DWR Grant Agreement 4600013458
Sonoma Ecology Center
Pilot Project for Using Biochar to Save Water In California Agriculture

Final Science Report, December 15th, 2021

Field Research conducted byMonterey Pacific Vineyard Management, Pacific Biochar, UCRiverside, and Sonoma Ecology Center

Doug Beck of Monterey Pacific Weighs Grape Clusters Photo: Raymond Baltar

County: Monterey
Appellation: Monterey
Vine Type: Pinot Noir

Executive Summary: Sonoma Ecology Center (SEC) and its several subcontractors initiated the Oasis Vineyard Biochar Field Trial in 2016 to study and document how biochar and compost treatments impact soil water use, soil health, vine growth, harvest yields, and grape quality in a newly planted vineyard outside of King City, CA in the Salinas Valley managed by Monterey Pacific Inc. SEC administered and oversaw this project, funded by the California Department of Water Resources (DWR). Researchers from the University of California, Riverside and Pacific Biochar, as well as the winery that has been using the grapes, provided important support.

This vineyard field trial used several replicates in which biochar and compost treatments were applied separately and in combination during soil preparation activities prior to planting 'Pinot Noir' (Vitis vinifera) vines. We observed significant increases in harvest yield compared to that in control plots for both compost and biochar treatments in all three growing seasons: 2019-2021. The highest overall yield resulted from the compost-biochar mixture. Total combined yields for all three seasons were seen in the compost-biochar plots (21.5 tons/acre) compared to both the biochar alone plots (19.7 t/ac), the compost alone plots (20.1 t/ac). In contrast, the control plots produced 15.8 t/ac combined over all three seasons. Increased pruning weights and higher cluster counts were observed for all compost and biochar treatments. Throughout this field trial all treatment plots received the same irrigation regime, demonstrating improved water use efficiency (fruit yield per unit of water applied) in both the compost and biochar treatment areas.

Grape bunches from biochar/compost row. Photo: Raymond Baltar

Results from this field research trial indicate clearly that biochar and compost treatments can improve water use efficiency, vine growth, harvest yields and soil health for vineyards newly planted on low organic matter sandy soils. While the data presented here show trends early in the life of this vineyard, clearly ongoing monitoring is warranted to evaluate the results over its entire 20-year production period.

1st year planting of the Oasis Vineyard. Photo: Raymond Baltar

Project Description
Vineyard: Pinot Noir vines planted with 1103P rootstock in Monterey Pacific's Oasis Vineyard located southwest of King City. Vines were planted at 9' by 5' spacing, 968 vines per acre. The vineyard is drip irrigated, with mechanically box-pruned sprawl on a high cordon trellis system.

Soil: Soil is variable throughout the hillside plot. Soil type is primarily Oceano Sand at 0.7% organic matter content; other areas could be described as Garey Sandy Loam with the same low level of organic matter.

Soil Preparations Done Pre-Planting: In early 2017, soil amendments were applied before planting in a ripped delve down the vine row using GPS, then mixed with a winged plow to a depth of 30 inches in a 'bowl' approximately 2 feet wide by 2.5 feet deep. This resulted in approximately 25 cubic feet of cultivated and amended soil per vine (2' deep by 2' wide and 5' spacing per vine) Biochar/compost distribution in the soil after mixing was not completely uniform, but of slightly varied concentrations within this treated area due to inability to mix completely.

Soil preparation activities prior to planting. Photo: Doug Beck

The biochar as applied (10 tons/acre wet weight) is equivalent to a 0.42% SOM increase in the planting row. The compost as applied (15 tons/acre wet weight) is equivalent to a 0.30% SOM increase in the planting row. (See Fig. 1 below for calculations.)

Fig. 1

%OM Calculations for Vineyard Treatments						
Cultivated Area_ Soil Volume and Weight						
Cu ft / vine	vine / acre	cu ft / acre	cu yd / acre	soil density g/cm	soil density ton/cy	tons soil/acre
25	1089	27225	1008	1.3	1.10	1104.64
Biochar Application Rate_ Ton/acre Input, %OM Output						
	biochar applied (wet ton)	biochar moisture %	biochar applied (dry ton)	biochar OM content	tons OM applied	% SOM achieved
Biochar	10.00	38%	6.18	74.50%	4.60	0.42%
Compost Application Rate_ Ton/acre Input, %OM Output						
	compost applied (wet ton)	compost moisture %	compost applied (dry ton)	compost OM content	tons OM applied	% SOM achieved
Compost	15.00	49%	7.70	42.50%	3.27	0.30%

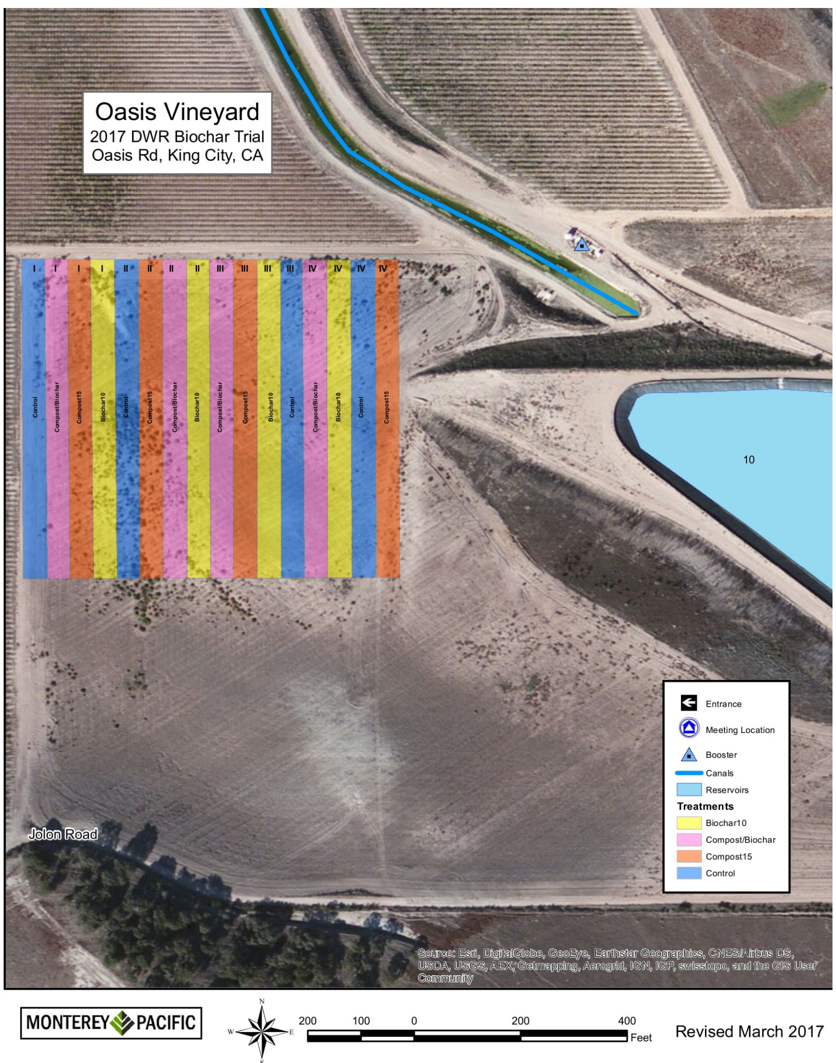
Descriptions of the Biochar and Compost Soil Amendments Used:

Biochar: Provided by Pacific Biochar. Made from softwood forestry residues, fired at 750C. Organic matter (dry) 74.5%, ash content (dry) 25.5%. NPK as delivered: 0.69, 0.6, 2.4. pH 10.5 carbonates (as $CaCO_3$ equivalent) 14.22%. Moisture content 38.2%. Bulk density (as delivered) 4.3 cubic yards per ton (17.1 lbs./cu.ft). Particle size ¼" minus. Biochar price ~ $240 per ton as delivered.

Compost: Provided by Keith Day Company. Described as a blend of spent mushroom compost, green material, and grape pomace. C/N ratio 14. NPK as delivered: 0.79, 1.9, 4.1. Organic matter (dry) 42.5%, ash content (dry) 57.5%. pH 7.9, carbonates (as $CaCO_3$ equivalent) 6.5%. Moisture content 48.7%. Bulk density (as delivered) 1.8 cubic yards per ton (41 lbs./cu.ft). Particle size ⅜" minus.

Treatments Applied:
All treatments were applied at depth down the planting rows (delved, as described above)
Control Plots: 0 tons/acre compost, 0 tons/acre biochar
Biochar 10 Plots: 0 tons/acre compost, 10 tons/acre biochar
Compost 15 Plots: 15 tons/acre compost, 0 tons/acre biochar
Compost + Biochar Plots: 15 tons/acre compost, 10 tons/acre biochar. Prior to application, biochar was thoroughly mixed with the compost windrow then left to continue composting for nearly a month. This enabled the biochar to become charged with biology and nutrients from the compost.

