al., 2020b). S. *perfoliatum* is a promising alterative because of its low production costs and resistant to poor or polluted soils (Peni et al., 2020b). In Lithuania, the acid rich soils are often highly unproductive; S *perfoliatum* proved to provide high biomass yields despite the conditions (Šiaudinis et al., 2012).

2.7 Civic Science

Civic science integrates community members into scientific research to incorporate ideas, diversity, stories, and the community (“Civic Science - The Land Institute,”). Civic science is defined as “a discipline that considers science practice and knowledge as resources for civic engagement, democratic action, and political change”(Garlick and Levine, 2017). There is great value in scientific dialogue outreach to public citizens and politicians by providing diverse voices informing people of scientific responsibilities (Garlick and Levine, 2017). Often, people do not trust science for its lack of open-minded work and inclusive dialogue. Civic science is a tool scientists can utilize to regain trust and understanding from the public (Garlick and Levine, 2017).

2.7.a Modern Day Civic Science, Challenges and Limitations

Civic science has been around since the art of science has been discovered. It was only recently that scientists received payment for their work. Modern day civic science is important to scientific research because the public is a source of free labor to scientists (Silvertown, 2009). In situations where large data sets need to be collected, civic science is often a useful resource for researchers to outsource labor, but with this comes some limitations and challenges. The most common limitation with civic science is the fact that most volunteers are not trained in the specific scientific field and the protocol training is usually limited (Silvertown, 2009). This requires the data to be validated and the methods for data collection should be standardized for a neutral reference point. (Silvertown, 2009). There is great potential for the development of civic science both in the field and online (Thornhill et al., 2016; Kosmala et al., 2016).

2.7.b Civic Science and the Land Institute

The Land Institute used civic science to evaluate plant performance across the United States while simultaneously involving the community and bringing awareness to the work they are doing. The volunteers collected data about specific characteristics of the plant's performance, such as number of stems, number of heads per stems, number of seed heads filled and unfilled. The environment in which the plants were grown was considered as well. This is valuable data for the Land Institute, while involving the community in their research brings more awareness and support from around the country. Civic science is an important bridge to engaging people both inside and outside of formal policy (Scott and Barnett, 2009). This project will attempt to integrate undergraduate students into the data collection and analysis to incorporate hands on learning into related classes. Civic science, as performed similarly to the Land Institute, requires accessibility of protocols and an understanding that there will be a knowledge gap for some participants.

2.7.c Course-Based Undergraduate Research Experience Network (CUREnet)

The National Science Foundation initiated the CUREnet back in 2012 with the goal of incorporating undergraduate research experiences into undergraduate courses (Auchincloss et al., 2014). CUREnet should serve all students in a course, not simply those who go out of their way to seek extra-curricular research experiences (Auchincloss et al., 2014). There are five baseline words or phrases that CUREnet defined as important for undergraduate research: Use of the scientific practices, Discovery, Broadly Relevant or Important Work, Collaboration, and Iteration. The American Association of the Advancement of Sciences (AAAS) has developed a series of strategies to meet undergraduate needs in the field of science to accompany CUREnet (Wei and Woodin, 2011). One of their reports, *Vision and Change*, suggests integrating the scientific method into undergraduate research as early as possible (Wei and Woodin, 2011). The integration of the scientific process has been explored thoroughly in the field of biology, where professors had the freedom to go about this in anyway appealing to them. There were many different unique projects and research opportunities that ranged from Authentic Research Experience in Microbiology (AREM) to Connecting Researchers, Educators, and STudents (CREST) (Wei and Woodin, 2011). AREM involved multiple courses that focused on a special strain of a plant pathogen to teach students extensive research skills. CREST was focused on the relationships between research labs and undergraduate research groups (Wei and Woodin, 2011). There are endless ways to enrich student's learning experiences and in turn there were many different outcomes.

2.7.d Civic Science: An Assessment on Quality

In order to better integrate the community with quality scientific research, an assessment on the reliability and predictability of data collected by volunteers is imperative for success. Although some scientists are skeptics of the quality of data coming from a civic science study, datasets produced from volunteers can high the same reliability as those produced from professionals but is dependent on volunteer experience and task difficulty (Kosmala et al., 2016). Even in realistic size pools of volunteers (200 or less) reliable data can be presented (Steinke et al., 2017). Familiarity of the task has impact on the data accuracy. This was demonstrated by a study done in the Serengeti, volunteers had an easy time identifying well known animals like a giraffe and a hard time identifying new and unfamiliar animals such as an aardwolf (Kosmala et al., 2016). A popular method for assessing the variability of data is calculating a coefficient of variance. This is an important concept for assessing variability in data collected by citizen scientists. A coefficient of variance is used to compare data variability and is popular because it standardizes the standard deviation in a way that allows for comparison across groups that would otherwise be comparable (Reed et al., 2002).

