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Sustainable Agriculture through Data Analytics

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Sustainable Agriculture through Data Analytics

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Sustainable Agriculture through Data Analytics

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Abstract

There is an increasing need for sustainable agriculture in light of climate change and growing populations. Certified B Corporations meet the highest standards of verified social and environmental performance, public transparency, and legal accountability to balance profit and purpose. This paper describes a student-learning project that developed an Environmental Management System (EMS) using data analytics to improve a family-owned farming business's decision-making process for efficient natural resource allocation, as well as the reporting requirements associated with their B Corporation Certification. This project's primary resource is water reporting, but it may be expanded to include other resources.

Introduction

Agriculture sustainability is an ever-increasing concern due to climate change, the desire to eradicate hunger due to poverty, and the goal of increasing the general wellbeing of humans (Rockström et al., 2017). One of the key challenges facing agriculture in the 21st century is the ability to farm sustainably while meeting increased food demand. The UN Sustainable Development Goals require an increase of global food production through sustainable means to meet a global population of nine to ten billion people in 2050 (Foley et al., 2005; IAASTD, 2008; Tilman et al., 2011; Pardey et al., 2014).

According to Rockström et al. (2017), human pressures on the environment are causing climate change as well as population growth, consumption growth, environmental change, and food security which are 'interconnected forces' that provide a framework to identify salient factors of sustainable agriculture. Agriculture has been identified as both the driver of climate change (Tilman et al., 2011; Foley et al., 2005; Godfray and Garnett, 2014; Kuyper and Struik, 2014) and the key to reducing human contributions to the degradation of the environment (Rockström et al., 2017). Hence, researchers are calling for paradigm shifts to attain global sustainability (Rockström et al., 2017; Steffen et al., 2015) locally, regionally, nationally, and globally (Folke et al., 2005). One such example is the call by Rockström et al. (2017), based on strong, scientific justification, for a shift from a primary focus on enriching production to a model with sustainability at the core of the strategy for agriculture development. According to the Intergovernmental Panel on Climate Change (2007), drought periods have been increasing in already drought-prone areas due to climate change, adding greater stress on food security systems (Rosegrant and Cline, 2003; Ericksen 2008). California is one of these areas where droughts pose a threat to the agricultural status quo (UNDP, 2004; Dilley et al., 2005; Helmer and Hilhorst, 2006). As an increasing food supply is required to meet the increasing demand for food, the agricultural status quo is defined as a rise in production to meet this requirement (FAO, 2000). This disruption has consequently affected food security (Tubiello et al., 2007). Water scarcity related to climate change is and will continue to be a key challenge for California in the coming years. Recently, the California Department of Water Resources (DWR) announced that water allocations requested

by farmers would be reduced to five percent of the requested amounts for the year 2021 due to drought conditions (Saam, 2021). In many ways, agriculture is the frontline for the challenge of climate change.

As our society continues to face these (and other) environmental issues related to climate change, we will need to adapt our current water management and usage to be more sustainable and more efficient. One such opportunity to adapt is to develop data-driven systems to record water usage and analyze the data in real-time to meet this goal. This paper outlines a student-learning project that sought to develop an environmental management system (EMS) that uses data analytics to track the usage of resources by a family-owned farming business. We posit that the EMS will benefit the client in achieving and maintaining B Corporation certification as it aligns with their mission. The B Corporation certification designation signifies that an organization adheres to strong sustainability and social responsibility standards (B Lab, 2021a).

Literature Review

Data science and analytics are becoming commonplace in the agricultural industry as the challenge of climate change pushes the industry to adopt new techniques. The adoption of new technologies is aided by the lowering of barriers such as cost. This project focuses on how data analysis techniques can be applied to sustainable agriculture. To better understand this environment, a review of previous research around the nexus of sustainability, agriculture, and data analytics will be explored in the following section.

Sustainable Agriculture

The World Commission on Environment and Development (WCED, 1987) defines sustainability as the process of developing in a manner that meets the society's current needs without compromising the needs of future generations. A significant threat to the needs of future generations is climate change (IPCC, 2021). According to Tahat et al. (2020), a key contributor to climate change is the development of food and agricultural land — a result of developing or underdeveloped economies' rapid population increases and infrastructure growth. These efforts increase demand for food and agricultural land development, contributing to the pressure on climate change and natural resources. Yunlong and Smit (1994) state agriculture has caused environmental changes that impact sustainability efforts; however, it also has a major role in a society's sustainability efforts.