Plot Design: The trial was set up and conducted as a complete randomized block design with 4 replications in an 8-acre portion of a 20-acre block being planted to commercial wine grapes.



Graphic Courtesy Doug Beck, Monterey Pacific

Methods Used

Cluster Counts: Early data on the number of inflorescences were obtained after fruit obtained from every 10th vine, with a total of 10 vines per plot counted. Clusters were also counted and averaged from the 20 vines harvested in each subplot.

Pruning Weight: During dormancy, data on the weight of pruned vines were obtained from every 10th vine, with a total of 10 vines per subplot counted. These data were measured only after the 2019 season.

Fruit Weight: At harvest, data on the weight of fruit per vine was obtained from every 5th vine, with a total of 20 vines per subplot counted.

Fruit Quality: In 2020 all subplots were evaluated for treatment effects on grape quality components using the ETS commercial lab. 300-berry samples from each subplot were collected from clusters collected for yield calculations.

Soil Health: In May 2021, all subplots were evaluated for soil health parameters at the Regen AgLab (a commercial facility). Samples were bulked as 20 cores taken 2” - 6” depth from each subplot, subsampled and shipped.

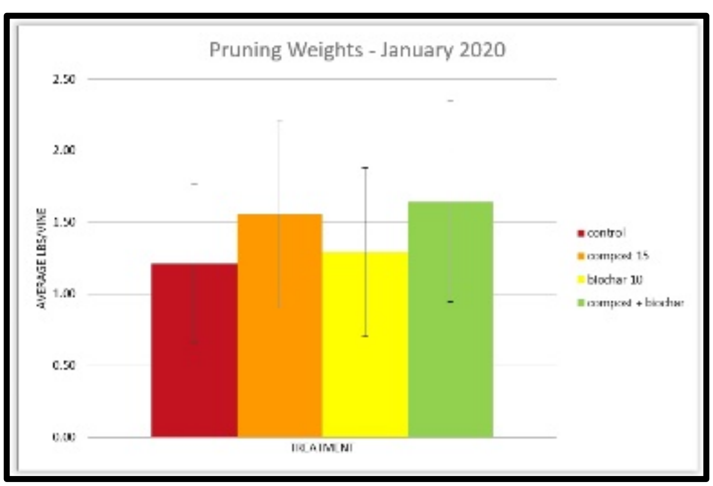
Vine Vigor: Plant vigor of the entire field was measured using aerial imagery in 2019-21, using data collected by VineView and represented as an Enhanced Vegetation Index (EVI). EVI is described by VineView as: “Our calibrated vine vigor data product created using the Enhanced Vegetation Index, a ratio of how much sunlight is reflected off the plants in different color bands, including infrared...Using additional wavelengths of light, we are able to correct the errors associated with NDVI.” VineView was used in 2020 to statistically evaluate individual subplots.

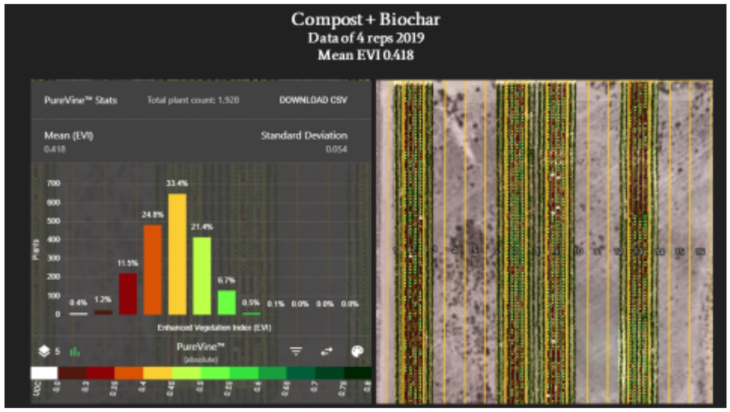
Moisture Sensors: Two Watermark sensors were installed in each subplot on February 1, 2018; one at 18-inch depth and the second at 30-inch depth. These sensors were hard-wired with their wires running through PVC pipes buried 2 ft. deep. Soil moisture data were recorded with four Watermark 9000 loggers.

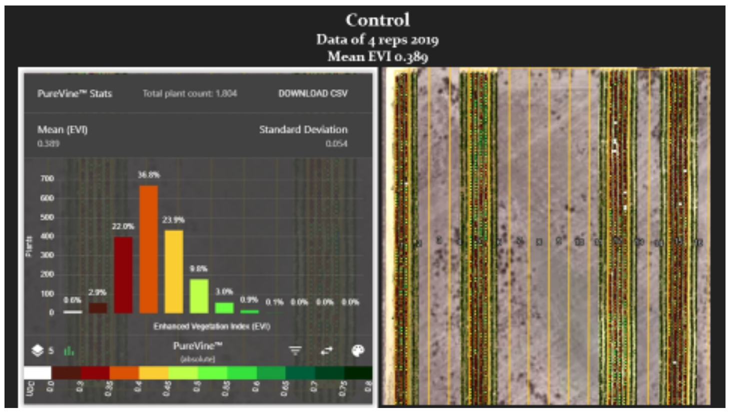
Results Obtained

All values reported are averaged over 4 replicates. All treatments and blocks received identical irrigation and fertilizer inputs.

Vine Growth: Pruning weights were taken in January 2020, to determine effects on vine growth. Because of the large variability in vines, while the differences seen at this time were not significant the compost and compost-biochar treatments both clearly produced the biggest vines. Aerial images from August 2019 showing EVI confirmed this, with the compost-biochar treatment giving highest vine vigor.







Vine Yields: No differences in cluster size/weight were seen in 2019 or 2020, but cluster numbers did differ and accounted for the yield differences in those two seasons (Yield Chart 1). The biochar treatment plot had the highest number of clusters in 2019, whereas the compost-biochar mix area had the most clusters in 2020. More clusters look to be the result of larger more vigorous vines. In 2021, poor weather conditions at and after fruit set reduced yields as compared to the high 2020 values. Yet 2021 again highlighted the value of the biochar-compost mixture plots, which showed the highest yields this season resulting from more and larger clusters (Yield Chart 2).

Harvest yield data taken during the first harvest showed 32%, 45%, and 27% yield increase in the compost, biochar-only, and compost-biochar treatments, respectively. The biochar only treatment plot, which showed a yield increase of approximately 1.3 tons/acre plot (45%) over the control was particularly interesting. Vine vigor however, was observed to be highest in the compost-biochar treatment plot, a trend that did not correlate with higher yield in first harvest but appears likely to have set the stage for greater yields in later harvests.

In the second production year (2020) the trial harvest average increased to 10.2 t/ac compared to 3.7 t/ac in 2019. In this season, all three treatment plots showed increased yields over the control -- by 22% for compost-biochar, 20% for biochar only, and 12%, for compost only. During this harvest collection period fruit was gathered for quality analysis, as discussed below.

The third production year experienced poor weather during and after fruit set, with yields in 2021 greatly decreased from the previous year. Average trial yield in 2021 was only 5.3 tons/acre, with the control yielding only 3.8 t/ac as contrasted with the best trial compost-biochar treatment producing 6.7 t/ac. In this season, all three treatment plots showed increased yield over control:

74% for compost-biochar areas; 40% for compost only, and 39% for biochar only. Biochar alone increased yields again by 1.5 tons/acre over the control while compost-biochar increased yields by 2.8 tons/acre.

