University of California, Davis

Sustainability at Russell Ranch
Carbon Footprint Analysis Report

Claire Halbrook
Richard Lee
Malak El Dirdiry
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Dr. Kurt Kornbluth
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We could not have done this without all of you.

Introduction

Background

The UC Davis Agricultural Sustainability Institute (ASI) operates the 300-acre Russell Ranch Sustainable Agriculture Facility in West Davis, California. Researchers at Russell Ranch have measured the long-term impacts of crop rotation, farming systems, and inputs of water, nitrogen, carbon, and other elements on agricultural sustainability for over 23 years. Russell Ranch is home to 72 one-acre plots, a quarter-acre barn, an air-conditioned sample storage facility, dedicated irrigation plots, and other larger plots for scale-up research. The ranch operates a variety of agricultural machines that run on electricity and fossil fuels including, two well pumps, two air-conditioned portable buildings, several tractors, trucks, ATVs, and various machine shop equipment.

Project Description

Russell Ranch has an ongoing mission to increase the sustainability of its operations and serve as a demonstration farming facility. While countless studies of specific farming practices have taken place on the farm, prior research has not endeavored to develop a holistic understanding of the farm's total greenhouse gas emissions. To address this gap in the existing literature, our team partnered with Russell Ranch's Director Dr. Kate Scow and Facility Manager Israel Herrera to collect data and create a tool capable of calculating the farm's carbon footprint. As part of this project, we agreed to provide the following deliverables:

1. Compile data about emissions sources on the ranch,
2. Provide a carbon footprint analysis of the baseline condition,
3. Identify relevant opportunities to reduce energy use and emissions, and
4. Analyze the feasibility of each recommendation.

This paper, along with the accompanying Excel model, is a means of providing each of these deliverables.

As can be seen in Figure 1 below, Russell Ranch's position as a research farm means that it grows several types of crops, including corn, tomatoes, wheat, and alfalfa. Water and nitrogen are supplied to these plots in a variety of ways as well. This means that each plot's carbon footprint is unique. This complexity, combined with time and data constraints led our team to modify the scope of the carbon footprint analysis. Following conversations with the client, we decided to compare two types of corn/tomato plots, both with and without cover crops. There are five one-acre tomato/corn plots with cover crops and seven without. These crops are grown in two-year rotations but we provide carbon intensity data for individual years as this is simpler for the reader and more consistent the methodology used in existing literature. With additional time and data, our carbon calculator could be used to calculate the farm's entire carbon footprint.