According to Tahat et al. (2020), sustainability measures may help meet food agricultural needs worldwide without compromising the planet's natural resources. These authors further argue that one of the major goals of sustainable agriculture is to increase crop productivity while mitigating climate change and preserving ecosystems. Smit and Smithers (1994) hold similar views, defining sustainable agriculture as the practice of producing agricultural products in a way that minimizes the destruction of the ”natural resource base” so it can be fruitful for the foreseeable future. As part of their effort to measure sustainability in agriculture, Yunlong and Smit (1994) further defined sustainable agriculture in terms of three sets of agricultural constraints: biophysical, socio-political, and economic and technological. The authors emphasize that sustainability involves "the continued productivity and functioning of ecosystems" (ecological), "the continued satisfaction of basic human needs[…] as well as higher-level social and cultural necessities" (social), and the presence of sufficient economic incentives to produce agricultural products (economic). Sustainable agriculture is an alternative methodology that places emphasis on developing new practices that are harmless or beneficial to the planet's natural resources (Tahat et al., 2020).

In an effort to mitigate the damage of climate change, international organizations, governments, and individual institutions have instituted policies to encourage sustainable natural resource management (Song et al., 2017). As reflected in the literature, considerable research efforts have been placed into sustainable agriculture to understand the meaning, salient factors, and practices. According to Song et al. (2017), big data is a possible aid to climate scientists, policy makers, and other stakeholders involved in sustainability. Keeso (2014) also refers to big data as a powerful, yet underutilized, tool for sustainable agriculture.

Sustainability and B Corporation

The Sustainable Business Network (2021) states that the integration of sustainable business strategies demonstrates the organization's ethics and sustainability goals, which may address global issues. Global issues include human rights issues, environmental climate change, and gender and income inequality. Palmer and Flanagan (2016) categorize initiatives set for a business to attain sustainability as "the three Ps": people, planet, and profit.

In addition to pursuing better social and environmental change, sustainability initiatives may contribute to an organization's overall success. Sustainability initiatives for an or-

ganization begin with identifying what sustainability means to them, taking into consideration their mission and goals. Organizations must then figure out how to incorporate sustainable practices into their operations while also building a culture of sustainability. The Sustainable Business Network (2014) has identified a number of advantages for organizations that implement sustainable measures. Some of these measures benefit outward-facing activities such as relationships with consumers and stakeholders, improved brand value, and reputation for green measures. Other advantages help organizations with market awareness such as consumer demand, market advantages, and understanding emerging trends. Additional benefits identified include helping organizations improve operations through activities such as reducing resource allocations, compliance with procurement and fulfillment processes, planning for business continuity, managing risk, and promoting change and innovation.

B Lab, founded in 2006, has sought to assist businesses in demonstrating and improving their commitment to positive, societal impacts by awarding a certificate of achievement known as B Corporation Certification (B Lab, 2021b). In order to earn the certificate, every business is required to demonstrate its social and environmental performance, accountability, and transparency with a minimum score of 80 points on the online B Impact Assessment tool (B Lab, 2021b).

Sustainability and Data Analytics

Sustainability efforts may be enhanced through the analysis of big data; however, this is an emerging area that needs to be explored through further application and research. Big data is defined as large data sets that can be examined and analyzed to reveal underlying trends and patterns through analytics (Lioutas and Charatsari, 2020). Analytic tools, specifically tailored for big data, enable data-driven decision-making through visualizations and data exploration. Raut et al. (2019) link big data analytics and sustainability to sustainable business management practices.

Early research indicates that big data analysis in agriculture has the potential to increase economic returns by enhancing farmers' decision-making performance (Wolfert, 2017); reducing input costs, and increasing yields (Ribarics, 2016); and has a significant, positive impact on the economic performance of farm enterprises (Lioutas and Charatsari, 2020). Moreover, research on the impact of big data use in agriculture has changed the perspective on sustainable agriculture (Lioutas and Charatsari, 2020). Machine learning and data analytics methods are beginning to be used in agriculture for descriptive and predictive purposes to aid decision-making and sustainability efforts. Machine learning, according to Mohri et al. (2018), is the scientific study of algorithms and computational models run on computers to progressively improve the model's performance based on historical data. In particular, Sharma et al. (2020) ascertain that data analytics in the form of machine learning techniques have been applied to sustainable agricultural endeavors resulting in optimal resource allocation. The researchers further assert that machine learning can provide multiple benefits from improving sustainability, increasing transparency, adding traceability, and increasing access to supply chain information.