Yield Chart 1

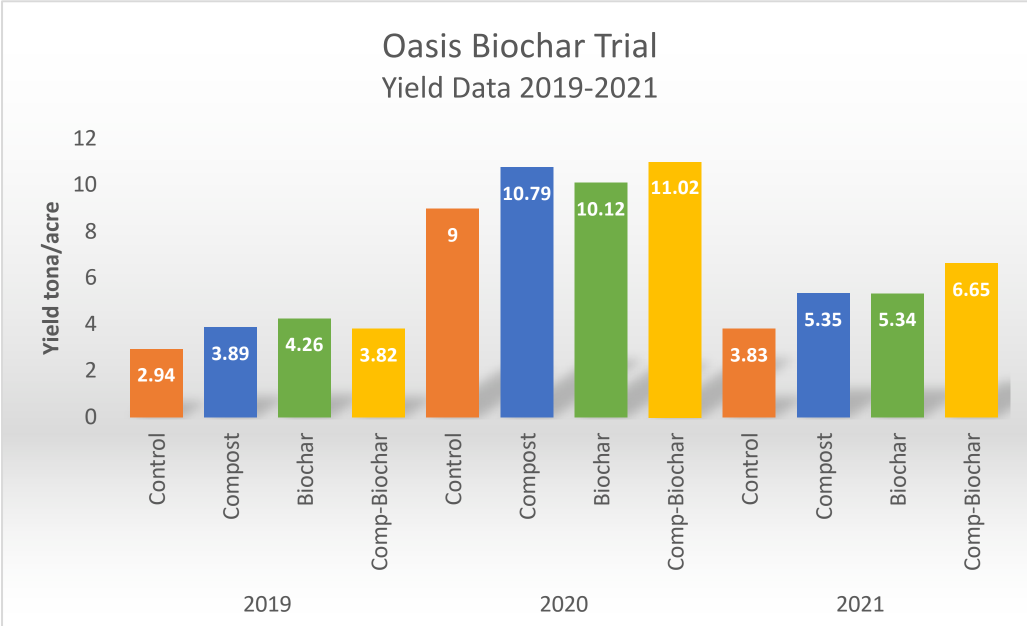
Harvest 2019 3rd Leaf	Yield	Cluster #	Cluster lb
R1	2.78	26.40	0.31
R2 Control	3.73	28.70	0.27
R3	2.82	23.10	0.25
R4	2.42	26.30	0.31
Control Average	**2.94**	**26.13**	**0.29**
R1	4.04	30.60	0.27
R2 Compost	3.30	27.10	0.25
R3	4.20	33.20	0.26
R4	4.02	27.60	0.30
Compost Average	**3.89**	**29.63**	**0.27**
R1	3.94	28.50	0.29
R2 Biochar	4.90	39.60	0.26
R3	3.63	27.30	0.28
R4	4.55	33.30	0.28
Biochar Average	**4.26**	**32.18**	**0.28**
R1	3.78	26.80	0.29
R2 Compost + Biochar	3.58	24.40	0.30
R3	3.83	36.90	0.21
R4	4.08	31.50	0.27
Compost-Bio Average	**3.82**	**29.90**	**0.27**

Harvest 2020 4th Leaf	Yield	Cluster #	Cluster lb
R1	9.22	54.60	0.31
R2 Control	10.12	53.95	0.34
R3	8.66	46.60	0.34
R4	8.00	41.85	0.35
Control Average	**9.00**	**49.25**	**0.34**
R1	10.37	55.25	0.34
R2 Compost	10.72	54.30	0.36
R3	11.39	62.60	0.33
R4	10.68	54.45	0.36
Compost Average	**10.79**	**56.65**	**0.35**
R1	10.71	57.00	0.34
R2 Biochar	10.79	57.40	0.35
R3	10.72	58.50	0.34
R4	8.27	45.55	0.33
Biochar Average	**10.12**	**54.61**	**0.34**
R1	11.21	58.80	0.35
R2 Compost + Biochar	10.23	55.15	0.34
R3	13.09	65.10	0.37
R4	9.57	49.85	0.35
Compost-Bio Average	**11.02**	**57.23**	**0.35**

Yield Chart 2

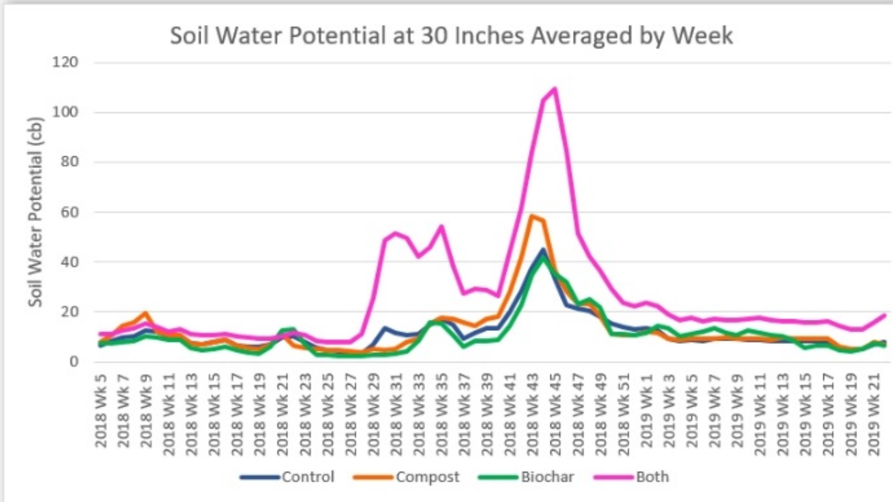
Harvest 2021 5th Leaf	Yield	Cluster #	Cluster lb
R1	2.897	24.45	0.22
R2 Control	3.376	30.25	0.20
R3	4.438	56.15	0.15
R4	4.62	48.60	0.17
Control Average	**3.833**	**39.86**	**0.19**
R1	4.397	33.00	0.24
R2 Compost	3.762	37.60	0.18
R3	6.044	49.65	0.22
R4	7.193	65.85	0.20
Compost Average	**5.349**	**46.53**	**0.21**
R1	4.108	32.30	0.23
R2 Biochar	5.418	45.40	0.22
R3	6.161	52.95	0.21
R4	5.685	50.05	0.21
Biochar Average	**5.343**	**45.18**	**0.22**
R1	4.775	36.50	0.24
R2 Compost+Biochar	6.382	41.00	0.29
R3	7.914	63.80	0.23
R4	7.533	68.30	0.20
Compost-Bio Average	**6.651**	**52.40**	**0.24**

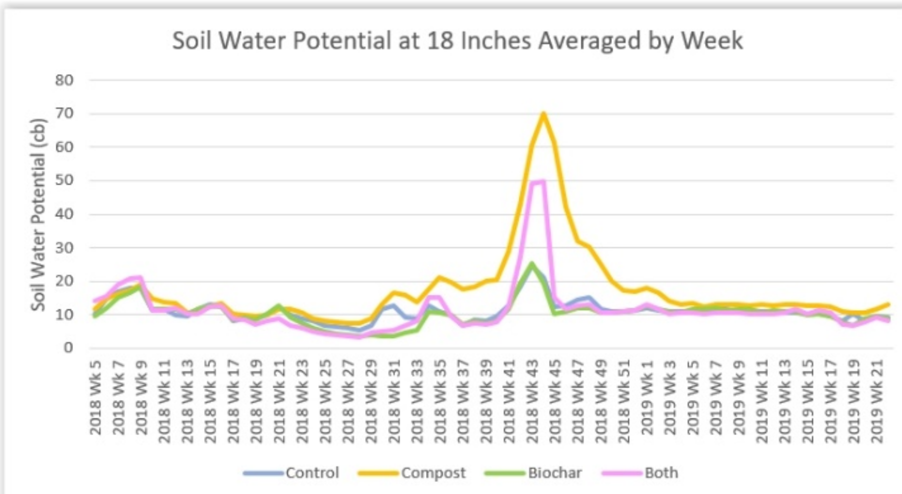
Combined Yield Data 2019 - 2021



Water Use Efficiency: Watermark soil moisture tension sensors were installed at 18 and 30 inches to monitor soil water potential. The main objective of this DWR project was to evaluate water savings from application of compost and biochar, and indeed we did see increased water use efficiency – with more crop produced from the same amount of irrigation - in the amendment treatment plots. All blocks received the same irrigation regime based on ET, with blocks that had drier soils producing more crop comparatively. Bigger vines with more grapes and more leaves had greater transpiration and water taken from the soil. The compost and compost+biochar treatment areas both dried the soil more than did the biochar treatment plots, at levels about equal to the control.

Each line in the figures below represents the average soil water potential for each treatment type over the course of a week in centibar values collected from Watermark sensors from February 1, 2018, to June 4, 2019. Higher measurements indicate drier conditions in the soil. Measurements were taken at both 18 inches (a) and 30 inches (b). Blue lines indicate the unamended control plots, orange lines indicate the compost amended plots, green lines indicate the biochar amended plots, and pink lines indicate the plots amended with both biochar and compost.





Grape Quality: We wanted to confirm that the use of biochar did not have any negative impacts on fruit quality. We therefore analyzed 300-berry samples from each subplot so we could evaluate treatment effects and calculate statistical differences. Samples were tested at ETS Labs for the full phenolic panel plus brix and acidity.

Sugar accumulation (brix) was highest in the biochar only blocks; it was a bit above control plots, but not significantly. Acidity was also increased in the treatment areas receiving biochar, but again not significantly. It is safe to say that there was some effect of biochar on brix and pH.

Adding biochar to the soil appeared to significantly increase berry volume, weight, and sugar-per-berry levels as compared to the control plots. Similarly, color (anthocyanins) and tannins, both positive quality characteristics, were increased in the biochar only treatment areas, at times though not always significantly. All these positive enhancements from biochar treatment are intriguing, and further indicate the absence of any negative impacts from biochar application.

