Permanent Cover Cropping with Reduced Tillage Increased Resiliency of Wine Grape Vineyards to Climate Change

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Abstract

Many viticulture areas in California rely on irrigation for production and the San Joaquin Valley is one of the leading irrigated viticulture regions in the world. However, decreases in precipitation amounts and increases in temperature as a result of climate change has exacerbated the loss of water and soil via soil degradation. Although cover crops are regarded as a promising and sustainable practice to mitigate the effects of climate change, there is a lack of information on how they work with different tillage systems. The aim of this study was to find the best management of vineyard soils using different cover crop and tillage systems to preserve plant available water in soil prior to the initiation of irrigation. A randomized study was conducted with three cover crops: a perennial grass (Poa bulbosa hybrid), annual grass (Hordeum spp.), and native vegetation under till vs. no-till systems in a Ruby Cabernet (Vitis vinifera spp.) vineyard in Fresno County, California. Our results indicated that the type of cover crop and tillage system had minimal effects on grapevine physiological status. Furthermore, neither yield per vine nor berry flavonoids responded to different vineyard floor management systems. Consequently, the net carbon assimilation of grapevines grown with the perennial grass cover crop under no-till management was enhanced. Combined, these results indicate the use of cover crops under no-till systems may be implemented in irrigated vineyards of San Joaquin Valley with no effect on grape productivity while improving soil quality and potentially mitigating the effects of climate change.

Introduction

As temperatures rise and rain events become more unpredictable, soils are under threat of loss of soil organic matter (SOM), nutrient imbalances, loss of soil biodiversity, compaction, and waterlogging (Panagos et al., 2020). Furthermore, it is estimated that almost 36 billion tons of soil are lost annually due to water and wind erosion (Borrelli et al., 2017). It is well demonstrated that mechanical tillage (cultivation) accelerates soil erosion and the frequent cultivation of the soil for weed control and aeration over the past half century has resulted in a significant loss of SOM across agricultural soils (Mitchell et al., 2017). However, as climate change threatens the world's agricultural systems, there has been a substantial increase in attention in the last decade towards using soils as a tool to mitigate the effects (Lal, 2004, 2012; Lazcano et al., 2020).

Traditionally, the interrows (also known as tractor rows) of vineyards are kept bare via the use of herbicides and tillage. However, it has been shown that both practices have detrimental effects on soil quality as well as the surrounding ecosystem (Gatti et al., 2022a). Thus, cover cropping and reduced tillage have been proposed as sustainable alternatives to traditional management of the vineyard floor (Sweet and Schreiner, 2010). Research suggests that cover cropping can not only reduce soil erosion and runoff, but also improve water infiltration and increase SOM in most soils of temperate regions (Steenwerth and Belina, 2008. Furthermore, SOM is preserved under reduced tillage where soil aggregates remain undisturbed, whereas when the soil is cultivated aggregates and the accompanying SOM are susceptible to oxidation by physical disruption.

The degree to which the benefits of cover cropping are observed are highly dependent upon site conditions including grapevine age and genotype, climate, soil physiochemical characteristics, and the overall goals for using a cover crop (Sweet and Schreiner, 2010). In some cases, cover crops may even have detrimental effects by reducing vigor and yield, increasing frost risk, and serving as an alternative host for vertebrate pests and diseases (Rodriguez-Lovelle et al., 2000; Ingels et al., 2005). Consequently, decisions regarding cover crop management must be adequate for the site as well as farming goals. This includes decisions in space (cover crop in row alleyways vs. under the vines), type (grasses vs. broadleaves, monoculture or mixture of species), and time (perennial vs. annual species and time/type of termination) (; Gatti et al., 2022b). Many combinations of these factors exist, which may also contribute to the variability of the benefits observed.