For these reasons, applying analytical methods to agricultural farming data is a suitable solution to optimize sustainability in this project. Specifically, descriptive, and diagnostic analytics were used to discover insights. Data visualizations were developed for descriptive analytics and discovering what happened based on historical data. Drill down and data mining techniques were also used for diagnostic (or why) purposes. Data analytics and the associated techniques will be leveraged to help the client maintain a B Corporation Certification. The project details and process are outlined in the following section.

Project Overview

A local farm organization sought assistance from undergraduates in a data analytics group to achieve and maintain a B Corporation Certification through the development of an EMS system. This collaboration was initiated through a grant awarded to the California Water Institute and an agreement with the client. The farm is a third-generation, family-owned business that produces almonds, tomatoes, pistachios, garlic, and other crops. This farm has continued to invest in land, water, infrastructure, food processing, and technology as a part of its commitment to sustainability. Their decision to pursue a B Corporation Certification is a tangible way of demonstrating these efforts.

In alignment with the B Impact Assessment criteria and continuous improvement efforts, the client would benefit from updating its processes as new technologies have emerged since their initial water and irrigation usage procedures were implemented. These technologies may help track resource consumption in a more streamlined, intelligent manner. At the outset of this project, the farm's foreman recorded crop irrigation attributes such as field, crop, meter readings, on and off dates, etc. with paper and pencil from the fields. The data was then stored in both electronic spreadsheets and physical

binders. At the end of each week and each season, this data was transferred from the written notes to a Microsoft Excel sheet for further analysis and archival. This process produced data validation issues and inhibited the real-time analysis of resource inputs.

The project objectives for the EMS were to: determine an industry baseline for each area of interest; document the innovative practices of the company; measure the amount of each resource used; and establish a reduction goal moving forward. The resource areas addressed in the EMS are water, fertilizer, land and life, pesticides, and greenhouse gas emissions. The first phase of the project, and the focus of this paper, was to tackle the development of the water and irrigation subsystem. The following section will describe the process of the data collection and analysis under the constraints laid out by the client.

The EMS solution needed to meet the client's specifications to fit in their current environment and processes, and thus, defined the constraints as minimize costs, streamline processes, minimize data entry errors, address the foreman's limited internet access, and minimize future updates of the project. None of these were more paramount than the inability to purchase data visualization software due to budget restrictions; thus, the optimal solution would need to consider open-source or low-cost software. The client sought a streamlined workflow whenever possible to minimize updates and maintenance. These constraints forced the system to be configured in a way that could collect data while automating repetitive tasks and procedures. A streamlined process would minimize employee input except in the data entry and decision-making steps. Along with this, the penultimate objective would be to ensure only valid, accurate data gets input into the system. The benefits from instituting a streamlined process include time savings and greater efficiency. The final constraint was the lack of internet accessibility in the fields (where the data collection would occur), so any solution needed to be accessible offline via mobile devices.

The EMS (conceptualized in Figure 1) system will build upon the current processes but will better leverage the technology available. The automation of existing processes is to be supplemented with data visualization to monitor water usage and to enable more sustainable irrigation. The overall automation process for water tracking should collect field-specific irrigation data, then sync with other relevant crop data specific to the client's farm in a spreadsheet, sync with external weather data from California Irrigation Management and Information System (CIMIS), and then update the visualizations in the Excel workbook.

The water tracking subsystem (Figure 2) consists of four phases 1) Data Entry, 2) Data Processing, 3) Data Analysis, and 4) Decision-making. The data entry phase is when the crop foreman enters the field-specific data such as the on and