Titratable Acidity			
AVERAGES	mg/L	% difference	ST DEV
Control	6.425	0.00%	0.26
Compost	6.375	-0.78%	0.29
Biochar	6.375	-0.78%	0.33
Com+Biochar	6.25	-2.72%	0.24

Berry Weight			
AVERAGES	g/berry	% difference	ST DEV
Control	1.3675	0.00%	0.02
Compost	1.33	-2.74%	0.05
Biochar	1.3925	1.83%	0.05
Com+Biochar	1.3575	-0.73%	0.02

Polymeric Anthocyanins			
AVERAGES	mg/L	% difference	ST DEV
Control	6.25	0.00%	0.9574
Compost	6.00	-4.00%	0.0000
Biochar	6.50	4.00%	0.5774
Com+Biochar	5.75	-8.00%	0.5000

pH			
AVERAGES	pH	% difference	ST DEV
Control	3.3925	0.00%	0.08
Compost	3.4125	0.59%	0.09
Biochar	3.4275	1.03%	0.12
Com+Biochar	3.4575	1.92%	0.09

Berry Volume			
AVERAGES	ml/berry	% difference	ST DEV
Control	1.1475	0.00%	0.04
Compost	1.185	3.27%	0.07
Biochar	1.24	8.06%	0.08
Com+Biochar	1.15	0.22%	0.03

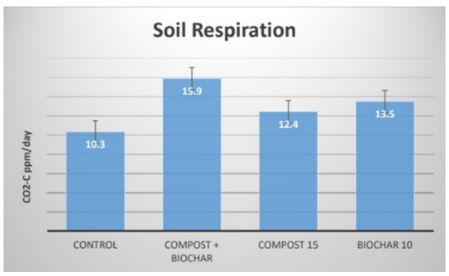
Tannin			
AVERAGES	mg/L	% difference	ST DEV
Control	207.50	0.00%	18.9473
Compost	200.25	-3.49%	18.9978
Biochar	211.75	2.05%	22.3961
Com+Biochar	201.00	-3.13%	20.4124

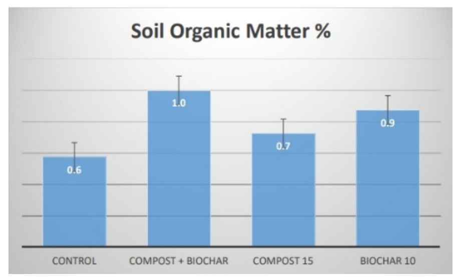
Brix			
AVERAGES	brix	% difference	ST DEV
Control	23.875	0.00%	1.01
Compost	23.35	-2.20%	0.47
Biochar	24.25	1.57%	0.99
Com+Biochar	23.75	-0.52%	0.87

Sugar per Berry			
AVERAGES	mg/berry	% difference	ST DEV
Control	271.5	0.00%	12.48
Compost	273	0.55%	16.15
Biochar	298.5	9.94%	12.79
Com+Biochar	270.5	-0.37%	16.82

Total Anthocyanins			
AVERAGES	mg/L	% difference	ST DEV
Control	627.50	0.00%	63.1057
Compost	628.50	0.16%	15.3514
Biochar	659.75	5.14%	49.5202
Com+Biochar	642.50	2.39%	60.7317

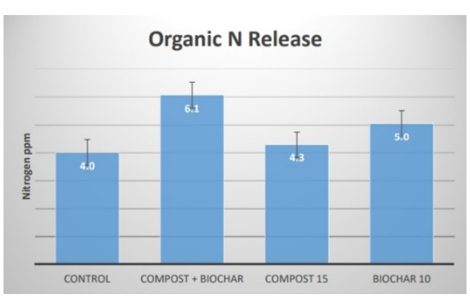
Soil Health: Addition of biochar, either alone or combined with compost, had profound effects on both soil health and nutrient availability. The following charts are indicative of the changes under way in the trial treatment blocks, more than 4 years after amendments were first applied.

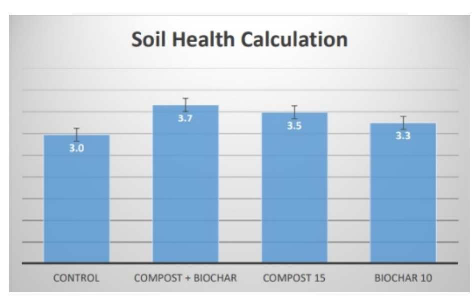




While soil organic matter (SOM) is made up mostly of organic carbon, it also contains many other essential plant nutrients. Clearly the compost-biochar treatment plots provided the most organic matter, but it was surprising that 10 t/ac biochar alone increased SOM percentages more than did compost at 15 t/ac. Additional organic matter produces additional water- and nutrient-holding capacity.

Soil respiration was tracked as ppm CO2-C released in 24 hours by soil microbes after a soil sample had been dried and rewetted. This measure of microbial biomass is related to a soil's potential microbial activity during ideal conditions. Rankings were made as follows: 0-10 Very Low; 11-20 Low; 21-30 Below Average; 31-50 Slightly Below Average; 51-70 Slightly Above Average; 71-100 Above Average; and 101-200 High. Soil in our control plots had very low microbial activity, showing how this soil is microbially-poor. Treatment trends followed the soil SOM % values with compost-biochar and biochar treatments having improved the most.





Soil health scores were calculated as soil respiration divided by 10 plus a weighted organic carbon and organic N addition. This factor summarizes the overall health of a system based on the indicators measured in the test. The score typically ranges anywhere from about 0 to 50, with higher numbers being better. While it is normal to see this number above 7 as a starting point, here we were well below 4! Clearly our organic matter additions improved overall soil health in this Monterey vineyard.

It is impressive that adding biochar alone increased organic N release more than did addition of compost alone, supporting the fact that microbial activity and food substrates for the microbes were increased by biochar even on its own.

Water Savings and Carbon Sequestration: Biochar and compost are valuable sources of soil organic matter. When applied as soil amendments both have been used to improve soil health, water conservation, and crop productivity in agricultural soils. Of particular interest in this vineyard field trial is the synergistic relationship seen between compost and biochar and the related impacts on water use efficiency. Because all treatment areas received identical irrigation, the observed increases in yield, pruning weight, and clusters were all achieved without additional irrigation. In fact, the soil water potential data show that soil moisture remained relatively unchanged between treatment types, with the sole exception of the compost + biochar treatment tests at 30-inch depth. This is consistent with growth data because vigorous vines with larger root systems, as observed in the compost + biochar treatment plots, tend to pull more water from the surrounding soil.

GHG Savings: California is appropriately ambitious in its efforts to improve drought resiliency, to build and maintain healthy soils throughout the state, and to support climate-smart agricultural practices. Healthy soils high in organic matter can help the state meet goals of drought resiliency, crop productivity, and carbon drawdown, as recognized in CDFA's Healthy Soils Program. Biochar is a naturally occurring and stable form of organic matter that holds great potential for long-term benefit when adopted with broader use in modern agriculture, and particularly in this western region where the woody biomass waste management can be measured in tens of millions of tons per year and soils low in organic matter are the norm.

Sonoma Water, one of the project partners, analyzed the biochar application rate data and came up with projections for the amount of carbon that was sequestered by the project as well as how much could potentially be sequestered if biochar was used throughout the state's agricultural lands. Sonoma Water also projected the amount of potential energy that could be saved through lowered pumping requirements if biochar was used throughout the state's agricultural lands. While these projections are theoretical they indicate the impact that the use of biochar could make if it is scaled significantly in California agriculture.