Although the adoption of annual cover crop species with termination by tillage is easier to incorporate into an existing farming system, perennial cover crops under no-till systems may present the greatest benefit to the soil (Rodriguez-Lovelle et al., 2000; King and Berry, 2005). The permanent coverage this system can provide has been shown to moderate temperature, conserve moisture, reduce dust, and increase soil organic matter through permanent coverage of the soil (King and Berry, 2005; Derpsch et al., 2014). However, perennial cover crops are widely considered to be excessively competitive with grapevines for water and nutrients despite much of the supporting research conducted with few species in non-irrigated vineyards (Rodriguez-Lovelle et al., 2000; Morlat and Jacquet, 2003; Ingels et al., 2005; Monteiro and Lopes, 2007; Lopes et al., 2008; Sweet and Schreiner, 2010). Furthermore, reports on the influence of both cover crops and no-till systems on grapevine functioning and yield are inconsistent, with some studies reporting yield reductions under no-till and others no effect observed (Monteiro and Lopes, 2007; Lee and Steenwerth, 2013). The present study thus investigates the use of a low stature grass that is indicated to require little to no water in the summer and is therefore spatiotemporally positioned for vineyard utility in Mediterranean cropping systems. This low maintenance cover crop could also potentially eliminate the need for mowing, thus decreasing greenhouse gas emissions (GHG) of the system. To contribute to the understanding of the influence of cover crops and tillage management on grapevines in irrigated vineyards, we aimed to (i) study the influence of various cover crop and tillage systems on grapevine physiological status using leaf water potential and gas exchange methods; (ii) examine the relationships between these variables and the grapevine's growth, yield, and berry composition over two seasons in California's San Joaquin Valley.

Materials and methods

Site description and experimental design:

The experiment was conducted during two consecutive growing seasons (2019-2020 and 2020-2021) in Fresno, CA (36.671514, -119.925823) in a Ruby Cabernet/Freedom (27% V. vinifera hybrid) vineyard. Grapevines were planted in 2012 with a spacing of 3.0 x 1.2 m (row x vine) with a row orientation of E-W. The grapevines were head-trained, and cane pruned. The vineyard is under a sprawling trellis system with catch wires at 1.54 m and at 1.68 m above vineyard floor. The soil texture of the site is classified as a sandy loam and vines were drip-irrigated with two emitters per plant delivering 4.0 L/h each. The experiment was arranged in a split-plot 3 × 2 factorial design (three different cover crops subjected to two tillage managements) with three replications. Each replicate consisted of 15 grapevines. Three grapevines in the middle were used for measurements and the distal plants on either end were treated as border plants. Treatments included a i) Perennial grass (Poa bulbosa hybrid cv. Oakville Blue); ii) Annual grass (Barley, Hordeum vulgare); iii) Resident vegetation (natural weed population) subjected to conventional tillage and no-till management. The cover crop seed was drilled in a 1.5 m wide strip according to seed manufacturer's recommended practices prior to receiving fall/winter rains in 2019 and 2020 at a rate of 605 kg/ha and 84 kg/ha for the perennial grass (PG) and annual grass (AG) treatments, respectively. Resident vegetation (RV) was allowed to grow within a 1.5 m strip and mowed according to vineyard manager's discretion.

Grapevine water status and gas exchange parameters (Ψ_L, Anet, E, gs, WUE)

Plant water status was measured as leaf water potential (Ψ_L) periodically during the growing season within 1.5 h of solar noon at approximately solar noon. Two fully expanded leaves per treatment-replicate exposed to sun and without signs of disease and/or damage were selected per treatment-replicate. Then, Ψ_L was directly determined with a pressure chamber (Model 610 Pressure Chamber Instrument, PMS Instrument Co., Corvallis, OR, United States). Leaf gas exchange was also measured every 2 weeks at solar noon on one fully expanded leaf with a CIRAS-3 portable photosynthesis system (PP Systems, Amesbury, MA, United States) equipped with a leaf chamber with a 4.5 cm2 window. Reference CO2 was set to 390 µmol/mol CO2 at a flow rate of 200 mL/min. The window of the chamber was oriented perpendicularly toward the sun to allow for saturation light conditions (1984 ± 52 µmol/m/s) and the cuvette left for 40–60 s until a steady state was reached for measurements to be taken in triplicate.

Yield components

Leaf area index (LAI) was measured in late spring to characterize grapevine canopy growth and converted into leaf area on by a smartphone program, VitiCanopy, via iOS system (Apple Inc., Cupertino, CA, USA). The gap fraction threshold was set to 0.75, extinction coefficient was set to 0.7, and sub-divisions were 25. A “selfie-stick” was used to place the device approximately 75 cm more effectively underneath the canopy. The device was positioned with the maximum length of the screen being perpendicular to the cordon, and the cordon in line with the middle of the screen according to previous work. The relationship between leaf dry mass and area was determined on a subsample of leaves using a leaf area meter. At harvest at both sites, clusters from three data vines per treatment replicate were manually removed, counted, and weighed on a top-loading balance. Leaf area to fruit ratio was calculated by dividing leaf area with crop weight.