Figure 1

EMS Overview

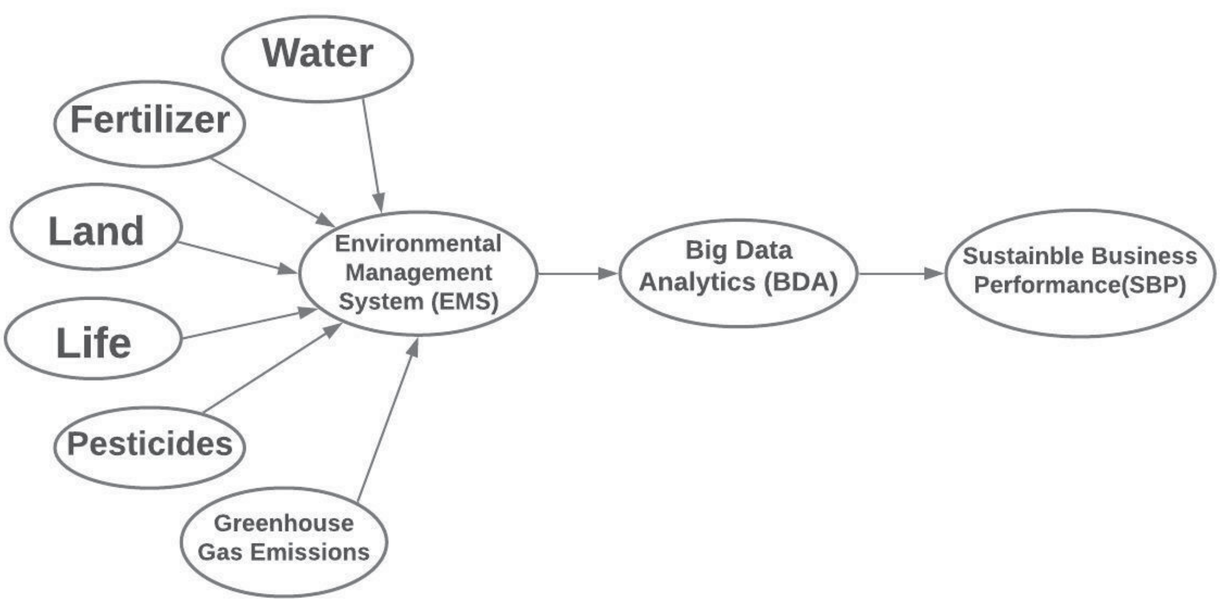
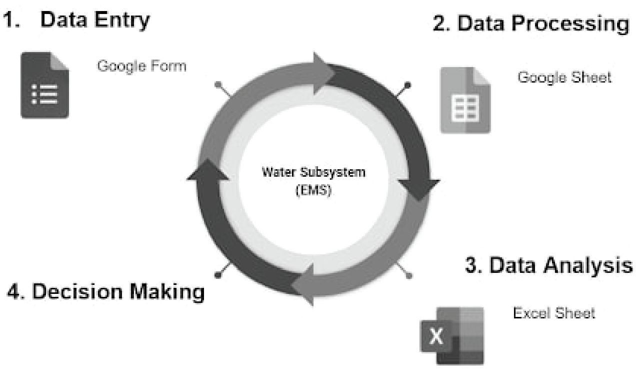


Figure 2

EMS Water Subsystem Flowchart



off dates for water irrigation from the fields via a Google Form on their mobile device.

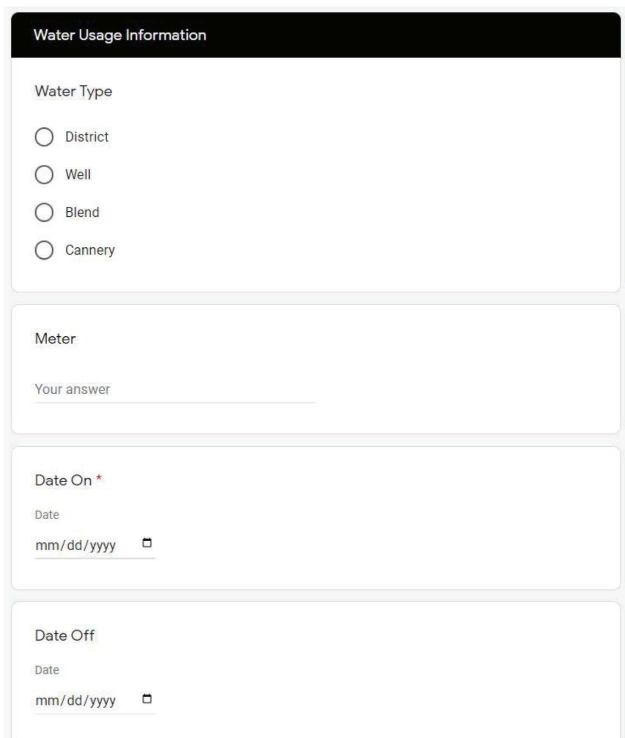
A portion of the form used to collect irrigation data is presented in Figure 3. This software was selected because it is free to use as part of the Google program suite and because Google Forms can be filled out on a mobile device without a Wi-Fi connection, thus meeting two key constraints. Data entry occurs at two distinct times, at the initiation and termination of irrigation; thus, the Google Form needs to be editable while also ensuring that each irrigation occurrence is collected as one record in the system. This form has multiple dependencies based on which user (typically a foreman in the farm setting) is inputting data; this reduces the complexity for the user by removing irrelevant fields from their section. The recorded information includes the various data for water, crops, and fields. If the foreman has completed the form while being offline, it is later synced to the system when a connection is available. The benefit of automating data entry includes minimizing errors in this process, whereas data validation processes serve to verify the entered data. These two activities work jointly to ensure accurate data is available for timely visualizations and correct calculations for items such as actual evapotranspiration for crops.