Projections Courtesy Sonoma Water

Water, Energy, & Greenhouse savings extrapolated statewide based on results of using biochar at Oasis test site		
0.5	acres/plot	

From California State Department of Agriculture	
Water use in the Central Valley	
https://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency	
In an average year, approximately 9.6 million acres are irrigated with roughly 34 million acre-feet of water;	

Water Savings		
3	tons of fruit per acre on baseline plot at Oasis	
4	tons of fruit per acre on biochar plot at Oasis	
33.3%	Percentage difference of fruit produced per acre using biochar at Oasis	
33.3%	Percentage less water required per acre to produce same amount of fruit = percentage difference of fruit produced per acre	
0.249	mt CO2e/AF, Avg Carbon intensity of California State Water Project Water, per water.ca.gov	
34.0	million acre ft of water used for irrigation California annually, baseline	
8.5	million mt CO2e emitted because of irrigation in California annually, baseline	MAF * mt CO2e/AF
22.7	million acre ft of water used for irrigation California annually, if using biochar	MAF * (1-%less water)
5.7	million mt CO2e emitted because of irrigation in California annually, if using biochar	MAF * mt CO2e/AF
11.3	**million acre ft of water saved for irrigation California annually, if using biochar**	MAF now - MAF if using biochar
2.8	**million mt CO2e saved because of irrigation water savings in all California agricultural annually, if u**	mt CO2e now - mt CO2e if using biochar

Biochar Sequester Calcs:
From: DWR Grant Agreement 4600013458 with Sonoma Ecology Center
For a Pilot Project for Using Biochar to Save Water
In California Agriculture
Quarterly Report, Oct. 15, 2020

Biochar per acre	10	tons/acre
Biochar per acre metric	9.1	mt/acre

From: Carbon Futures
https://platform.carbonfuture.earth/balancer/portfolios For
Pacific Biochar 2020 biochar deliveries to california

Certificate ID, ending in	average		05ae8	ab475	4d8fe	113cf
Gross weigth, us tons	16.5	tons	19.08	18.34	16.48	12.09
Gross weight, metric tons	15.0	mt	17.3	16.6	15.0	11.0
Volume	63.2	m^3	61.16	68.81	61.16	61.54
Moisture	0.50	%	59%	52%	52%	35.14%
Bulk density	0.13	t/m^3	0.1269	0.1269	0.1269	0.1269
Certificate amount	1,868	ta	1705	2018	1871	1878
Carbon Sequestered	18.7	mt CO2e	17.05	20.18	18.71	18.78
Dry weight biochar = gross weight * (1-moisture%)	7.3	dry metric tons	7.1	8.0	7.2	7.1
Carbon sequestered per dry ton Pacific Biochar	2.54	mt CO2e/dry mt	2.40	2.53	2.61	2.64
Carbon sequestered per actual ton Pacific Biochar	1.25	mt CO2e/ mt biocha	0.99	1.21	1.25	1.71

Carbon sequestered per acre	11.3	mt CO2e/acre
*Assumes Oasis pilot plot biochar same composition as Carbon Futures		
Oasis pilot land area that had biochar applied	4	acres
Carbon sequestered in Oasis pilot	45	mt CO2e
California land area under cultivation	9.6	million acres
Carbon sequestered if all California land using biochar	109	million mt CO2e

Because the biochar-treated plots produced X more fruit, they could have used Y less water that would have translated to Z GHG emissions based on WEN Reporting Protocols from The Climate Registry.
Using DWR GHG intensity (kg CO2/AF)
The difference between fruit yields of the control plots vs. the biochar and compost/biochar plots is shown as estimated total water conserved:
-- Biochar plots water conserved (X): 1 ton/acre * number of acres treated = X tons of water conserved.
-- Biochar/compost plots water conserved: 2 tons/acre * number of acres treated = Y tons of water conserved.

-- Biochar GHGs saved: X tons of water conserved * State Water Project average kWh or GHG / AF of water.
-- Biochar/compost GHGs saved: Y tons of water conserved * State Water Project average kWh or GHG/ AF
-- Carbon sequestered/stored:
Assumption: 10 mt of biochar/acre would translate equally to 10 mt of carbon stored

In sum, the C-sink potential of biochar is calculated from the carbon content of the biochar minus all emissions caused by its production and use. Specifically, C-sink potential is calculated as follows:

1. The carbon content of the biochar is determined according to the EBC method. It indicates the amount of organic carbon stored in the biochar as a mass proportion (in %) based on the biochar's dry weight.
2. All greenhouse gas emissions caused by biochar production are recorded in CO2eq for the entire EBC production batch (usually production form one year, see EBC certification guidelines). This concerns: (a) Emissions from provision of the biomass (cf. Chap. 2) (b) Emissions from storage of the biomass (cf. Chap. 3) (c) Emissions from the pyrolysis process and other equipment at the production site (cf. Chap. 5). Methane (CH4) and nitrous oxide (N2O) emissions are converted into CO2eq according to their 20-year global warming potential by a factor of 86 and 300, respectively.
3. To include all emissions not covered under Point 2, a safety margin of 10% of all GHG emissions covered under 2) is added (cf. Chap. 6). EBC Carbon Sink certification – www.european-biochar.org 6.
4. Using the factor 0.2727 (ratio of the atomic mass of carbon and the molecular mass of carbon dioxide = 12 u / 44 u = 0.2727), the total determined amount of CO2eq is converted into atomic carbon and results in the carbon expenditure. The carbon expenditure of a production batch indicates the "C-costs;" i.e., it provides the amount of carbon emitted as CO2eq to produce the total amount of biochar of a production batch
5. The carbon expenditure is given as mass proportion based on the dry weight of the biochar. It is calculated by dividing the total amount of carbon expenditure per batch by the dry weight of the total amount of biochar produced per batch.
6. The proportion of carbon expenditure is subtracted from the biochar's carbon content, resulting in the C-sink potential in mass percent of the biochar (DM) – (cf. Frame 4). Thus, the EBC C-sink potential accounts for the complete CO2 footprint of the biochar from the origin of the biomass until it leaves the premises on which the EBC-certified pyrolysis system operates. The C-sink potential indicates the proportion by dry weight of a given amount of biochar that can be converted into a long-term C-sink. Practical calculation examples are provided below in Frames 3 & 4.
7. Further, CarbonFuture credit registration, noted above, uses the EBC C-sink potential as the baseline and subtracts the emissions associated with any processing, packaging, and/or delivery of biochar from its point of creation to its final end-use.

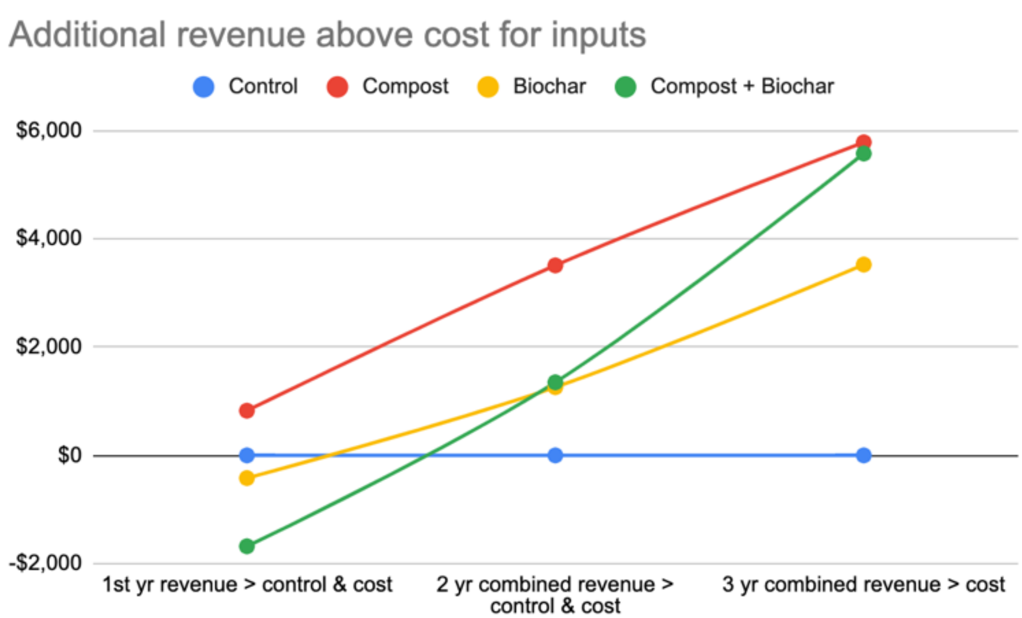
Discussion

Economics:
For an economic assessment, we used the price of grapes as of October 2021 (about $1,500 per ton); the price of biochar delivered in 2016 (about $240 per ton -- wet weight, delivered); and the price of compost ($40 per ton --wet weight, delivered). The inputs of water and fertilizer had the same cost across all treatment types.

In looking back at three years of data from this field trial, we can assess the economic gains of the initial investment made in each chosen input. When measuring grape revenue above the control plots and after subtracting for costs of soil amendments, the treatment actions provided substantial revenue increases: $6,384 for the addition of compost; $5,577 from the combined compost-biochar treatments; and $3,525 for the biochar-alone usage. (See Economics Figure 1 below.)