Primary metabolites

At harvest, fifty berries were randomly collected from the three middle vines within each replicate and immediately processed. Berries were weighed and gently pressed by hand to squeeze the juice. Total soluble solids (TSS) were determined using a temperature compensating digital refractometer (Atago PR-32, Bellevue, WA, United States). Must pH and titratable acidity (TA) were determined with an autotritrator (Metrohm 862 Compact Titrosampler, Herisau, Switzerland). TA was estimated by titration with 0.1 N sodium hydroxide to an end point of 8.3 pH and reported as g/L of tartaric acid.

Results and discussion

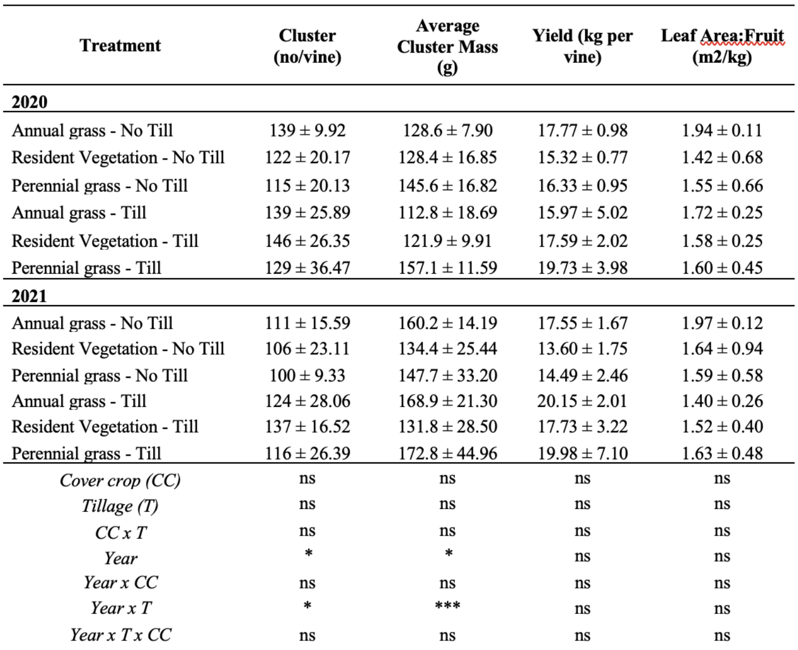
While results of the present study were variable, it appears that tillage was minimally influential on juice characteristics while little to no effects were observed on yield or yield components. Most differences were observed between years which was as expected due to a 4-week difference between 2020 and 2021 harvest dates. No changes were seen in stomatal conductance or net carbon assimilation, indicating that the physiological state of the vines was not influenced by the type of cover crop or tillage system, nor were there interactions of the two factors. Likewise, the nutrient status of the vines at bloom only differed between years and was not affected by treatments, indicating little to no competition with the cover crop for resources. It was hypothesized that the perennial grass would improve vine water status due to temporal and spatial complementarity, whereby the shallow rooting depth does not compete with vines and peak water use of the cover crop occurs during vine dormancy. Indeed, the perennial grass improved grapevine water status compared to resident vegetation and annual grass in early spring of the first season, however this was not observed in the following year and ultimately treatments had no effect on Ψ_L.

Furthermore, no differences were observed among water footprint components, which is defined as the volume of irrigation water used per unit yield produced and is a useful indicator of the total water used for grape production. This result is particularly important as it indicates that despite different growth habits of the cover crop (the annual grass is a tall stature grass and thus produces more biomass than the low stature perennial), there was no competition with the grapevines for water, as previously indicated by a lack of differences in Ψ_L between treatments. Although yield and yield components were not affected by cover crop or tillage system, tillage imposed few effects on juice characteristics (Table 1). TA was significantly higher from tilled vines compared to no-till in both years as has been previously reported when permanent grass is compared to conventionally tilled soil (Table 1) (Reeve et al., 2016). This may suggest that tillage hastens the ripening process, however, no statistically significant effects were observed within TSS (°brix) which would support such a claim. Finally, carbon assimilation of the six different systems were calculated via the sum of the grapevine, soil, and cover crop values. Over the course of both seasons, it was found that the perennial grass cover crop under no-till management enhanced carbon assimilation compared to both barley and resident vegetation systems.