The Data Processing phase begins once a response is filled out in the Google Form. The responses are stored in a connected Google Sheet. In this sheet, a programming script automatically runs to affix the proper crop to each entry based on the field selected. The crops currently assigned to a field are accessed via a VLOOKUP function that pulls the most up-to-date crops. As crops are rotated, the crops assigned to which field are updated annually in a separate table. Another key script is in place to email an editable link to enable a foreman to complete their Google Form responses. These emails include the foreman's name and the field in the subject line to reduce the confusion when multiple Google Forms are filled out in quick succession. There are two additional scripts, one that emails a list of uncompleted entries weekly (to ensure that all entries have been completed once started) and another that moves the data into an archive worksheet. Once the data is processed, the archived data is synced from Google Sheets to Microsoft Excel, and the dashboards are updated in the Excel Workbook.

As a critical component of the system, the link to CIMIS data merits a much more in-depth discussion of its significance to the overall EMS. CIMIS is a program under the California Department of Water Resources tasked with maintaining and storing data from over 145 weather stations in California to assist irrigators in managing their water resources. The water subsystem will combine the client and CIMIS data to automate the calculation of the farm's actual evapotranspiration (ETc). The CIMIS data serves as a baseline for required water use levels, and the dashboards can show this by linking it to crop data. The CIMIS data provides reference values that can be converted to values specific to the

Figure 3

Water Irrigation Google Form



client's crop data, allowing the EMS dashboards to compare the amount of water required to replace water lost through evapotranspiration. According to the CIMIS (n.d.), evapotranspiration is the water lost by a plant due to evaporation from the soil as well as transpiration from the plant itself. The amount of water loss depends on plant type, foliage density, plant height, and soil quality which are difficult to measure precisely. Thus, a standardized measurement is necessary. This measurement is known as reference evapotranspiration (ETr) and is a calculation derived from a standardized field of grass or alfalfa surfaces near a CIMIS reference station that records additional data such as weather, wind, and solar radiation. This data is provided by CIMIS on an hourly or minute-by-minute basis for each of its stations.