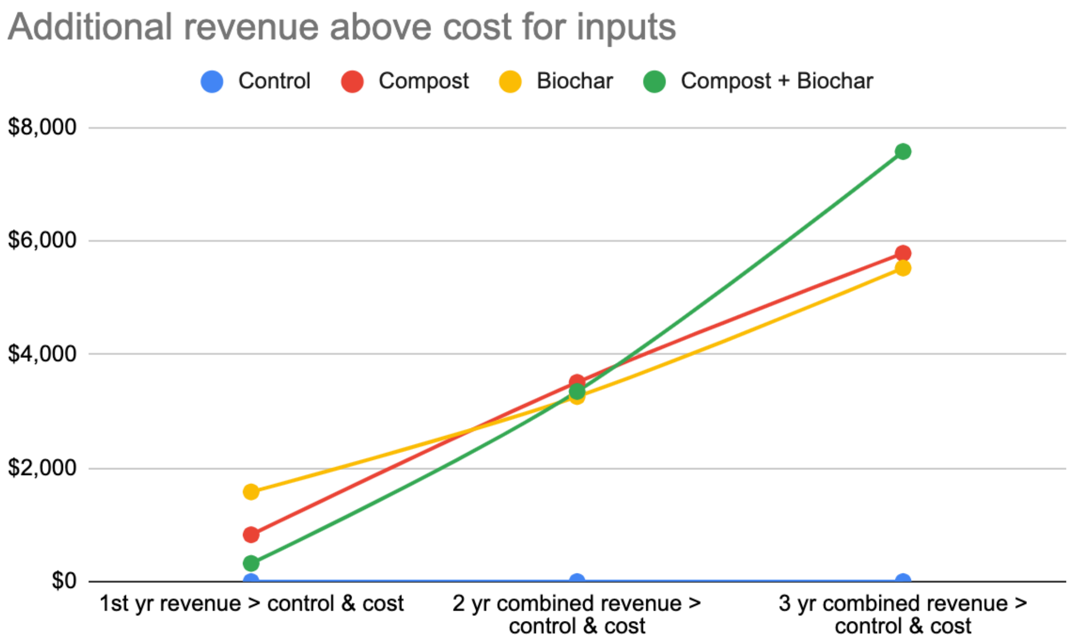
From this perspective, all treatment types produced increased value, with all of them providing a positive return on investment (ROI). While the compost-biochar combination was the most expensive treatment in this trial, it also shows the steepest upward trajectory in financial returns.

Economics Figure 1



As an alternative modeling exercise, we set the prices of biochar and compost equal to one another– each at $40 per ton. It is anticipated that biochar producers will be able to reduce their commercial sales prices once upcoming carbon credits and subsidies are more widely incorporated. As seen in the Economics Figure 2 graph below, the returns for compost-only and biochar-only results are relatively parallel, whereas the returns for the compost-biochar combination are on a steeper trajectory from the first harvest to the third. A potent synergistic effect of adding biochar and compost together has been observed in other field trials, and appears to be evident here as well. Compost and biochar may potentially present a more profitable pathway than using either one alone.

Economics Figure 2



In Economics Figure 3 below this data is represented in spreadsheet format, clearly showing a positive economic impact of all three amendment applications, with the biochar and compost plots showing the greatest gains over the control plots in successive harvests. Perhaps most importantly, in 2021, a bad weather year for grapes, the yield value of the crop per acre was significantly better than the control and providing more income for the farmer.

Economics Figure 3

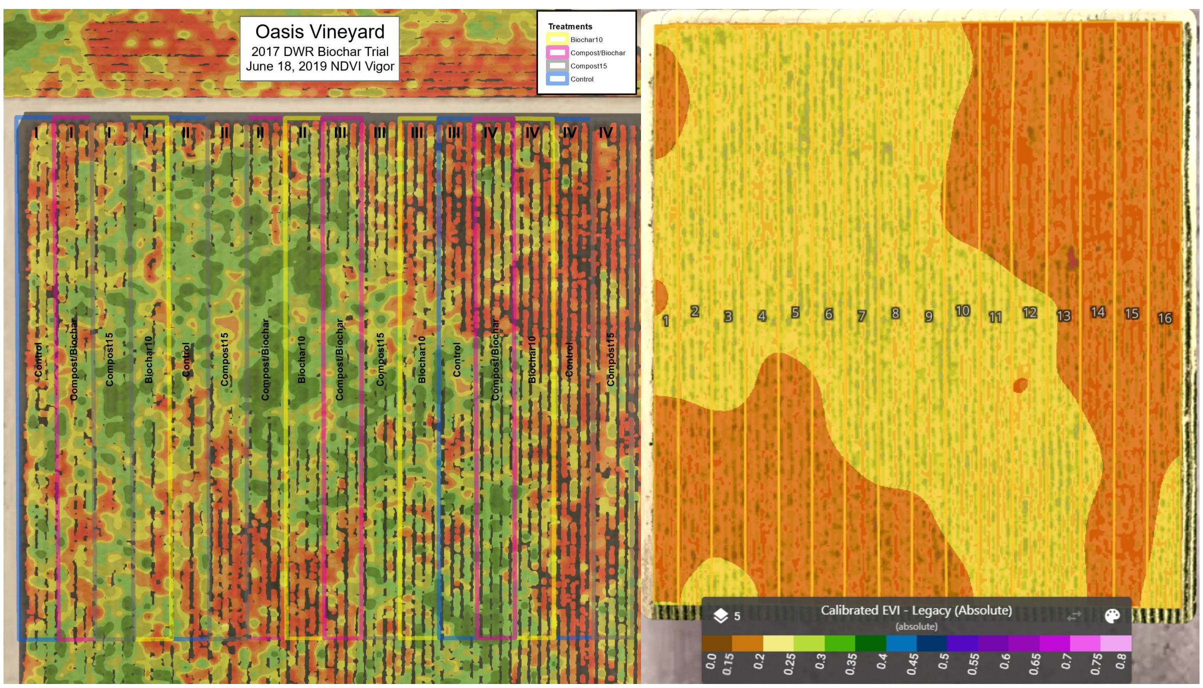
		2019, first harvest year	Control	Compost	Biochar	Compost + Biochar
Cost of inputs/ ton		initial cost per acre	$0	$600	$2,400	$3,000
Cost of compost	$40	yield per acre	2.94	3.89	4.26	3.82
Cost of biochar	$240	yield value	$4,410	$5,835	$6,390	$5,730
		1st yr revenue above control	$0	$1,425	$1,980	$1,320
Tons per acre						
Compost	15	**2020, second harvest year**	Control	Compost	Biochar	Compost + Biochar
Biochar	10	yield per acre	9	10.79	10.12	11.02
		yield value	$13,500	$16,185	$15,180	$16,530
Revenue source		2nd yr revenue above control	$0	$2,685	$1,680	$3,030
yr 1, grapes/ton	$1,500					
yr 2, grapes/ton	$1,500	**2021, third harvest year**	Control	Compost	Biochar	Compost + Biochar
yr 3, grapes/ton	$1,500	yield per acre	3.833	5.349	5.343	6.651
		yield value	$5,750	$8,024	$8,015	$9,977
		3rd yr revenue above control	$0	$2,274	$2,265	$4,227
		Outcomes	Control	Compost	Biochar	Compost + Biochar
		3 yr combined revenue > control	$0	$6,384	$5,925	$8,577
		3 yr combined revenue > control & cost	$0	$5,784	$3,525	$5,577
		2 yr combined revenue > control	$0	$4,110	$3,660	$4,350
		2 yr combined revenue > control & cost	$0	$3,510	$1,260	$1,350
		1st yr revenue > control	$0	$1,425	$1,980	$1,320
		1st yr revenue > control & cost	$0	$825	($420)	($1,680)

Time is an interesting factor to consider in the value of these biochar applications. The biochar applied in this field trial has an estimated decay rate measured in centuries and will therefore remain in this vineyard field with relatively little decay over the estimated ~ 20-year cycle before its anticipated re-planting. Will these biochar inputs continue to provide yield gains at a steady rate? Further field studies at this trial site could generate particularly-valuable results for California grape growers.