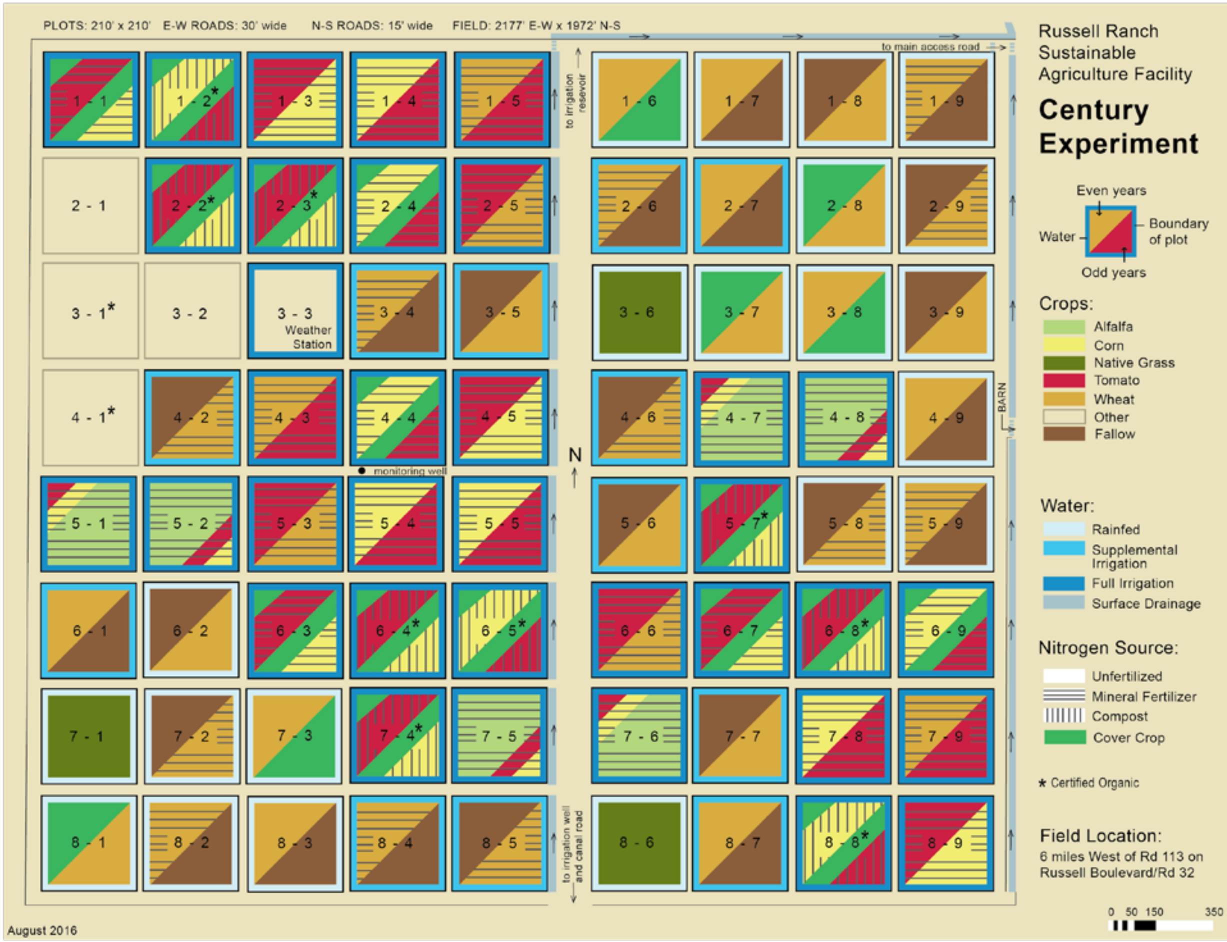

Figure 1: 72 one-acre plots at Russell Ranch, broken down by crop type, irrigation method, and nitrogen source

Methodology

For this project we compared a corn/tomato plot without cover crops against a corn/tomato plot with cover crops over two years to complete a full field cycle. In order to compare the carbon footprint of the two plots, we used the UC Davis Climate Action Plan (CAP) [8] as our foundation. We took what the CAP called Scopes 1 and 2, direct and indirect emissions. The classification of emissions sources in our analysis is slightly different than the CAP. Direct emissions were defined as carbon sources which the farm has direct control over: fuel usage, fertilizer, and energy. The other sources were labeled as indirect emissions: Fertilizer production, packaging, storage, distribution, volatilization, and leeching/run-off. It also included pesticides, tillage losses, and carbon sequestration. Note that this work is not a full lifecycle analysis (LCA). With additional time and data, our carbon footprint tool could be used to conduct a more robust analysis of Russell Ranch's carbon footprint.

Data Sources

1. Diesel Consumption

Russell Ranch fuels its tractors on site with conventional diesel, but consumption is not currently tracked. We accounted for tractor diesel usage through a back-calculation based on data from a full cost analysis of farm operations conducted by Deirdre Griffin, Ph.D. candidate in the Soils and Biogeochemistry Graduate Group at UC Davis. This back-calculation used the fuel rate ($/acre) to calculate fuel usage (gallon/acre). All fuel was assumed to be diesel priced at $4.00 per gallon. This methodology only accounts for diesel consumption associated with farming operations and does not include diesel and gasoline usage in trucks and ATV's (e.g., staff moving around the farm).

2. Electricity

Russell Ranch consumes electricity to run its two well pumps (90- and 62-kW) and to light and cool its on-site office and sample storage spaces. The buildings' electricity consumption was determined using meter data from Pacific Gas and Electric Company (PG&E). This total electricity consumption was then divided equally amongst 67 of the 72 plots due to only 67 having crop rotations. Since each crop uses different quantities of water, we felt an methodology was needed to calculate well pump energy consumption by plot. We began with drip irrigation data taken from the Russell Ranch database to calculate the amount of water used by each crop on the farm. We then took cost data from Deirdre Griffin's study, which suggests the farm spends $90 per acre foot of water. Using that figure, combined with the specific $/kWh for each month of the irrigation, the analysis can calculate the respective energy used to pump the water utilized in each crop rotation.

To find the carbon intensity of electricity consumed, we used the PG&E 2009-2013 average emission factor of 457 lbs CO_2 / MWh.[i] While this average emissions factor fails to account for the increasing number of clean generation sources supply electricity to California, it better accounts for the impact of drought years on the emissions intensity of California's grid. It therefore is a better representation of an "average year" than selecting any two specific years.

3. Fertilizer

Due to the high emissions rates associated with fertilizer production, use, and runoff along with well-established literature and calculation methodologies we decided to measure both the direct and indirect emissions associated with fertilizer. According to a recent study, "the current mix of N sources used in North America result in a general GWP coefficient of about 4 kg CO_2 kg^{-1}."[ii] To calculate the direct emissions from managed soils, we followed the approach described by the Intergovernmental Panel on Climate Change (IPCC) [7]. This approach takes the amount of nitrogen put into the soil and uses an emissions factor of 0.01 to calculate the quantity of nitrous oxide (N_2O) emitted. We then used the N_2O global warming potential conversion factors listed both in the IPCC and the UC Davis Climate Action Plan to find the carbon equivalence.

Our indirect analysis explored the emissions associated with three aspects of fertilizer production and use. We began with emissions from the production, packing, storage, and distribution of synthetic fertilizer. To do so, we used a case study which provided estimates of carbon emissions based upon the amount of nitrogen, phosphorus, and potassium applied to the soil (Lal et al 2004). The study approached this through taking an energy approach to quantity of energy used as reported by various case studies. This work has room for improvement and needs specific lifecycle analysis (LCA) data to better calculate the footprint of these processes. We then looked at volatilization which accounts for N_2O emissions from atmospheric deposition of N that evaporates from managed soil. This was estimated using an equation from the IPCC which takes into account the amount of synthetic fertilizer applied to soils. We used the advised factors of 0.1 and 0.01. The final step was to examine the GHG emissions associated with fertilizer leaching and run-off. This was estimated using yet another IPCC equation. This equation accounts for the amount of synthetic fertilizer, N, applied to soils where leaching takes place.

4. Pesticides

Our analysis takes into account emissions produced during the production, packaging, storage, and distribution of fertilizer. We leverage a case study that provides estimates of carbon emissions based upon the main ingredients in a number of commonly used pesticides (Lal et al 2004). This area of our analysis would benefit from additional work. LCA data and a breakdown of the ingredients in the specific pesticides used at Russell Ranch would help further refine our analysis.

5. Tillage Losses

While tilling soil is a necessary part of any farm’s operations, this practice is yet another source of GHG emissions. Turning soil releases sequestered carbon. Our analysis calculated emissions released during tillage by using an online tool called COMET Farm [10]. This tool is a GHG accounting system and also provides estimates as to how much carbon is lost through farm operations. [10] Unfortunately, the amount of GHG emissions released during tillage is very site specific. This area of our analysis would benefit from additional research at Russell Ranch. An experiment measuring the flux rates of notable gasses before and after tillage could provide valuable data.

6. Carbon Sequestration

Russell Ranch does not currently measure the amount of carbon sequestered by crops and soils. This absence of data limits not only the extent to which we can incorporate the benefits of sequestration, but also constrains the analysis of the losses associated with tillage processes. To account for the benefits of carbon sequestration, we leveraged work performed by Deirdre Griffin which found that using cover crops sequestered .1109 tons C/acre more than fields that did not use cover crops. To account for the extra sequestration, the footprint for fields with cover crops have had this amount subtracted from their footprint.

Results

The major contributors to the overall carbon footprints of both plot types were electricity consumption (from water pumping), fertilizer, and tillage. Diesel consumption also played a significant role in some cases. We also learned that the cover crop rotation has a lower overall footprint due to less fertilizer usage and the benefits of additional carbon sequestration.

Corn/Tomato Plots without Cover Crops

Each of these plots had a footprint of approximately 1600kg CE per year. For comparison's sake, that's about the equivalent of the emissions produced by driving 14,000 miles in the average American passenger vehicle.[iii] The top three contributors to the overall carbon footprint were energy (including the building partition) at 32%, fertilizer (direct and indirect) at 27%, and tillage losses at 25%. Additionally, we found that the corn crops had a higher carbon intensity than the tomato crops. The corn crops, not including building energy use, had a footprint of 825kg CE per year. Unlike the plot as a whole, the largest sources of emissions for the corn crops were tillage losses at 30%, energy (no building) at 28%, and fertilizer at 30%. The tomato crop (not including building energy use) had a footprint of 690 kg CE per year. The primary contributors to the tomato crop's carbon footprint were energy (no building) at 28%, fuel usage at 24%, and fertilizer (direct and indirect) at 25%. These results further highlight the need to include crop-specific data when calculating the carbon footprint of Russell Ranch and any other diverse farms.

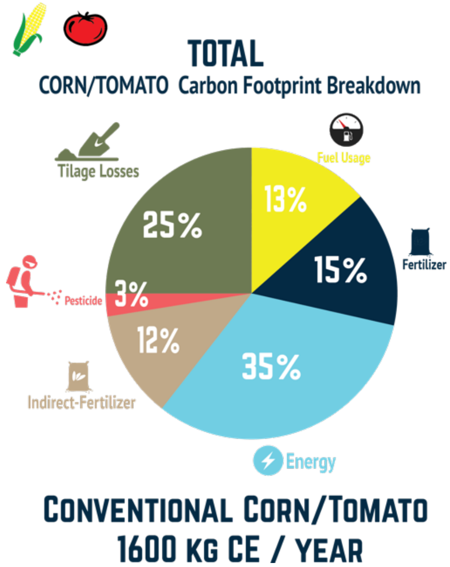

Figure 2: Carbon Intensity of Corn/Tomato Plots without Cover Crops

<u>Corn/Tomato Plots with Cover Crops</u>

The corn/tomato plots with cover crops were less carbon intensive than those without, coming in at approximately 1,500kg CE per year per plot. Cover crops utilize less fuel due to the additional benefits to the soil. This reduces the need for both tillage and fertilizer use. Cover crops increase water retention from higher soil organic matter, and also potentially higher yields.

The top three contributors to the overall carbon footprint were energy (including the building partition) at 36%, tillage losses at 23%, and fuel usage at 16%. The corn plots with cover crops (not including building energy use) each had a footprint of 700kg CE per year. The primary emission sources were energy (no building) at 38%, tillage losses at 29%, and fertilizer at 22%. The tomato crops with cover crops (not including building energy use) had a footprint of 800kg CE per year. The top emission sources fertilizer at 43%, energy (no building) at 23%, and fuel at 20%.

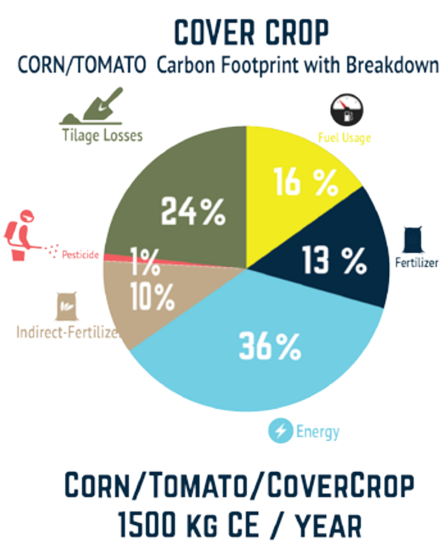

Figure 3: Carbon Intensity of Corn/Tomato Plots with Cover Crops

Carbon Footprint Reduction Strategies

Based on the plots we studied, it appears that activities to reduce the consumption and carbon intensity of electricity, fertilizer, and diesel would have the greatest impact on Russell Ranch's carbon footprint.

Increase Use of Cover Crops

Because those plots with carbon crops emitted approximately 100 kg CE per year less than those without, it seems like adding cover crops to more of Russell Ranch's plots is a clear way to reduce the farm's carbon footprint. Russell Ranch currently applies cover crops to 21 of their 72 one-acre plots. Switching to cover crops could possibly reduce the farm's emissions by over 5,000 kg CE per year. That is the equivalent of displacing the emissions of four passenger vehicles each year.[iv] However, cover crops do have a few drawbacks. They represent an additional procurement cost to the farm and also increase operational costs like labor and equipment. Research from Deirdre Griffin suggests that cover crops can increase the annual costs of growing tomatoes by over $27,000.[v] Nearly half of this cost comes from an increase in equipment rental. Another concern of note is that cover crops require additional irrigation during growing seasons.

Use Digestate from On-campus Digester to Replace Synthetic Fertilizer

UC Davis currently operates an anaerobic digester on the site of its former campus landfill. The system converts 50 tons of organic waste to 12,000 kWh of renewable electricity each day using state-of-the-art generators. In doing so, the digester diverts 20,000 tons of waste from local landfills each year.[1] Along with electricity, the digester produces 13,500 gallons of digestate a day. Digestate is the mix of liquid and solid material that remains after organic waste has been digested. The campus currently sends the digestate offsite at a cost of $250,000 annually. A number of recent studies suggest that digestate can replace synthetic fertilizer due to its high nutrient content.[1, 2] It is even possible that using digestate to fully replace or partially offset synthetic fertilizer could result in net-negative emissions, meaning that this source of fertilizer reduces more emissions than it produces.[vi] This is because the digester itself is already acting as an alternative use for organic waste than a landfill and produces clean energy. The digestate is simply a byproduct of an already low-carbon process. It could also reduce the costs the campus incurs by sending less of the digestate off site.

To reduce its carbon footprint, Russell Ranch might consider using some of the digestate produced by the digester in the farm's drip irrigation system. Our team is aware that Dr. Kate Scow and Dr. Rui Zhang recently explored this possibility, but the results of their research have not yet been published and it is our understanding that they explored benefits outside of carbon. We are already aware of a number of hurdles including increased labor, transportation of the digestate, and the potential for the digestate to clog the drip system. Offsetting the carbon emissions associated with fertilizer use could reduce the farm's emissions by 25%.

Use Compost from On-campus Compost Bins to Replace Synthetic Fertilizer

The 11,000 tons of organic waste that UC Davis currently diverts from landfills would produce 4,500 tons of cured compost yearly. This amount of compost could be used to treat an area of up to 1,500 acres, far larger than entirety Russell Ranch. The compost is currently sent offsite where the campus incurs a tipping fee of $60 per ton at the Yolo County Composting Facility, that is over $500,000 each year. Recent Research out of the Marin Carbon Project found that cured compost not only reduces upstream carbon emissions associated with the manufacture of synthetic fertilizer, but it also sequesters carbon better than manure and synthetic fertilizers. Like digestate, compost can have a net-negative carbon impact because it sequesters more carbon than it emits over its lifetime—approximately one ton per acre each year.[vii] Applying compost to fields reduces the amount of water needed to irrigate a crop and thus the energy associated with pumping that water. It can also reduce the amount of fertilizer needed. Offsetting the carbon emissions associated with fertilizer use could reduce the farm's emissions by 25%.

Like each of our carbon reduction strategies, applying compost is not without its challenges. First, the compost must be processed. This adds additional costs and increases emissions from transportation and the processing itself. Fortunately, this can be performed at two local sites, Zamora and Yolo County Landfill. We also understand that UC Davis is considering installing its own on-site composting facility. If the campus pursues this option, many of the hurdles associated with applying compost to the plots at Russell Ranch could be significantly mitigated. It should also be noted that the Marin study focused on rangeland. The carbon impact of compost application may vary due to the specific weather, crops, and soil health at Russell Ranch. It is unclear whether the impact would be less or greater.

Use a Biodiesel Blend to Fuel Tractors

Approximately 100 vehicles operated by UC Davis Fleet Services run on B20 biodiesel, a blend of 80% petroleum diesel and 20% biodiesel.[2] Russell Ranch on the other hand fuels its vehicles on-site with conventional diesel. B20 is a common blend because it can be used in conventional engines without needing any modifications. According to the U.S. Department of Energy (DOE), engines operating on B20 "have similar fuel consumption, horsepower, and torque to engines running on petroleum diesel."[3] UC Davis uses a carbon intensity of 10.21 kg CO_2/gallon for diesel and 9.45 kg CO_2/gallon for its B20 blend. 10.5% reduction in carbon emissions associated with diesel consumption. Data from DOE suggests that the national average price of B20 is actually 6 cents/gallon cheaper than conventional diesel.[4] We have heard some concerns about whether older tractors can really tolerate diesel blends, but Russell Ranch is currently planning to replace all of its tractors for which this could be an issue.

Install On-site Solar

Installing on-site solar that could meet or exceed Russell Ranch's annual electricity demand could offset over 74,000 kg CE per year, over a third of the farm's carbon footprint. Russell Ranch consumed 2,660 kWh in the two years from 2014 through 2015 at an average cost of 18.6 cents/kWh, about $500 per year. Compare this to the seven cents/kwh UC Davis pays for the electricity produced from its on-site solar farm. Given the scale and conventional technology of the current campus solar farm, it is likely that Russell Ranch would pay more for its own solar installation, but it seems unlikely that it would pay 11 cents/kWh more. However, owning the system could cost upwards of $200,000 according to a quote from SunRun. Given Russell Ranch's low electricity bill, the economics of ownership probably do not make sense. One of the other teams in our course is conducting a deeper dive into the potential for installing solar at Russell Ranch. We refer you to their work for more on this possibility.

Install a Rainwater Catchment System

There are many benefits to rainwater catchment. Rainwater can be used in multiple applications, including gray water for the farm buildings for purposes such as flushing toilets and washing tools. It also can be used for irrigation or groundwater recharge, but only after being filtered. The potential quantity of collectable rainfall can be measured using the following equation: "roof area (m2) x run-off coefficient x filter efficiency factor x annual rainfall (mm)." [15] Based on that number you can estimate the type and size of storage tank needed. Some storage tanks come equipped with filters designed for collecting rainwater that will reject the first flush from the roof so there will prevent dirt and other substances from entering the tank.

The advantages of a rainwater tank system is that it is low cost. If the team at Russell Ranch were to elect to build their own system, the costs would be $20-$50 if using a standard tools, a 40-80 Gallon plastic barrel or drum, and PVC piping. Note that this excludes labor costs. However, it will likely be more efficient to install a prefabricated rain barrel which would cost between $70 and $300, depending on the tank size and amount rainwater collected. Collected rainwater can also reduce floods, reduce the use of groundwater and associated pumping, and reduce water bills as it can be suitable for non-potable water functions.

Evaluation Matrix

To evaluate the carbon reduction strategies listed above, we created the following matrix which ranks the strategies on a number of key metrics of importance to the team at Russell Ranch.

GHG Reduction Activity	GHG Impact	Weight	Low Cost	Weight	Collaborate	Weight	Transferable	Weight	Compatible	Weight	Demo-strable	Weight	Total Score
A) Cover Crops	3	3	3	3	5	3	6	2	6	1	4	1	57
B) Digestate	5	3	3	3	6	3	3	2	5	1	3	1	56
C) Compost	5	3	3	3	6	3	3	2	4	1	3	1	55
D) B20	2	3	6	3	2	3	4	2	1	1	2	1	41
E) On-site Solar	6	3	5	3	2	3	2	2	3	1	6	1	45
F) Rainwater Catchment	2	3	6	3	5	3	6	2	5	1	5	1	42

Figure 4: Carbon Reduction Strategies: Evaluation Matrix

The matrix suggests that Russell Ranch should begin to reduce carbon by expanding the use of cover crops. While the GHG impact is more moderate than some of the other options, this strategy can be transferred to the farming community in Yolo County, California, the U.S., and globally. It's also a much lower cost strategy than purchasing a solar installation. Additionally, the team at Russell Ranch is already very familiar with using cover crops so this strategy should prove easier to implement than some of the other options and would likely require little disruption to current operations. Lastly, cover crops are a demonstrable carbon reduction strategy that visitors to the farm can see. This offers an opportunity to engage in dialogue about the carbon and many other co-benefits of using cover crops.

Next Steps

As mentioned above, time and data availability significantly restricted the scope of this project. However, our team was able to build a strong foundation upon which others can build. The team at Russell Ranch can use our carbon footprint tool to create a more complete picture of the farm as a whole, once additional data for the other plots becomes available. The tool could be built out even further to more closely mirror a full lifecycle analysis. An LCA could prove particularly valuable for Russell Ranch as the team weighs various carbon reduction strategies. This is because the LCA could tell the user when a strategy represents a complete net reduction in emissions or whether it simply shifts emissions upstream or downstream in the supply chain. Lastly, Russell Ranch should explore the possibility of small pilot projects for fertilizer replacements, including digestate and compost. Additional information regarding the feasibility, costs, and benefits of synthetic fertilizer alternatives would benefit Russell Ranch and the farming community as a whole.

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Appendix

Table 1. Conventional Corn & Tomato Footprint Summary

Total Summary	
Direct Emissions	kg CE / year
Fuel Usage	219
Fertilizer	239
Energy	515
Total	972
Indirect Emissions	
Fertilizer (indirect)	189
Pesticide	44
Tillage Losses	400
Total	633
Grand Total	1606
Corn Summary	
Direct Emissions	kg CE / Rotation
Fuel Usage	53
Fertilizer	141
Energy (no building)	234
Indirect Emissions	
Fertilizer (indirect)	111
Pesticide	36
Tillage Losses	250
Total	826
Tomato Summary	
Direct Emissions	kg CE / Rotation
Fuel Usage	165
Fertilizer	97
Energy (no building)	192
Indirect Emissions	
Fertilizer (indirect)	78
Pesticide	8
Tillage Losses	150
Total	690

Table 2. Mixed Corn & Tomato w/ Cover Crop Footprint Summary

Total Summary	
Direct Emissions	kg CE / year
Fuel Usage	239
Fertilizer	198
Energy	539
Total	976
Indirect Emissions	
Fertilizer (indirect)	155
Pesticide	15
Tillage Losses	349
Total	519
Grand Total	1495
Corn Summary	
Direct Emissions	kg CE / Rotation
Fuel Usage	73
Fertilizer	101
Energy (no building)	258
Indirect Emissions	
Fertilizer (indirect)	47
Pesticide	7
Tillage Losses	200
Total	685
Tomato Summary	
Direct Emissions	kg CE / Rotation
Fuel Usage	166
Fertilizer	198
Energy (no building)	192
Indirect Emissions	
Fertilizer (indirect)	155
Pesticide	8
Tillage Losses	99
Total	818

Chart 1. Corn/Tomato Crop foot prints

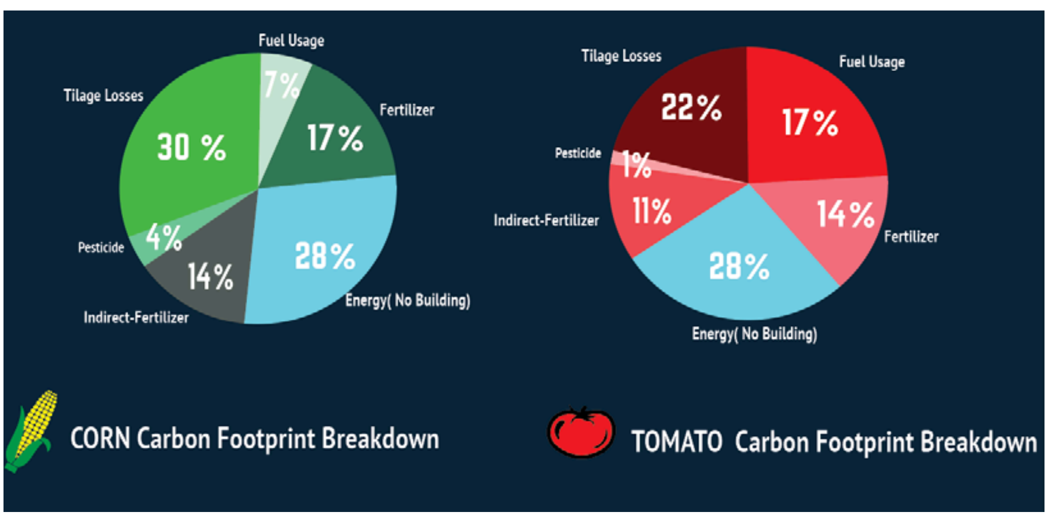
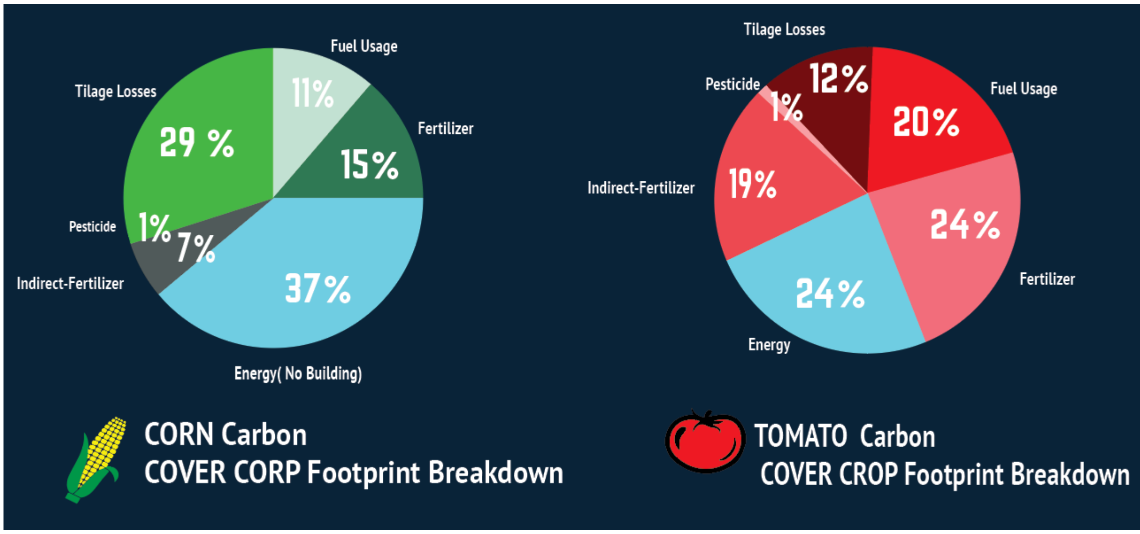


Chart 1. Corn/Tomato COVER Crop Footprint



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