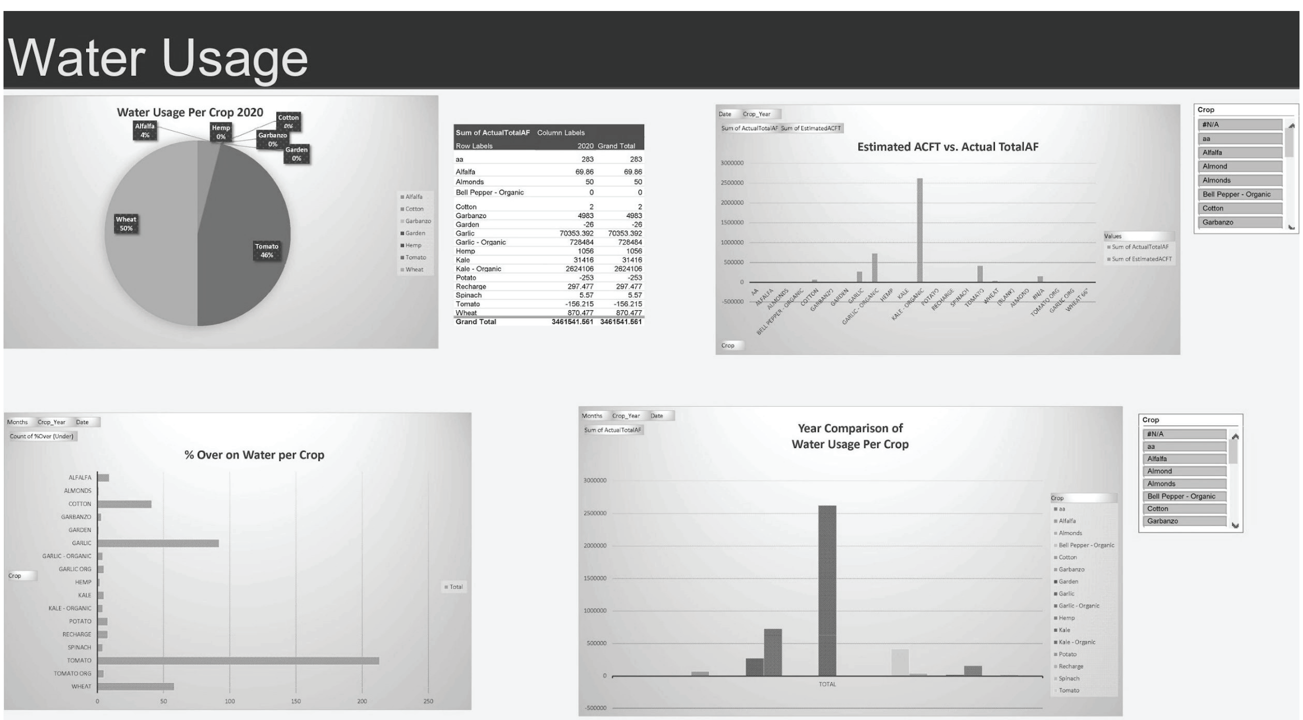
CIMIS data enables an irrigator to convert a standardized, reference evapotranspiration measurement to an actual evapotranspiration (ETc) for a specific crop using crop factors, namely crop coefficients (Kc). The client must currently manipulate the data manually, and the conversion requires several steps. The goal is to automate this process. The ETr values were obtained from the California Irrigation Management Information System (CIMIS) via an API. Once the data is accessed, it is converted from a JSON format into a more easily manipulable format. The ETr value is then multiplied by the Kc for the crop in question at its stage of growth to calculate the final ETc. Lastly, the ETc data is entered into the Microsoft Excel dashboard to be used as a baseline.

Data analysis is the third phase. Data is transferred, in real-time, ensuring that the client has up-to-date water usage and comparisons. The dashboards are configured to display actual water versus budgeted water in various scenarios, such as water usage per crop. An example dashboard visual is shown in Figure 4. Furthermore, a higher-level view of water usage can be analyzed through visualizations of the total amount of water estimated, used, and wasted from one year to the next. The automated system with dashboards improves the client's overall water management. The foreman will be able to estimate the required water more accurately for irrigation using visualized historical data. Ordering the correct amount of water at the correct time will lower the farm's costs and prevent overirrigation. Furthermore, timely water ordering can prevent issues with delivery of the water to their fields. Consequently, the farm is better able to meet the standards set by B Corporation and the B Impact Assessment.

These takeaways lead to the fourth phase of Decision

Figure 4

Sample Dashboard with Dummy Data



Making, in which the user can make informed decisions in real-time. For this subsystem of the EMS, end-users can visualize the efficiency of their water usage, see whether their actual water usage exceeds their budgeted water usage, and filter the data by crop and year. Automating the data entry process will provide real-time monitoring of water usage, allowing them to make adjustments before errors occur, such as extreme over or under usage. These insights drive the client's decisions for current or future production and can be reported to stakeholders such as the B Corporation team.

Preliminary Results

The team's deliverable was to create a system to automate the process of collecting and analyzing water usage data. The automated water subsystem collects data from the field and syncs it with the data analysis system to provide real-time access to water sourced from surface water or groundwater. These dashboards provide deeper insights, ensuring that the crops requiring the most irrigation receive it; thus, the dashboards better enable the farm to achieve optimal yields. The dashboard displaying the percentage of water overuse, for example, measures the water allocation per crop. The farm can use this information to determine whether one crop uses more water than another, comparable crop. This insight will aid in achieving an optimal water mixture under rapidly changing conditions such as drought conditions, climate change, and other crop priorities.

The newly developed water use tracking system has been delivered to the client and is in the process of being implemented. The farm earned B Corporation status during the course of the project. It is expected that the EMS will assist in maintaining the certification by monitoring the use of resources and revisiting their objectives. The EMS provides a comparison of water usage across different years, across fields of the same crop in the same year, water usage throughout a single crop year (for all crops), and the actual water used versus the amount the farm estimated from this subsystem.