Conclusion

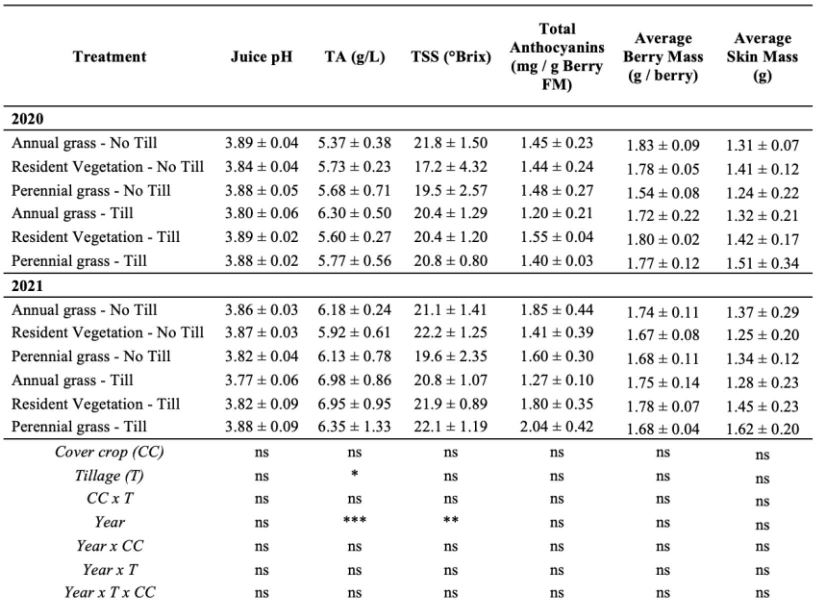
In addition to the threat that climate change poses on agricultural soils and the subsequent biogeochemical cycles, a heavy reliance on mechanical tillage over the past century has put soils at risk of degradation and depletion (Borrelli et al., 2017). In response, sustainable soil management practices such as reduced tillage and cover cropping have become two promising sustainable options to conserve SOM and improve soil health (Cataldo et al., 2020). While the effects of these practices on the soil are mostly understood, the link between management practices to grapevine responses and berry composition remains unclear (Ingels et al., 2005; Wheeler et al., 2005; Guerra and Steenwerth, 2012; Fourie et al., 2017; Cataldo et al., 2020; Gatti et al., 2022b). The results obtained from this two-year study highlight the importance of site characteristics such as the age of the vineyard, soil type, and climatic conditions regarding vineyard floor management. Minimal effects were observed on the grapevine physiological status indicating competition with the cover crop may be of little concern in vineyards of these climates. No changes to yield or berry primary metabolism among the six-cover crop and tillage systems were detected, which suggests that the use of cover crops and/or no-till practices may be implemented in an irrigated vineyard in the San Joaquin Valley with little to no effect on production. Further experimentation that incorporates additional elements of spatial considerations such as the use of these practices in alternate rows and root growth of the cover crop and grapevine could provide further insight into the mechanisms underlying the responses seen in the present study.

Table 1. Yield components of Ruby Cabernet grapevines subjected to different cover crops and tillage systems, collected in the 2019–20 and 2020–21 seasons.



Treatment	Cluster (no/vine)	Average Cluster Mass (g)	Yield (kg per vine)	Leaf Area:Fruit (m2/kg)
2020				
Annual grass - No Till	139 ± 9.92	128.6 ± 7.90	17.77 ± 0.98	1.94 ± 0.11
Resident Vegetation - No Till	122 ± 20.17	128.4 ± 16.85	15.32 ± 0.77	1.42 ± 0.68
Perennial grass - No Till	115 ± 20.13	145.6 ± 16.82	16.33 ± 0.95	1.55 ± 0.66
Annual grass - Till	139 ± 25.89	112.8 ± 18.69	15.97 ± 5.02	1.72 ± 0.25
Resident Vegetation - Till	146 ± 26.35	121.9 ± 9.91	17.59 ± 2.02	1.58 ± 0.25
Perennial grass - Till	129 ± 36.47	157.1 ± 11.59	19.73 ± 3.98	1.60 ± 0.45
2021				
Annual grass - No Till	111 ± 15.59	160.2 ± 14.19	17.55 ± 1.67	1.97 ± 0.12
Resident Vegetation - No Till	106 ± 23.11	134.4 ± 25.44	13.60 ± 1.75	1.64 ± 0.94
Perennial grass - No Till	100 ± 9.33	147.7 ± 33.20	14.49 ± 2.46	1.59 ± 0.58
Annual grass - Till	124 ± 28.06	168.9 ± 21.30	20.15 ± 2.01	1.40 ± 0.26
Resident Vegetation - Till	137 ± 16.52	131.8 ± 28.50	17.73 ± 3.22	1.52 ± 0.40
Perennial grass - Till	116 ± 26.39	172.8 ± 44.96	19.98 ± 7.10	1.63 ± 0.48
Cover crop (CC)	ns	ns	ns	ns
Tillage (T)	ns	ns	ns	ns
CC x T	ns	ns	ns	ns
Year	*	*	ns	ns
Year x CC	ns	ns	ns	ns
Year x T	*	***	ns	ns
Year x T x CC	ns	ns	ns	ns

Table 2. Primary metabolites of Ruby Cabernet grapevines subjected to different cover crops and tillage systems, collected in the 2019–20 and 2020–21 seasons.



Treatment	**Juice pH**	**TA (g/L)**	**TSS (°Brix)**	**Total Anthocyanins (mg / g Berry FM)**	**Average Berry Mass (g / berry)**	**Average Skin Mass (g)**
2020						
Annual grass - No Till	3.89 ± 0.04	5.37 ± 0.38	21.8 ± 1.50	1.45 ± 0.23	1.83 ± 0.09	1.31 ± 0.07
Resident Vegetation - No Till	3.84 ± 0.04	5.73 ± 0.23	17.2 ± 4.32	1.44 ± 0.24	1.78 ± 0.05	1.41 ± 0.12
Perennial grass - No Till	3.88 ± 0.05	5.68 ± 0.71	19.5 ± 2.57	1.48 ± 0.27	1.54 ± 0.08	1.24 ± 0.22
Annual grass - Till	3.80 ± 0.06	6.30 ± 0.50	20.4 ± 1.29	1.20 ± 0.21	1.72 ± 0.22	1.32 ± 0.21
Resident Vegetation - Till	3.89 ± 0.02	5.60 ± 0.27	20.4 ± 1.20	1.55 ± 0.04	1.80 ± 0.02	1.42 ± 0.17
Perennial grass - Till	3.88 ± 0.02	5.77 ± 0.56	20.8 ± 0.80	1.40 ± 0.03	1.77 ± 0.12	1.51 ± 0.34
2021						
Annual grass - No Till	3.86 ± 0.03	6.18 ± 0.24	21.1 ± 1.41	1.85 ± 0.44	1.74 ± 0.11	1.37 ± 0.29
Resident Vegetation - No Till	3.87 ± 0.03	5.92 ± 0.61	22.2 ± 1.25	1.41 ± 0.39	1.67 ± 0.08	1.25 ± 0.20
Perennial grass - No Till	3.82 ± 0.04	6.13 ± 0.78	19.6 ± 2.35	1.60 ± 0.30	1.68 ± 0.11	1.34 ± 0.12
Annual grass - Till	3.77 ± 0.06	6.98 ± 0.86	20.8 ± 1.07	1.27 ± 0.10	1.75 ± 0.14	1.28 ± 0.23
Resident Vegetation - Till	3.82 ± 0.09	6.95 ± 0.95	21.9 ± 0.89	1.80 ± 0.35	1.78 ± 0.07	1.45 ± 0.23
Perennial grass - Till	3.88 ± 0.09	6.35 ± 1.33	22.1 ± 1.19	2.04 ± 0.42	1.68 ± 0.04	1.62 ± 0.20
Cover crop (CC)	ns	ns	ns	ns	ns	ns
Tillage (T)	ns	*	ns	ns	ns	ns
CC x T	ns	ns	ns	ns	ns	ns
Year	ns	***	**	ns	ns	ns
Year x CC	ns	ns	ns	ns	ns	ns
Year x T	ns	ns	ns	ns	ns	ns
Year x T x CC	ns	ns	ns	ns	ns	ns

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