As discussed in this review, civic science plays an important role in The Land Institute's evaluation of their perennial sunflowers. Further analysis of the reliability of civic scientist produced data is necessary for improvement in the implementation of civic science. This experiment is designed to build upon The Land Institute's civic science framework in an effort to nail down methods that are most likely to produce reliable data from the civic scientists.

Chapter 3: METHODS

Modern plant breeding can quickly develop plants with specific traits, like high yield, that are desirable for a commercial operation. However, there can be a drawback to this process. While selecting for such characteristics, plants often lose desired traits related to environmental resistance such as drought tolerance, making them more susceptible to extreme conditions. Therefore, it is important to maintain populations of wild relatives with diverse traits so breeders can use them to improve the sustainability of their breeding population.

3.1 Experimental Design:

The 12 populations in our common garden experiment are wild *Silphium* genotypes, each collected from a different prairie in the southern United States. By characterizing the phenotype of these plants over time one can identify genotypes of potential importance that can be re-incorporated back into the breeding program at The Land Institute. Additionally, we will be able to determine which genotypes are best adapted to our local climate and pest communities.

1. $P = G + E$

P = Phenotype: observable traits of the plant

G = Genotype: the genetic make-up of the plant

E = Environment: local climate in which the plant is growing

In a standard experimental design, a common garden experiment is designed to observe local adaption to a genus, incorporating Equation 1. Phenotype is a function of genotype and environment. The same species can display different phenotypes when subject to different environments. Understanding how plants respond to differing climates can help scientists and growers accurately predict a plant's viability in a given growing zone (Kang et al., 2000). In the experiment at the student experimental farm, we will be holding the environment constant to see how the silphium genus differs on the central coast of California.

The two common garden experiment beds hold 6 genotypes, while each of the genotypes has 8 repetition plants within the plot. An assessment of the overall plant's health was carried out via a lab assignment in an ecology class with Dr. Nicholas Babin from the Department of Natural Resources at Cal Poly. Quantitative plant health was evaluated by the following plant traits: plant height, number of seed heads, average seed width, percent (%) herbivory, % disease, and a two-minute pollinator count. To get the full scope of plant health, % herbivory is an assessment of damage done to a plant by insects or bugs in the form of plant tissue consumption. Similarly, % disease is an estimation of the amount of disease found on an individual leaf.

Plant height was measured by choosing the tallest stem in the plot of eight plants and recording the height in cm. The total number of seed heads included all eight plants in the plots while excluding unopened buds (Figure 1). These same seed heads were measured and averaged to calculate the average seed head width. This did not include the petals, simply the length of the seed head (Figure 1). Percent disease and herbivory were both evaluated by estimating the percent cover on a random leaf. Using a random number generator, students chose leaves randomly throughout the plot until the number chosen is called. This was done on 5 different leaves for disease and 5 different leaves for herbivory before being averaged for the whole plot. The pollinator count required students to sit and watch the plots for two minutes and record the number of flying pollinator visits. This was done separately for each of the plots. The class was divided into eight different groups with 3 to 4 students in each collecting the data.