Discussion

The team demonstrated a practical application of data analytics by developing the EMS to contribute to the sustainable agriculture realm. The insights provided by the system described in this paper may assist farmers in sustainably producing high-quality products. This project models how addressing ecological needs for sustainability can meet the economic needs of producers without jeopardizing society's need for quality produce as suggested by Yunlong and Smit (1994).

Although the primary goal of this project is to assist irrigators in conserving resources such as water, there are additional advantages. The dashboards for this subsystem may provide insights into greenhouse gas emissions, as more groundwater pumped for irrigation necessitates more electricity. This electricity is frequently derived from fossil fuels, which contribute significantly to greenhouse gas emissions. Dashboards such as these will provide insight into agricultural operations and the numerous input factors that affect yield volumes as well as how those operations impact the environment.

Conclusions

A new Environmental Management System for small-scale farms was developed using data analytics. In its current development stage, the EMS monitors water usage. The project was successfully delivered to the client with preliminary results being positive. The farm has earned and is attempting to maintain a B Corporation certification, as described in the paper. With only one EMS subsystem completed (water and irrigation), the team can continue to optimize the data collection, data storage, and data analysis tools to meet any changing requirements. As the data for the current and future crop years are collected, it will be used to update the EMS on an annual basis, then archived for future reference as historical data. Automation and integration of the other planned subsystems to track fertilizer usage, pesticide usage, air and climate impacts, waste management, and impacts upon soil and wildlife will be included in future work. Small-scale efforts, such as this farm's development of a water and irrigation tracking system, are critical to re-aligning the agriculture industry to focus on sustainability.

Sustainability has become a pressing issue across a variety of human activities as a result of climate change, growing populations, and other threats to our resources. Utilizing data analytics and the tools developed for working with large, intricate datasets to make more informed, less wasteful resource allocation decisions is one tool for developing sustainable agriculture practices. Currently, the farm included in the project is seeing improvements from the new processes, tools, and methodology. This system provides a preliminary demonstration of bringing data analytic techniques to agriculture, one that provides a model for others to address sustainability, tackle climate change, and add value to our communities.

References

B Lab. *About B Corporations* (2021a). Certified B Corporation. Retrieved on September 3, 2021, from https://bcorporation.net/about-b-corps

B Lab. *Certification* (2021b). Certified B Corporation. Retrieved September 3, 2021, from https://bcorporation.net/certification

California Department of Water Resources. (n.d.). *Home*. CIMIS. Retrieved January 13, 2022, from https://cimis.water.ca.gov/

Dilley, M. (2005). *Natural disaster hotspots: a global risk analysis* (Vol. 5). World Bank Publications.

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*(1), 234-245. https://doi.org/10.1016/j.gloenvcha.2007.09.002.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., ... & Snyder, P. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570-574. http://dx.doi.org/10.1126/science.1111772

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, *30*, 441-473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Food and Agriculture Organization of the United Nations. (2000). The state of food and agriculture 2000. II. World food and agriculture: lessons from the past 50 years. FAO, Rome. https://www.fao.org/publications/card/en/c/59a00c0c-773f-5128-9783-26f090ce48e2/

Godfray, H. C. J., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Nisbett, N., ... & Whiteley, R. (2010). The future of the global food system. https://doi.org/10.1126/science.1185383

Heinemann, J. A., Abate, T., Hilbeck, A., & Murray, D. (2009). Agriculture at a Crossroads: The Synthesis Report of the International Assessment of Agricultural Knowledge, Science and Technology for Development. https://www.researchgate.net/publication/43174769_Agriculture_at_a_Crossroads_The_Synthesis_Report_of_the_International_Assessment_of_Agricultural_Knowledge_Science_and_Technology_for_Development

Helmer, M., & Hilhorst, D. (2006). Natural disasters and climate change. *Disasters*, *30*(1), 1-4. https://doi.org/10.1111/j.1467-9523.2006.00302.x

Intergovernmental Panel on Climate Change. (2021). *AR6 Climate Change 2021: The Physical Science Basis*. IPCC. Retrieved January 13, 2022, from https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (Eds.). (2007). *Climate Change 2007-Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC* (Vol. 4). Cambridge University Press.

Keeso, A. (2014). Big data and environmental sustainability: a conversation starter. *Smith School Enterprise Environment, Oxford, UK, Working Paper*, 14-04. https://www.smithschool.ox.ac.uk/publications/wpapers/workingpaper14-04.pdf

Kuyper, T. W., & Struik, P. C. (2014). Epilogue: global food security, rhetoric, and the sustainable intensification debate. *Current Opinion in Environmental Sustainability*, *8*, 71-79. https://doi.org/10.1016/j.cosust.2014.09.004

Lioutas, E. D., & Charatsari, C. (2020). Big data in agriculture: Does the new oil lead to sustainability?. *Geoforum*, *109*, 1-3. https://doi.org/10.1016/j.geoforum.2019.12.019

Mohri, M., Rostamizadeh, A., & Talwalkar, A. (2018). *Foundations of Machine Learning*. MIT press.

Pardey, P. G., Beddow, J. M., Hurley, T. M., Beatty, T. K., & Eidman, V. R. (2014). A bounds analysis of world food futures: Global agriculture through to 2050. *Australian Journal of Agricultural and Resource Economics, 58*(4), 571-589. https://doi.org/10.1111/1467-8489.12072

Palmer, T. B., & Flanagan, D. J. (2016). The sustainable company: looking at goals for people, planet and profits. *Journal of business strategy*. Vol. 37 No. 6, pp. 28-38. https://doi.org/10.1108/JBS-09-2015-0095

Raut, R. D., Mangla, S. K., Narwane, V. S., Gardas, B. B., Priyadarshinee, P., & Narkhede, B. E. (2019). Linking big data analytics and operational sustainability practices for sustainable business management. *Journal of Cleaner Production*, *224*, 10-24. https://doi.org/10.1016/j.jclepro.2019.03.181

Ribarics, P. (2016). Big Data and its impact on agriculture. *Ecocycles*, *2*(1), 33-34. https://doi.org/10.19040/ecocycles.v2i1.54

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., ... & Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, *46*(1), 4-17. https://doi.org/10.1007/s13280-016-0793-6

Rosegrant, M. W., & Cline, S. A. (2003). Global food security: challenges and policies. *Science*, *302*(5652), 1917-1919. https://doi.org/10.1126/science.1092958

Saam, K. (2021, March 24). California's water allocations slashed to 5 percent after dry winter. *ABC 7 KRCR*.

Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., & Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Computers & Operations Research*, *119*, 104926. https://doi.org/10.1016/j.cor.2020.104926

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). The trajectory of the Anthropocene: the great acceleration. *The Anthropocene Review*, *2*(1), 81-98. https://doi.org/10.1177/2053019614564785

Smit, B., & Smithers, J. (1993). Sustainable agriculture: interpretations, analyses and prospects. *Canadian Journal of Regional Science*, *16*(3), 499-524.

Song, M., Cen, L., Zheng, Z., Fisher, R., Liang, X., Wang, Y., & Huisingh, D. (2017). How would big data support societal development and environmental sustainability? Insights and practices. *Journal of Cleaner Production*, *142*, 489-500. https://doi.org/10.1016/j.jclepro.2016.10.091

Sustainable Business Network. (n.d.). *Why should my business become more sustainable?* Retrieved June 9, 2021, from https://sustainable.org.nz/guide-to-sustainability/

Sustainable Business Network. (2014, Feb 09). *Nine reasons to make your business more sustainable.* Retrieved June 9, 2021, from https://sustainable.org.nz/sustainable-business-news/nine-reasons-why-you-should-make-your-business-more-sustainable

Tahat, M., Alananbeh, K., Othman, Y., & Leskovar, D. (2020). Soil health and sustainable agriculture. *Sustainability, 12*(12). https://doi.org/10.3390/su12124859

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences*, *108*(50), 20260-20264. https://doi.org/10.1073/pnas.1116437108

Tubiello, F. N., Soussana, J. F., & Howden, S. M. (2007). Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19686-19690. https://doi.org/10.1073/pnas.0701728104

United Nations Development Programme. Bureau for Crisis Prevention. (2004). *Reducing Disaster Risk: A Challenge for Development-a Global Report*. United Nations. https://www.undp.org/sites/g/files/zskgke326/files/publications/Reducing%20Disaster%20risk%20a%20Challenge%20for%20development.pdf

WCED, S. W. S. (1987). World commission on environment and development. *Our Common Future*, *17*(1), 1-91.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming–a review. *Agricultural Systems*, *153*, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Yunlong, C., & Smit, B. (1994). Sustainability in agriculture: a general review. *Agriculture, Ecosystems & Environment*, *49*(3), 299-307. https://doi.org/10.1016/0167-8809(94)90059-0