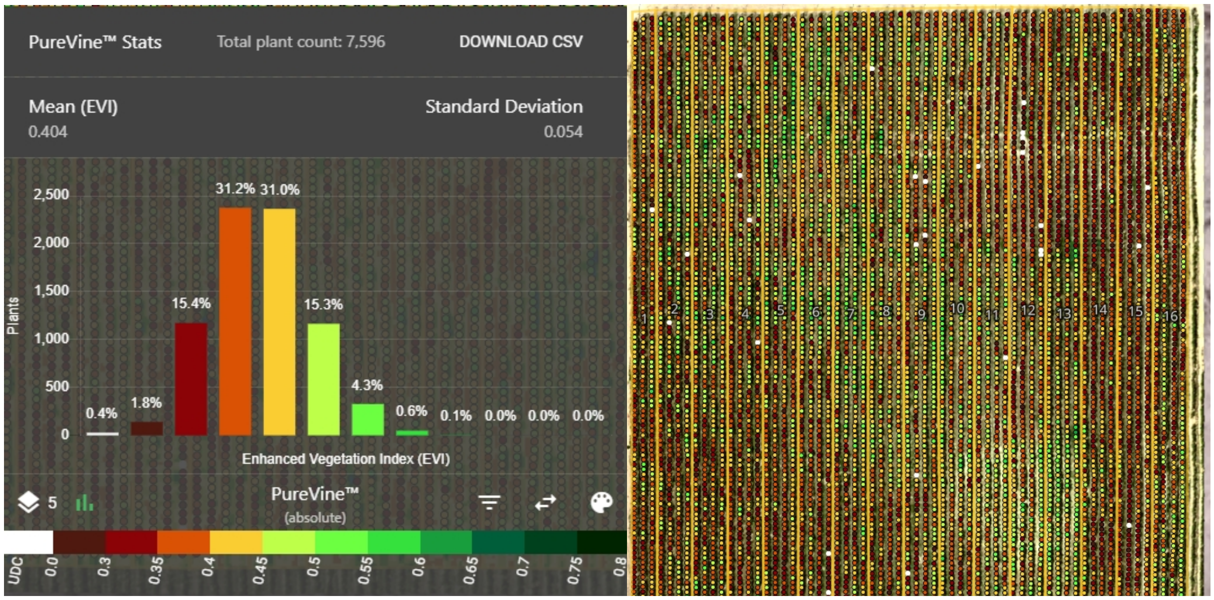
Grape Quality:
Wine grape quality metrics were measured in the second harvest. Industry professionals have suggested that in addition to the soil health and yield volume metrics, data on grape quality will be critical in supporting widespread adoption of biochar. It was clear from our replicated data in this field trial that there were no negative impacts on fruit quality. In fact, nearly every quality metric pointed to improved fruit quality in the biochar treatment areas although improvements were not always significant.

Water Conservation:
Increases observed in yield and plant growth characteristics are reflective of improved water use efficiency where the same amount of water resulted in increased vigor and crop production.

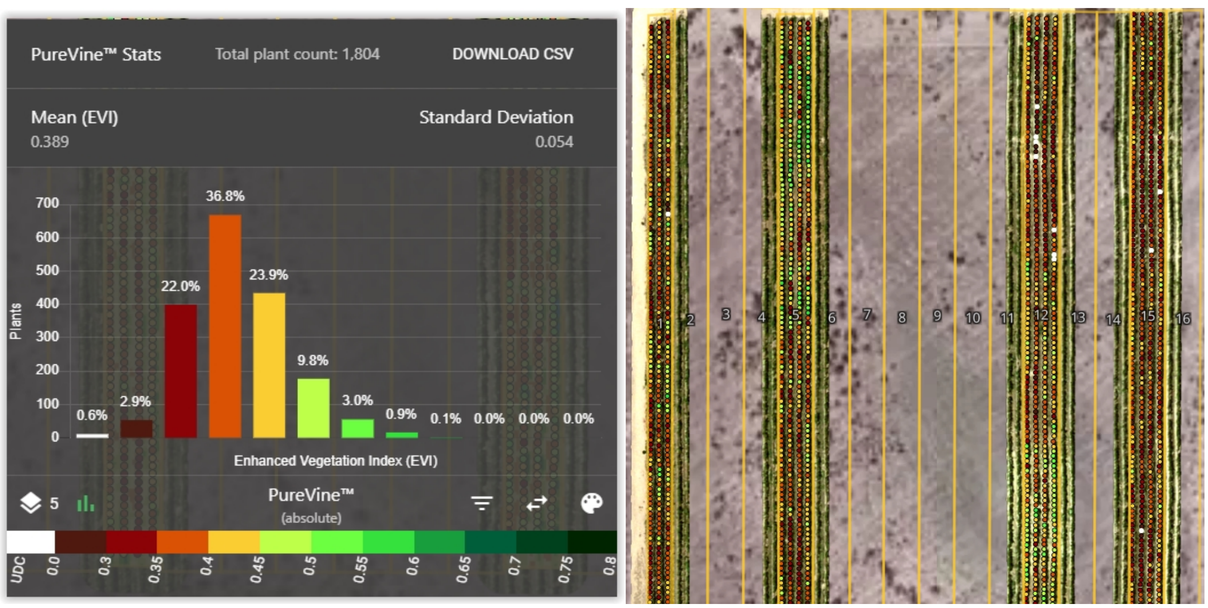
Vine Vigor:
The vine vigor shown in the charts below, taken from August 2019 aerial images, shows the very large range of variability in this field experiment. High weed and rodent pressure, as well as highly variable soil composition, provided tough trial conditions. For this reason, standard deviations for measured parameters were high and so differences were not all significant, but were large enough to indicate real effects.



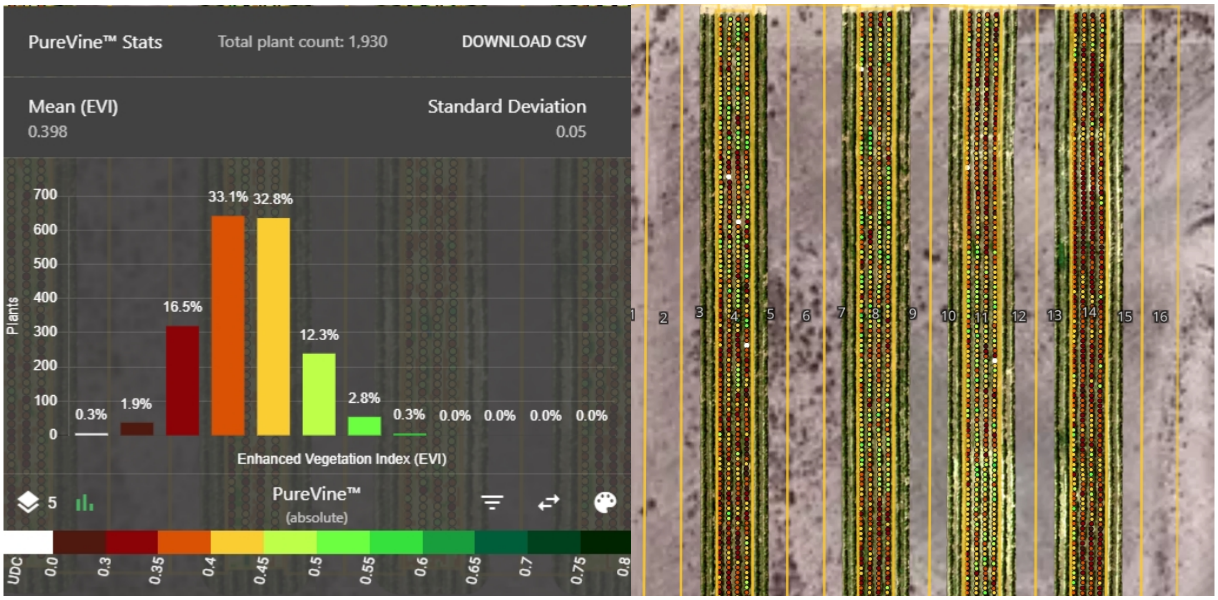
Normalized Difference Vegetation Index (NDVI - left) & Enhanced Vegetation Index (EVI - right)



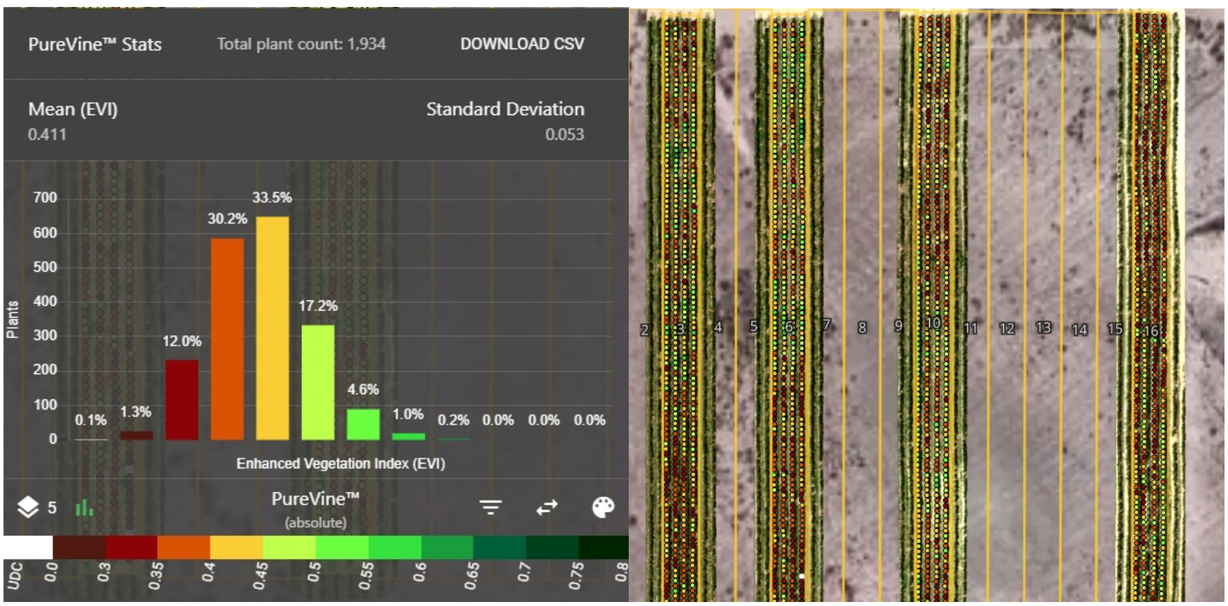
VineView PureVine Stats - All Blocks - Mean EVI 0.404