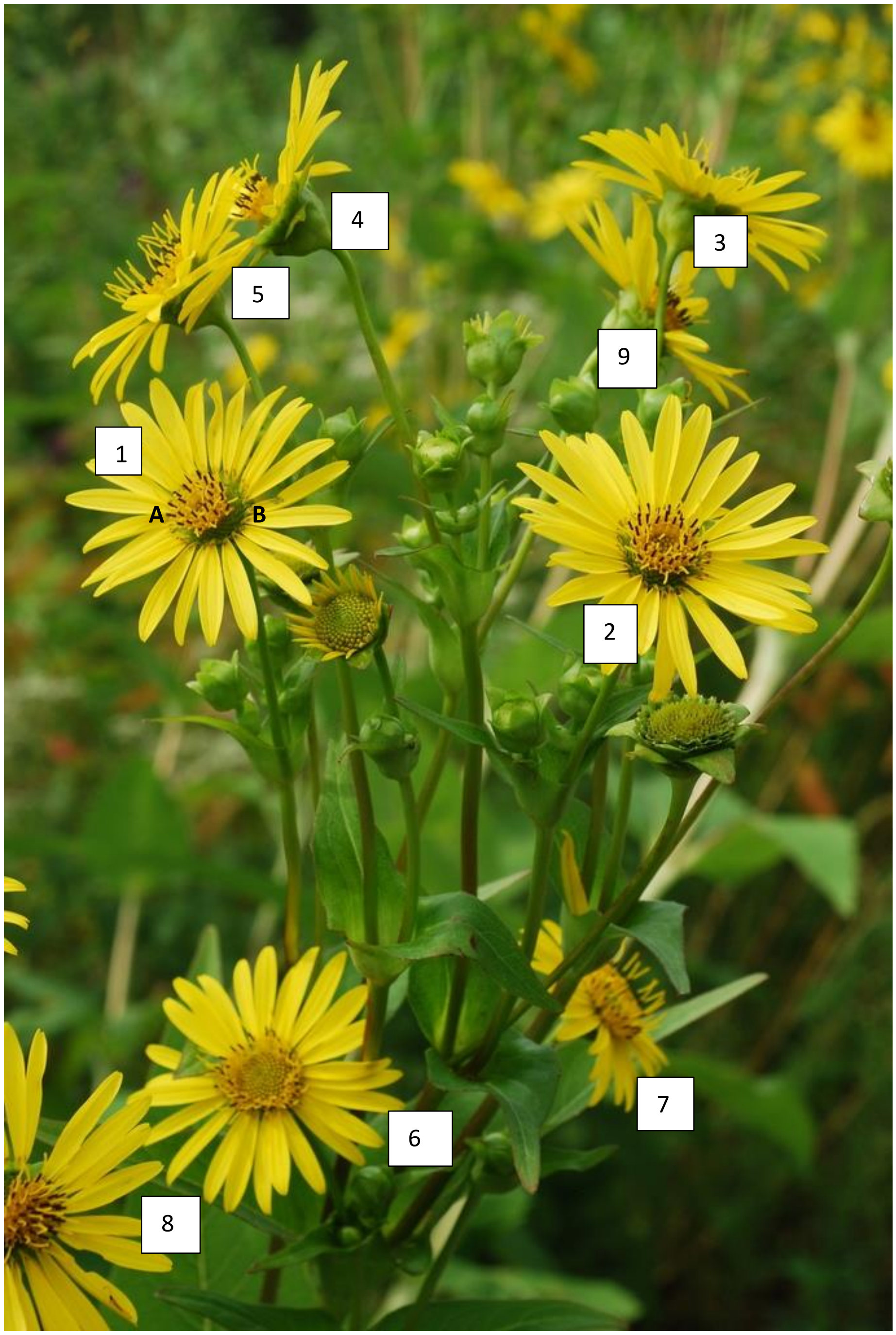

Figure 3-1

Silphium flowers numbered to demonstrate which flowers would be counted for the experiments protocol. A to B on flower 1 represents where to measure for collecting data on the average seed head width.

Interpretation of these data are to be carried out by analyzing the coefficient of variance (CV), calculated by dividing the standard deviation by the mean, to measure the relative dispersion the data within the data set around the mean. The CV is a popular method of analysis because it standardizes standard deviation to allow for comparisons regardless of variations within the analyte (Reed et al., 2002). The CV was calculated for each variable and each genotype. Further analysis of the CV was done through an Analysis of Variance (ANOVA) and a Tukey Post-hoc honest significant difference (HSD) test. The ANOVA was run for each of the variables on the means from each group.

Chapter 4: Results

Data collection was completed in the Spring of 2022. Eight groups of Cal Poly undergraduates quantified the health of 12 wild crop varieties of the Silphium genus. The coefficient of variance (CV), a ratio between the standard deviation and mean, was calculated for each of the 12 genotypes. To further examine the variation of data across the traits, the CV for each genotype was averaged before running through an ANOVA with a Tukey-Kramer HSD test to determine any significance in the variation. The ANOVA was run to compare how variations in the data were compared across the plant traits. The mean CV, calculated from the ANOVA and Tukey tests, indicated a high or low variation across the data (Table 1). Lower CV values are representative of small variation in the data, indicating the groups all collected very similar values. High CVs suggest the group variation is sporadic and less reliable.

Pollinator count

The pollinator count data collected from the students was the least consistent as shown in figure 4-1. There is a lot of variation within the genotypes from each group, giving the pollinator count the highest mean CV of 1.119 (Table 1). The mean and standard deviation from each genotype was determined before calculating the CV which is done by dividing the standard deviation by the mean. From here, the CV for each genotype was averaged to get one number representing the average CV of all the 12 genotypes for each plant trait. The pollinator count had an average CV from all groups and genotypes of 104% (table 4-2). The same method was used to calculate the average CV of each genotype for each plant trait.

Number of Seed Heads, Head Width, and Height

The number of seed heads, average seed head width, and plant height all had CV values that ranged from .34 to .08 and were all significantly similar (table 4-1). These low CVs suggest the data collection was mostly consistent across the groups for these three plant traits which can be seen in figures 4-2 through 4-4.

The most consistent data of all the plant trait was plant height with a CV of 0.08 (Table 1). Figure 4-4 shows how closely the groups plant height measurements were to each other for each genotype. The average seed head width has a CV of 0.22 while the total number of seed heads was 0.34. Counting and measuring seed heads was more tedious data collection for the students, but the mean CV was still significantly related to the CV for plant height suggesting it is reliable data. Figures 4-2 and 4-3 demonstrate more variation between each group's data for the number of seed heads counted and their average width.

Percent Herbivory and Disease

Percent herbivory and disease were both an estimation of coverage area performed on 5 random and different leaves. They were significantly similar to each other with relatively high mean CV values. The CV value for herbivory is 0.77 and disease is 0.80 (Table 1). This is a dramatic jump from other plant traits, suggesting these methods of collection are not reliable. Disease and herbivory had very similar CVs, possibly due to the lack of practice in estimating percent cover as a data collection method.

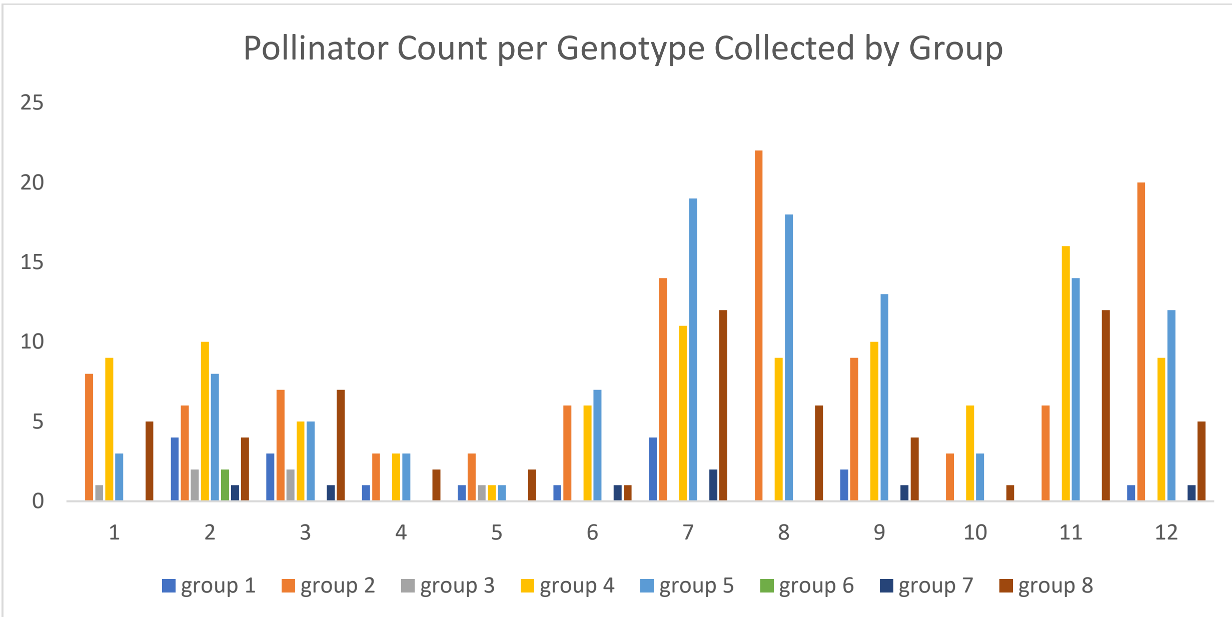

Figure 4-1

Pollinator count as collected by each group for each of the 12 genotypes.

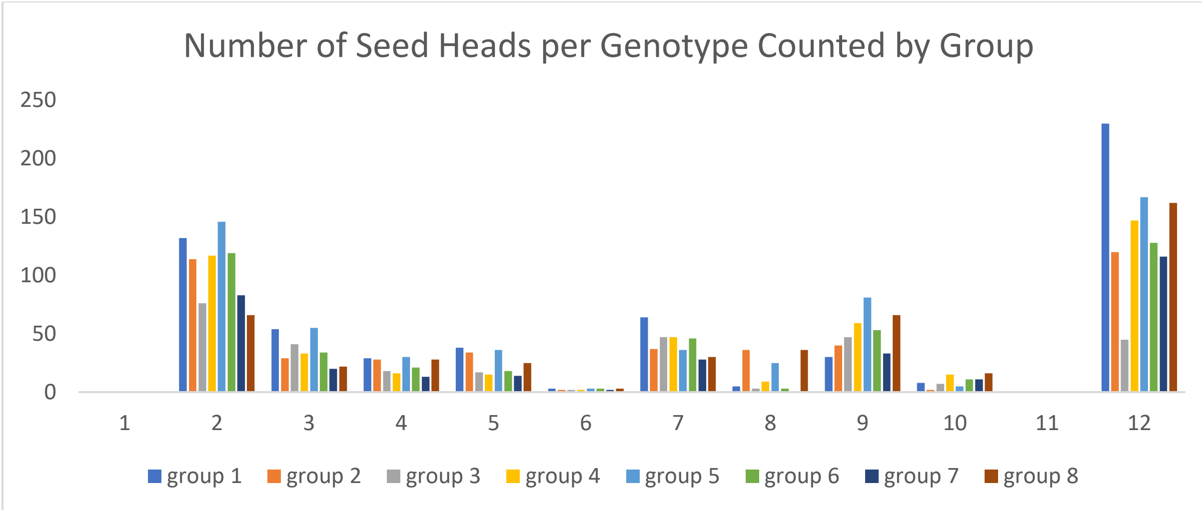

Figure 4-2

Data collected by eight groups to determine the number of seed heads of each genotype. (Data from plots 1 and 11 are not available since the genotypes were not flowering)

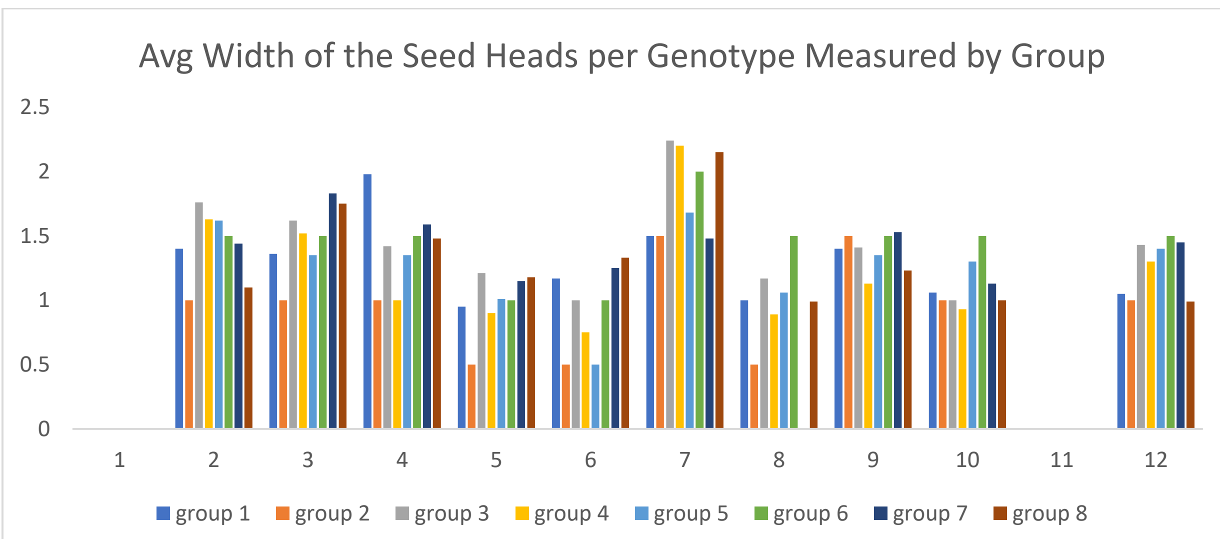

Figure 4-3

Data collected by eight groups to determine the average width of the seed heads for each genotype. (Data from plots 1 and 11 are not available since the genotypes were not flowering)

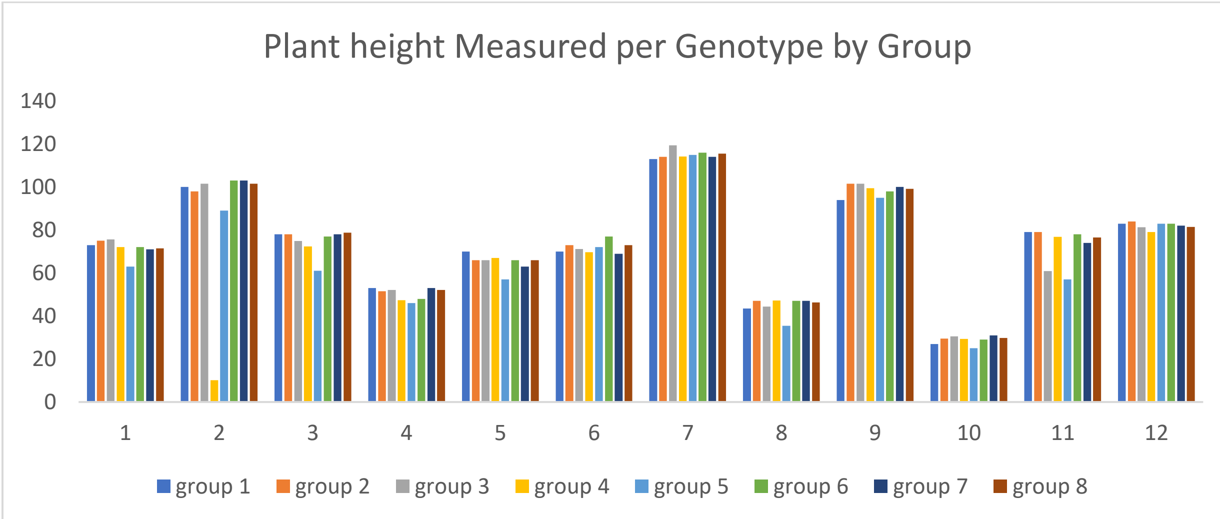

Figure 4-4

Data collected by eight groups to determine the plant height for each genotype.

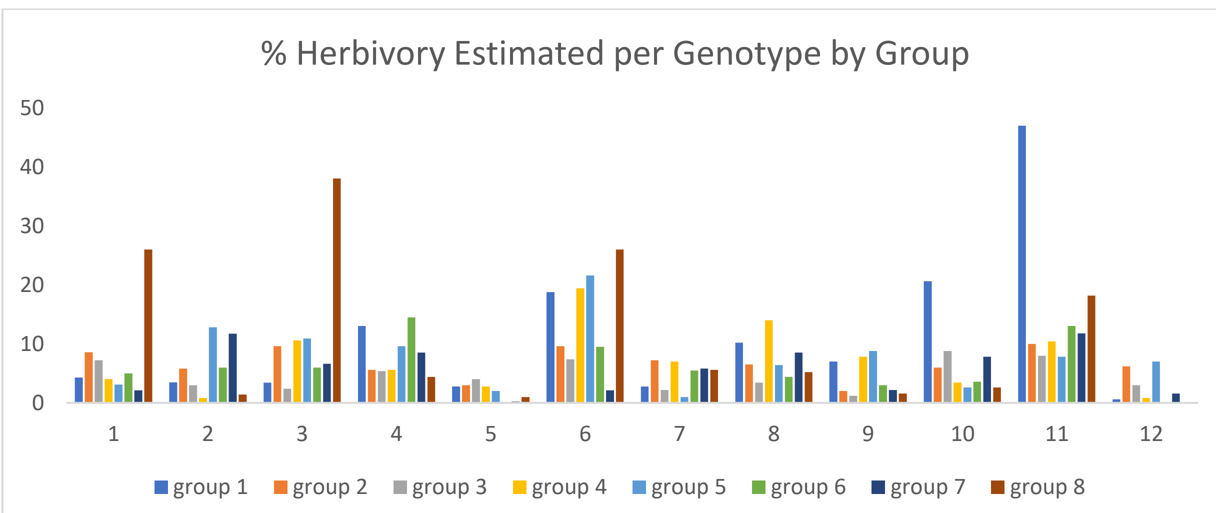

Figure 4-5

Data collected by eight groups to determine the percent herbivory for each genotype.

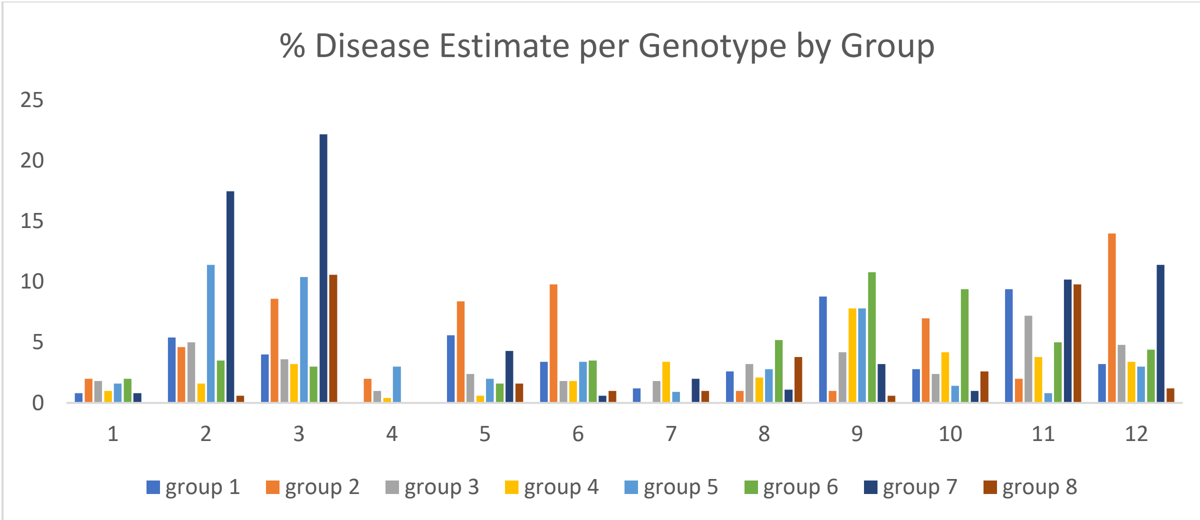

Figure 4-6

Data collected by eight groups to determine the percent disease for each genotype.

Table 1

ANOVA run on the CV for all plant traits with Tukey-Kramer HSD significance test

Level				**Mean CV**
# pollinators	A			1.12
% disease		B		0.803
% herbivory		B		0.768
# seed heads			C	0.340
head width (cm)			C	0.221
height (cm)			C	0.083

Levels not connected by same letter are significantly different.

Table 2

Average CV values for each plant trait calculated from all 12 genotypes

Plant Traits	Mean CV for Each Genotype
Plant Height	8%
# Seed Heads	37%
Average Seed Head Width	23%
% Herbivory	77%
% Disease	80%
Pollinator Count	104%

Chapter 5: Discussion:

Based on the results in chapter 4, simple measurements and calculations have shown to be the most reliable and predictable types of data collection for civic science participants. Since most volunteers are not equipped with scientifically related background knowledge, simple and straight forward protocols would help produce the best results. Methods that require estimation and sub-sampling have proven to be less reliable due to higher complexity of the protocol.

The coefficient of variance (CV) can help to better understand the variations shown throughout the data. Pollinator count had the highest CV value suggesting the data collected was not consistent across the groups. There is some natural variation expected from this protocol due to human error and the time lapse style measurements taken. There was a high risk of pollinators being double counted because of the plot design. Differentiating between flying and non-flying pollinators could have been a source of confusion within this protocol. Although stated in the directions, only flying pollinators should have been counted. Overall, this method was found to be unreliable.

Although the number of seed heads, plant height, and the average width of the seed heads all have CV values that are significant to each other, there are a few explanations as to why the number of seed heads and their average width have a higher CV than plant height. The most likely explanation is that the students were either overcounting or missing countable heads. The students were supposed to include the seed heads that had already gone to seed; potential confusion here could have led to miscounting. Similarly, the average seed head width was reliant on students counting the same heads as other groups and not including the petals. Due to the high volume of seed heads, missing some or incorrectly measuring them are both likely reasons for more variability in the data. However, these three data collections were found to have the most consistent data values across the groups most likely due to the simplicity of each protocol.

The method of estimation for % herbivory and % disease, as well as the small sample size, were the two most likely reasons for a lack of reliability and predictability in this data collection. The sample size was limited to 5 random leaves (a different set of 5 were used for both disease and herbivory) because of the time restraint of the student's lab period. A larger sample size would have been desirable for better results. Additionally, the processes of estimating percent cover are tedious and difficult. The students had limited practice and instruction with this method resulting in unreliable data.

They are two possible sources of unreliability in the data: measurement error and sampling error. Measurement error can be anywhere from errors in equipment use, data transcription, or a lack of direction following. These errors were present in many areas of this experiment, specifically while the students were counting seed heads. Some of the plants had over 200 heads to count all while calculating the average width of those seed heads. Recording all 200 plus seed heads before taking the average is tedious with high potential of miscalculation or bad transcribing. Sampling error is in reference to the sampling design that might occur based on the biological and ecological traits of the system. During the time of data collection, some of the genotypes had not yet flowered, whereas several had already gone to seed. As a result, the entire population was not properly represented. Sampling error was also prevalent in the pollinator count. Since the plots are closely grouped together the pollinators were easily double counted or missed altogether. The experimental design was not ideal for pollinator count measurements. The overall differences in the reliability of each groups data, can be mostly attributed to data collection method.

As seen from this study, the type of measurement required for data collection was important for the quality of data collected. For future citizen science involvement, simple protocols involving measuring and counting have proven to be reliable. The students found difficulty in visually estimating the % herbivory and % disease. They had limited practice in this type of measurement resulting in unreliable data across the groups. If this type of measurement is to be used in other studies, specific diagrams and training is highly recommended. Training type and amount has been found to have a profound impact on the amount of errors found in an pollinator count civic science study (Ratnieks et al., 2016). Additionally, as an alternative to estimating percent of disease or herbivory, simply recording if it is present or not with "yes" or "no" can be extremely effective. This worked well in a study that involved volunteers identifying phenophases in plants (Fuccillo et al., 2015). The participants were asked to report if the phenophase was present or not, and correctly identified the phenophase 91.3 %±4.6 % of the time (Fuccillo et al., 2015). Presence and absence of a trait instead of estimation measurements is a promising alternative to assessing % disease and % herbivory in future studies.

A potential limitation to this study is our lack of a standardize data set that could be used to compare to the student's data. A comparison of such would allow us to test the accuracy of the data, not just the predictability or reliability. An accuracy assessment could help us improve the implementation of citizen science through better delivery of data collection protocols.

Improvements to the experimental design could help decrease sampling and measurement errors. Increased training on the protocols would be helpful, particularly for the percent herbivory and percent disease estimations. Determining the percent coverage of an area can be difficult to do by eye. Before the students began their data collection, it would have been helpful to show examples of area coverage on a leaf through pictures. This would have allowed for practice in the estimation process and potentially more consistent data. Additionally, the pollinator count could have been done all at the same time while no other protocols were being performed. This would have allowed for each group to focus on one plot at a time without other students in the way. Additionally, doing the pollinator count simultaneously could help reduce double counting of insects, as well as, provided space for more pollinators to visit the plants. Since the students were in the beds and plots, pollinators could have easily been scared away affecting the final count. Finally, a huge improvement for this experimental design would have been to standardize the data as a reference for the students' data to be compared to. This would require a professor or graduate student to perform the same data collection carefully and thoroughly to act as a baseline for the student's data sets.

For future research, examining the impact of training style and amount could help the researchers prepare the volunteers for the tasks in a way that will improve the quality of the data output. Splitting the volunteers into groups and training each one in a different way or dividing the groups by background knowledge and experience surrounding the topic could bring good insight to the importance of training and experience level in a civic science experiment.

Chapter 6: Conclusion

In this paper, a study to assess the predictability and reliability of civic science was conducted at the student experimental farm on Cal Poly's campus. Eight groups of students collected data from 12 different wild genotypes of the silphium sunflower species. The objective of this study is to determine how well civic science can be incorporated into plant research with the goal of improving future integration of civic science in environmental research. The results of the study have shown that method of data collection is extremely important for the predictability of the outcome. Measurements involving recording length or height have shown to produce reliable data. However, estimation measurements did not successfully produce reliable or predictable data. This study provides insight to the types of problems researchers might run in to while incorporating civic science into their studies. Our results may help guide smoother data collection which, in turn, will produce more reliable results. Civic science plays an imperative role in environmental research. Helping the community understand the role perennial sunflowers play in our agricultural system as well as the environmental benefits they provide with spark further support and involvement. Civic science plays a huge role in the future of perennial sunflower research; with the right protocol and training reliable data in this field is highly obtainable.

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