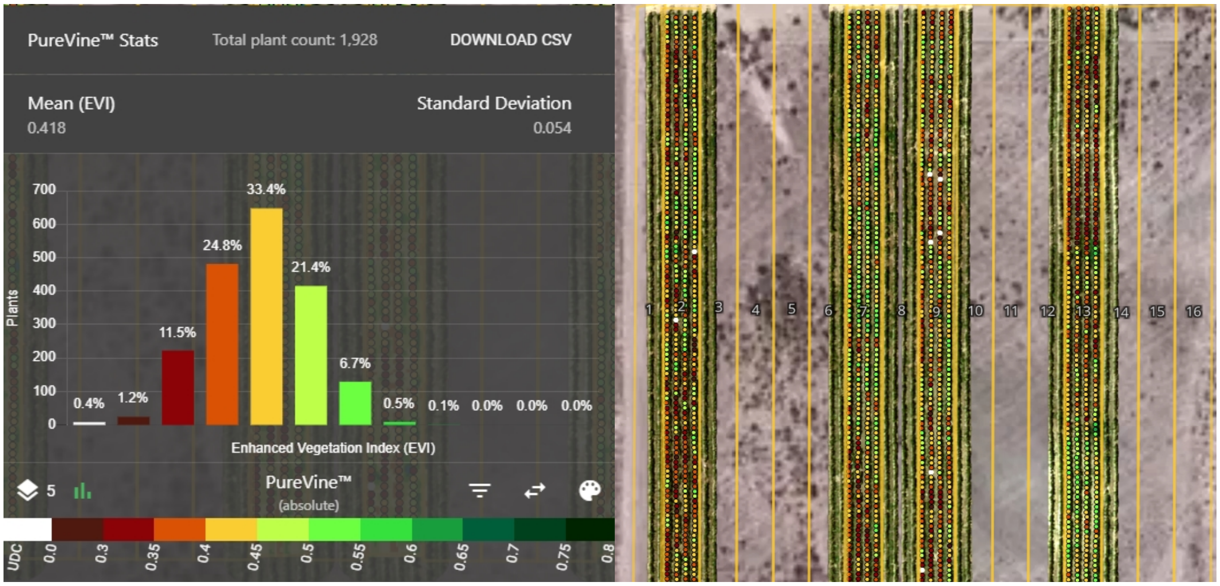
VineView PureVine Stats - Control - Mean EVI 0.389



VineView PureVine Stats - Biochar Treatment - Mean EVI 0.398



VineView PureVine Stats - Compost Treatment - Mean EVI 0.411



VineView PureVine Stats - Compost + Biochar Treatment - Mean EVI 0.418

It appears clear that adding organic matter, whether compost or biochar, improved productivity in this vineyard where sandy soil and low organic matter were defining characteristics. This finding is consistent with results reported in many research articles. The observations provided in this field trial appear to identify an application of biochar worthy of being repeated. Further research and development is recommended.

Significant additional data on this field trial has been supplied to DWR as part of the quarterly reporting we have done over the course of this field trial. Monterey Pacific and Pacific Biochar have a vested commercial interest in continuing to monitor this field trial in coming years. Any additional data supplied by these partners to Sonoma Ecology Center will be submitted to DWR in annual emails.

Supplemental Graphics, Images & Links Section

	As-Received	Dry Weight Basis
Moisture	38.2 %	0.0 %
Bulk Density	0.27 g/cc	0.17 g/cc
	17.1 lb/cu ft	10.6 lb/cu ft
Carbon (C)	43.0 %	69.7 %
Hydrogen (H)	1.1 %	1.7 %
Nitrogen (N)	0.4 %	0.7 %
Oxygen (O -calc.)	1.5 %	2.5 %
Ash	15.7 %	25.5 %
	100.0 Sum	100.0 Sum
Volatile Matter	12.3 %	19.9 %
Butane Activity	3.6 g/100 g	5.8 g/100 g
Surface Area Correlation	196.5 m^2/g	318.0 m^2/g
Organic Carbon	42.0 %	68.0 %
H/Corg.	0.30	0.30
Carbonates (as $CaCO_3$)	8.78 %	14.22 %

Biochar analysis representative of material delivered by Pacific Biochar.

Nutrients	Dry wt.	As Rcvd.	units
Total Nitrogen:	1.5	0.79	%
Ammonia (NH_4-N):	18	9.1	mg/kg
Nitrate (NO_3-N):	450	230	mg/kg
Org. Nitrogen (Org.-N):	1.5	0.77	%
Phosphorus (as P_2O_5):	3.7	1.9	%
Phosphorus (P):	16000	8300	mg/kg
Potassium (as K_2O):	7.9	4.1	%
Potassium (K):	66000	34000	mg/kg
Calcium (Ca):	27	14	%
Magnesium (Mg):	2.7	1.4	%
Sulfate (SO_4-S):	4000	2000	mg/kg
Boron (Total B):	110	58	mg/kg
Moisture:	0	48.7	%
Sodium (Na):	1.6	0.83	%
Chloride (Cl):	0.83	0.43	%
pH Value:	NA	7.59	unit
Bulk Density :	21	41	lb/cu ft
Carbonates ($CaCO_3$):	130	66	lb/ton
Conductivity (EC5):	13	NA	mmhos/cm
Organic Matter:	42.5	21.8	%
Organic Carbon:	22.0	11.0	%
Ash:	57.5	29.5	%
C/N Ratio	14	14	ratio
AgIndex	5	5	ratio

Stability Indicator:			Biologically
CO2 Evolution		Respirometery	Available C
mg CO_2-C/g OM/day		0.73	1.0
mg CO_2-C/g TS/day		0.31	0.44
Stability Rating		*very stable*	*very stable*
Maturity Indicator: Cucumber Bioassay			
Compost:Vermiculite(v:v)		1:2	
Emergence (%)		93	
Seedling Vigor (%)		109	
Description of Plants		*healthy*	
Pathogens	Results	Units	Rating
Fecal Coliform	8.5	MPN/g	*pass*
Salmonella	< 3	MPN/4g	*pass*
Date Tested: 20 Apr. 16			
Inerts	% by weight		
Plastic	< 0.5		
Glass	< 0.5		
Metal	< 0.5		
Sharps	ND		

Compost analysis representative of material delivered by Keith Day Company

Grant partners harvest grapes in test plots. Photo: Raymond Baltar

Grape bunches from Biochar/Compost Vine Row
Photo: Raymond Baltar

Grant partners harvest grapes in test plots. Photo: Raymond Baltar

Soilworks delves the vine rows for amendment application. Drone Photo: Doug Beck

Installation of Watermark Sensors. Photo: Raymond Baltar

Installation of Watermark Sensors. Photo: Raymond Baltar

Doug Beck records grape cluster weights. Photo: Raymond Baltar

Additional Links:

IPCC Special Report on Land and Climate Change, of which Chapter 4, Land Degradation, is particularly useful as a reference for biochar https://www.ipcc.ch/srccl/

Scaling Biochar Forum (25 presentations produced by Sonoma Ecology Center, October, 2020) http://www.scalingbiochar.com

Biochar to Biomass: Maximizing the Carbon Value: A comprehensive report by Washington State University on the state of the biochar industry and what is needed to develop it into a mature industry. https://s3.us-west-2.amazonaws.com/wp2.cahnrs.wsu.edu/wp-content/uploads/sites/32/2021/01/Biomass-to-Biochar-Executive-Summary-9Feb2021.pdf

Attachments:

Biochar effects_crop yields_with and without fertilizer_meta-analysis_Ye 2019.pdf
Composting_Organic Waste_Role of biochar_Sanchez-Monedero 2018.pdf
Joseph et al, 21_ how biochar works and when it doesn't.pdf
Meta-analysis_ Schmidt et al. 2021.pdf
Oasis biochar trial data 2019-2021 2.xlsx

Thanks to all of our grant partners: