UNIVERSITY OF CALIFORNIA, MERCED

Quantifying the Spatial-temporal Variability in Carbon Stocks in a California Vineyard

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Environmental Systems

by

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QUANTIFYING THE SPATIAL-TEMPORAL VARIABILITY IN CARBON STOCKS IN A CALIFORNIA VINEYARD

ABSTRACT

Quantifying terrestrial carbon (C) stocks in vineyards represents an important opportunity for estimating C sequestration in perennial cropping systems. Considering ~230,000 ha in California (8.2% of total land cultivated in CA) are dedicated to wine grape production, annual C capture and storage in woody biomass is substantial. In this study, destructive sampling was used to measure C stocks in the woody biomass of a 15-year-old Cabernet Sauvignon vines from a California Northern San Joaquin Valley vineyard. The objectives were to characterize C stocks in terms of allometric variation between biomass fractions of roots, aboveground wood, canes, leaves and fruit, and then test correlations between easy-to-measure variables such as trunk diameter, pruning weights and harvest index to vine biomass fractions. Carbon stocks were also estimated from the volume of biomass in mounds generated during vineyard removal, and compared with previous estimates of standing biomass.

Total vine C was estimated at 12.3 Mg C/ha, of which 8.9 Mg C/ha came from perennial vine biomass, whereas annual biomass was estimated at 1.7 Mg C/ha from leaves and canes and 1.7 Mg C/ha from fruit. High positive correlations were found between the diameter of the trunk and overall woody C stocks ($r^2 = 0.84$), pruning weights and annual C stocks ($r^2 = 0.93$), and between fruit weight and annual C stocks ($r^2 = 0.95$). Carbon estimates in the mounds of vine biomass fractions wood, root and canes (10.25 Mg C/ha) were not significantly different than for individually measured vines (10.02 Mg C/ha).

This research demonstrates that allometric equations represent strong predictive power for C estimations due to high correlations and low error between these simple measurements and C stocks. Such equations, using information collected from vineyard management practices, could enable growers to estimate C stocks more easily and would facilitate managing C at a vineyard level. This might also provide the basis to calculate future C stock estimations, especially important considering the significance that C sequestration is taking in the production function of agro-ecosystems.

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1 INTRODUCTION

Agriculture is one of the most relevant human activities in terms of its role in the global carbon cycle. California agriculture is unique due to its variety of perennial crops and high value specialty crops (Kroodsma and Field, 2006). The state produces nearly half of U.S.-grown fruits, nuts and vegetables (CDFA, 2010 – 2011), with viticulture experiencing a substantial increase during the last couple of decades.

In contrast to other types of crops, grapes can be grown in diverse climates and soils (Bisson *et al.*, 2002)**,** most of them present in California. The wine grape, *Vitis vinifera*, is native to Mediterranean environments, and is ideally suited to being grown throughout the Mediterranean biome − temperate regions on the western side of continents with cool, wet winters, and hot, dry summers promoted by atmospheric circulation (Viers *et al.*, 2013) represented by California as one of the five spots in the world.

Economically, wine grape production represents an important contribution to California agriculture, generating $121.8 billion in revenue annually (Wine institute, 2009). Currently, 230,000 ha in California are managed for wine grape production, with more than 4 million tons of wine grapes harvested, representing more than 110 grape varieties (Wine institute, 2009). The cultural and economic significance of wine has supported research to better understand the biogeochemistry of vineyard agroecosystems and the influence that land use may have on greenhouse gas (GHG) emission (Carlisle *et al.*, 2010; Alsina *et al.*, 2013), on-site energy balance (Kavargiris *et al.*, 2009), water use (Herath *et al.*, 2013), and potential impacts of climate change on productivity and the distribution of grape production (Hannah *et al.*, 2013).

Grape growing is a land-intensive industry with considerable environmental impact. Native ecosystems continue to be modified for new vineyard plantations. Given current concerns about GHG emissions and global warming, vineyard C footprint accounting is becoming a priority. Although many economic and environmental aspects of wine production systems are actively being quantified, efforts to quantify C capture and storage in annual and perennial biomass are limited (Williams *et al.*, 2011a). Studies from Mediterranean climates have focused mostly on C cycle processes in annual agroecosystems or natural systems (Andrews *et al.*, 2002; Veenstra *et al.*, 2007).

Carbon sequestration involves the removal and storage of CO_2 from the atmosphere into sinks (such as oceans, vegetation, or soils) through physical or biological processes (Jose, 2009). Two major recent trends have the potential to improve C storage in California agriculture: increases in perennial agriculture and an increase in crop yields. The perennial nature and extent of vineyard agroecosystems have brought increasing interest from growers and the public sector to reduce the GHG footprint associated with wine production.

In 2010, quantifying C sequestration in promising systems was suggested as one of the three critical research needs for developing and implementing US agricultural C sequestration and non-CO2 greenhouse gases mitigation practices (Morgan *et al.*, 2010). Vineyards are considered one of the most promising systems in California where the fact of counting with information about the C harvested could motivate growers to implement management practices to increase it, especially considering that C sequestered in agroforestry systems could be used to offset fossil fuel C emissions and sold in C credit markets where such opportunities exist. As a matter of fact, recent interest in the clean development mechanism (CDM) under the Kyoto Protocol offers promise for economic returns for C sequestration benefits of agroforestry systems (Jose, 2009).

The development of a Carbon Accounting Protocol for the International Wine Industry reflects the increased attention this industry is putting on climate change, GHG emissions and offsets. It is expected that the use of this Protocol will define a companies' C emissions to the extent, and level of detail, that when combined with accounting practices and allocation rules, also supports the apportioning of greenhouse gas emissions to individual products to meet the requirements of expected international standards (Forsyth *et al.*, 2008).

However, there are many aspects of the Protocol still in the development phase. GHG emissions are not well understood or documented in many sectors of the wine industry. In some cases there is almost no information available to use in the development of a model (Forsyth and Oemcke, 2008). Better metrics for vineyard C-sequestration data such as vine biomass, cover crop biomass, and soil C storage capacity, are needed since this information is absent from C budget protocols in the wine sector (Schultz, 2010).

Considering this evident gap, and that C quantification in vineyards is starting to be explored, it is necessary to see what researchers and other sectors of the industry are doing with that respect. Characterizing intrinsic relationships between size, mass or shape of an organism and easily measured physical parameters (allometry) have been investigated broadly across biological sciences. Relationships between trunk diameter and plant height have been used to estimate wood volume across trees of varying size and architecture (Chave *et al.*, 2005). In natural ecosystems, several studies have been performed using allometric equations in order to estimate aboveground biomass to assess potential for C sequestration. A research in natural forests of Africa, Latin America and Southeast Asia used plots to develop functional relationships between the ground-measured Lorey's height (basal area weighted height of all trees >10 cm in diameter) and aboveground biomass derived from allometric equations (Saatchi *et al.*, 2011). In the vineyard setting, husbandry and annual pruning constrain the size and shape of vines making it likely that strong predictive relationships between various aspects of standing biomass and simple physical measurements exist.

Although most studies on C sequestration in vineyards have been focused on soil C, some attempts to quantify biomass C stocks have been carried out in both agricultural and natural systems. In vineyards, studies in California in the late 1990s have reported net primary productivity (NPP) or total biomass values between 550 g C/m^2 (5.5 Mg C/ha) and 1100 g C/m^2 (11 Mg C/ha) (Christensen, 2000). In terms of spatial distribution, some data of standing biomass collected by Kroodsma et al. (Kroodsma and Field, 2006) from companies that remove trees and vines in California (Noni Enterprises and Orchard Removal, Fresno, California, USA; Wilson

Agriculture Company, Shafter, California, USA; Volks and Sons Orchard Removal, Fresno, California, USA) yielded values of 1.0 to 1.3 Mg C/ha woody C for nuts and stone fruit species, and 0.2 to 0.4 Mg C/ha for vineyards. It has been reported that mature California orchard crops allocate, on average, one third of their NPP to the harvested portion (Rufat and DeJong, 2001) and mature vines 35-50% of the current year's production to grape clusters (Williams, 2000). Pruning weight has also been quantified by two direct measurements which estimated 2.5 Mg of pruned biomass per ha for both almonds (Holtz *et al.*, 2004) and vineyards (Christensen, 2000).

No studies were found that have quantified belowground biomass in vineyards. In fact, none of the biomass studies of California perennials accounted for fine roots, although they have been estimated as 20-30 % of total NPP and 45% of the dry matter as C (Elderfield, 1998).

The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture (Sharrow and Ismail, 2004). Additional forest planting would be needed to offset current net annual loss of aboveground C, representing an opportunity for viticulture to incorporate the surrounding woodlands into the system. A study assessing C storage in California vineyards found that on average, surrounding forested wildlands had 12 times more aboveground woody C than vineyards and even the largest vines had only about one-fourth of the woody biomass per ha of the adjacent wooded wildlands (Williams *et al.*, 2011b).

Since this study is seeking to quantify net movement of C into elements of the vineyard system, no attempt was made here to quantify and analyze soil organic carbon (SOC) except for topsoil measurements to have some referential data. Additionally, SOC values might be represented by fractions attributable to historic systems (seasonal flooding) previously established in the study site, which would bias results strictly ascribable to the vineyard. There is a large variation in the length of time for and the rate at which C may accumulate in soil, related to productivity of the recovering vegetation, physical and biological conditions in the soil, and the past history of SOC inputs and physical disturbance (Post and Kwon, 2000). The direction of changes, loss or gain of soil C stocks after land-use change, depends also on soil properties, climate and management (Novara *et al.*, 2012). It is important, however, to mention the magnitude of SOC values in vineyards provided by some studies in order to understand the relative magnitude of C stocks in the soil with respect to those in the plant. In terrestrial ecosystems the amount of C in soil is usually greater than the amount in living vegetation (Post and Kwon, 2000).

The general tendency of vineyard managers to configure vines in evenly-spaced rows with fixed distances between plants also makes scaling up of C estimates across the landscape and comparison across growing regions feasible and relatively straightforward. What the industry is largely lacking, however, are accessible, affordable examples of how to conduct such estimates. While researchers have used empirical data to compare soil and aboveground C stocks in vineyards and adjacent oak woodlands in California, comparing the relative contributions of vineyards and natural vegetation to C storage (Williams *et al.*, 2011b), we know of no study that estimates the entire C storage capacity of a vine, including the relative contribution of its component parts (root, trunk and cordons, canes, leaves and fruit), and dependable allometric relationships among these components.

This study focuses on two objectives: first, finding suitable estimates of vine C partitioning, including above and belowground structures as well as differentiating annual from perennial biomass production; and second, illustrating how C stored in vineyard biomass can be quantified and estimated at different scales, from individual plants to entire vineyard blocks. We also use these measurements to generate simple allometric relationships for vines and C storage, using easy-to-quantify vine properties, such as trunk diameter, cane biomass, and fruit yield, to provide growers and land managers with a tool to rapidly assess the C content of their vines.

It is important to note that the methodologies addressed in this study are low cost, considering how often a vine has to be visited during the season. Furthermore, information used for biomass estimations such as fruit mass and cane weight could be obtained as part of the management itself at no extra cost, representing a very practical and simple tool. This study seeks to fill the above-mentioned voids through an assessment of multiple measurement approaches of grapevine biomass C in a California vineyard. We sampled individual vines to estimate biomass quantity through two methods, standing biomass and bull dozer wood mound volumes following vineyard removal.

This study aims to take advantage of the consistencies in vine age, form and growth conditions in vineyard blocks to deliver an affordable technique for developing predictive equations to estimate the annual and perennial biomass at both the individual vine and vineyard-wide scales.

2 METHODS

2.1 STUDY SITE

Our study site was a vineyard recently annexed to the Cosumnes River Preserve (CRP) in southern Sacramento County, California, USA (Figure 1). CRP is a collection of properties managed by a consortium of public agencies and non-governmental organizations, including The Nature Conservancy (TNC). As part of CRP management, TNC conducted a seasonal floodplain restoration program that included breaching of a levee system previously protecting the study vineyard from seasonal flooding and subsequently switching over to an alternative land use (annual cropping and/or pasture) more compatible with seasonal flooding post-levee breach. As such, we were able to take advantage of the pending removal of this vineyard to measure vine C by different methods, including destructive ones, needed for the study.

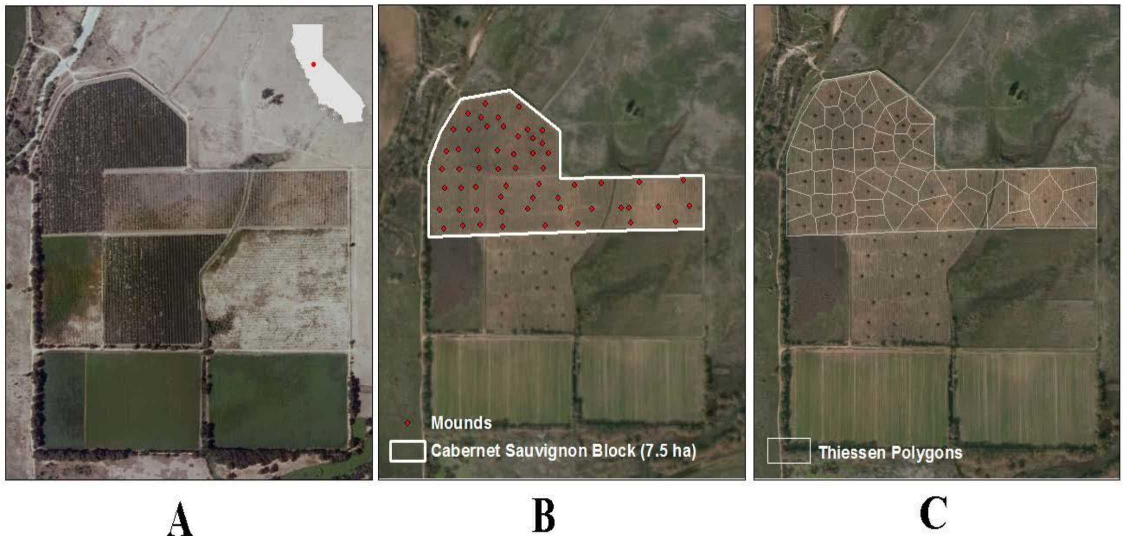

Figure 1 Study site in Cosumnes River Preserve. The location of the vineyard is shown in A (inset), boundaries of the Cabernet Sauvignon vineyard are highlighted in image B. Mounds of vine wood (red symbols) were pushed up after the vines were uprooted, and each one represents wood (trunk and cordons), root and cane biomass harvested in the area delimited by its respective Thiessen polygon (C).

The region is characterized by a typical California Mediterranean climate, with cool wet winters and warm dry summers. The Sacramento-San Joaquin Delta allows for the ‘delta breeze’ at night (cool Pacific air flows) that often moderates peak summer temperatures compared to areas north and south of this location. The site (121°22'33"W, 38°18'19"N) has an annual average precipitation of 15.5 inches which most of the years falls between November and April (Associates, 2008). Daily mean temperatures range from an average of ~11 Celsius degrees (°C) during winter time to ~24 °C during summer time (Table 1). Total growing degree day units (base temp 50°F) for the area are approximately 4,015 (WRCC, 2012) and the frost-free season is approximately 360 days annually (Chave *et al.*, 2005).

Table 1 Summary of daily temperature and annual precipitation in the study area.

Temperature (°C)			Precipitation (Inches)	
Average daily	Summer (Jun-Jul-Aug)	Winter (Jan-Feb-Mar)	Maximum annual	22.8
High	32.4	16.1	Mean annual	15.5
Mean	23.6	10.5	Minimum annual	4.1
Low	14.6	4.9		

Thornton Station, Galt, CA. Elev 3 ft. 38.23 °N, 121.53 °W. Information of the last 10 years. Source: Weather Underground (http://www.wunderground.com/us/ca/thornton)

The site is situated on an extensive alluvial terrace landform with a San Joaquin Series (fine, mixed, active, thermic Abruptic Durixeralfs) (McElhiney, 1992). This soil-landform relationship is widespread, covering approximately 161,874 ha across the east side of California's Great Valley and it is used extensively for wine grape production. The dominant soil texture is clay loam with some sandy clay loam sectors, and the mean soil C content in the top fifteen centimeters is reported at 1.2%.

The vineyard plot consisted of 7.5 ha of Cabernet Sauvignon vines, planted in 1996 at a density of 1,631 plants/ha (3.35 m by 1.83 m spacing). Flood irrigation was implemented during spring and summer seasons.

The vines were trained to quadrilateral cordons using a 2-wire trellis system similar to a modified Geneva Double Curtain structure attached to T-posts (Figure 2). An unusual aspect of these vines is they were own rooted and not grafted onto a phylloxera resistant rootstock and therefore not to a rootstock that might modify vigor or other growth related issues. A likely reason for this approach is the lack of deep ripping of the site's soil that has a root restricting duripan approximately 50 cm below the soil surface. This common vineyard soil type is used for wine grape production with deep ripping to increase rooting depth.

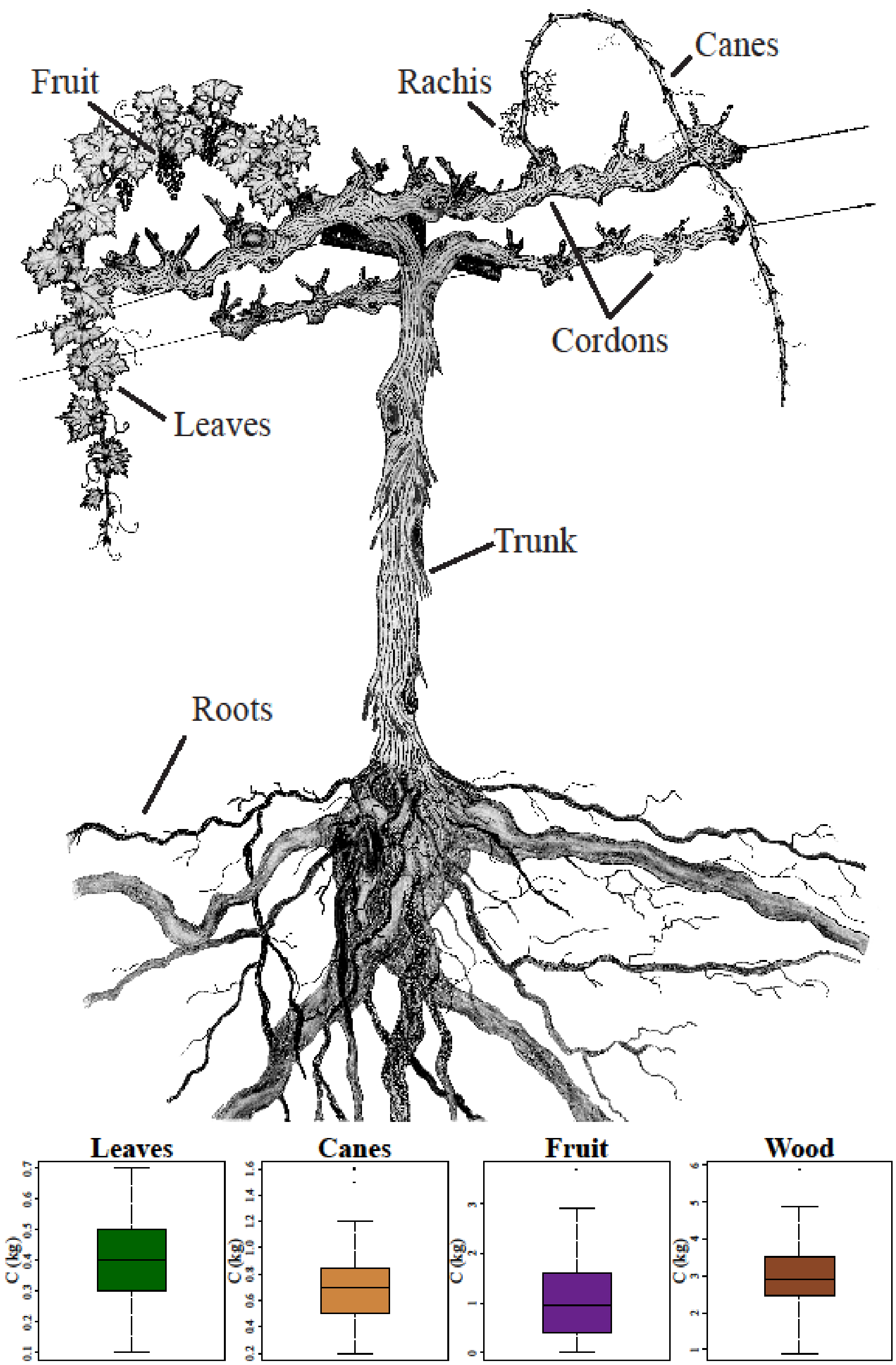

Figure 2 Vine diagram describing major categories of C stocks measurements. Fruit was weighed separately in berries, seeds and rachis. Cordons represent the horizontal arms where the canes grow from. Boxplots show the median and range of C stocks for four categories in Kg C/plant yielded by 60 samples. Axis scales in boxplots are not consistent.

2.2 STANDING BIOMASS QUANTIFICATION

In late summer of 2011 (Sept-Oct), aboveground biomass was measured from 72 vines and belowground biomass was obtained from 3 vines, where the entire root system was pneumatically excavated, dried and weighed. The vineyard (7.5 ha) was divided equally in twelve randomly assigned blocks, and six individual vines from each were processed into major biomass categories of leaf, fruit, cane and trunk plus cordon (Figure 2). The fruit was collected in buckets and weighed fresh in the field. Leaves and canes were collected separately in burlap sacks, and the trunks and cordons were tagged. The biomass was transported off site to partially air dry on wire racks and then in large ventilated ovens.

Plant tissues (leaves, canes, wood, roots, grape skins, pulp and seeds) were dried at 60° C for 48 hours then ground to pass through a 250 μm mesh sieve using a Wiley Mill (www.thomassci.com). Total carbon (%) in plant tissues was analyzed using a PDZ Europa ANCA-GSL elemental analyzer (http://stableisotopefacility.ucdavis.edu/13cand15n.html). Fresh grape berries were frozen and the skins and seeds were separated by hand while berries were kept frozen on dry ice. Juice and pulp were collected and insoluble solids (sugars) measured with a Pocket Refractometer PAL-1 (www.atago.net). Percent C in grape juice was estimated from the measured soluble solids (sugar) concentration. The fraction of insoluble solids (pulp) was measured by filtering out the soluble solids using Q2 filter paper (1-5 um retention, Fisher Scientific) and calculating the weight difference.

In vineyard systems, annual C increment can be represented by fruit, leaves and canes, and is either removed from the system and/or incorporated into the soil C pools, the turnover and decomposition of which was beyond the scope of this study. Structures whose tissues remain in the plant (trunk plus cordons and roots) represented the perennial fraction of C. Perennial wood biomass volume estimates were calculated for model development. Cordon and trunk diameters were measured using a digital caliper at 4 locations per piece and averaged, and lengths were measured with a tape measure. The length and diameter of trunks and cordons were measured with diameters collected at 3-4 locations (generally 10-15 cm from each end and 1 or 2 locations that equally split this distance) to support volume estimates and model development.

The root system exploration started with a pneumatic excavation of 2 m^3 volume (3.3m x 1.6m x 0.4m) of soil using an air gun and compressor. The soil was pre-wetted to field capacity (FC) the previous day using a water truck and hose. The root restricting duripan, common in this soil, provided an effective rooting depth of 40 cm at this site with only 5-10 small roots (generally < 20 mm diameter) seen to penetrate below this depth in each plot.

Employing compressed air applied at 0.7 Mpa (100 psi), moist undisturbed soil material was dislodged and removed exposing root systems for harvest. Root tensile strength was considerable and allowed roots < 2 mm in diameter to remain connected to larger branch roots. We observed very few if any roots in the removed soil. Although no independent measurements were made, the majority of the root system was retained from each vine. The roots were washed, cut into smaller segments and segregated into four size classes (< 2, 2-6, 6-20 and >20mm), oven-dried at 60°C for 48 hours and weighed. The larger roots were left in for 4 days. The average results of root measurements were applied for estimating total C in the rest of the samples.

The underground root scaffold (fraction of the stump immediately above the roots but still located underground) was considered part of the root system for the purposes of this study. Three harvested underground roots were air-dried and weighted.

2.3 Regressions and C models

Simple linear and loess regressions were run using the data collected from 60 out of 72 vines to evaluate relationships between C biomass of different vine fractions. Data for 12 plants were discarded due to lack of a requisite plant organ (e.g., short canes consistent with a diseased vine or lack of leaves or fruit).

The predictive power of the measured vine components for total C biomass was tested by fitting power functions to the relationship between them for the 60 vine samples. For annual C estimations, linear regressions were run for fruit and pruning weight whereas quadratic regression was run to test the power of trunk diameter to estimate woody C (trunk plus cordons).

2.4 Mound Volume and Mass Estimation

A bulldozer was used to uproot vines, and push them together to form mounds representing approximately comparable spatial footprints within the vineyard area. This is a common management practice to concentrate biomass for removal by burning, and the homogeneous distribution of the mounds pursued to optimize time and resources in the transportation of the plant material.

Twenty-six mounds consisting of trunks plus cordons, roots and canes were generated across the northern section of the site. Mound properties, including physical size (basal area, circumsurficial distance, and height) and average mound density, were measured to calculate C mass, compare quantification methods (standing biomass vs mound) and provide support for assessment at increasing spatial scales.

Biomass contribution areas

Biomass contribution areas were defined applying the concept of Thiessen polygon (polygons whose boundaries define the area that is closest to each point relative to all other points). Thiessen polygons were calculated on each mound center using ArcGIS (ESRI, Redlands; v. 10.0). This approach has a central assumption that all vines were pushed equidistantly to the polygon centroid (Figure 1C).

PHYSICAL SIZE

A Topcon Hiper V Real Time Kinematic GPS was used to map boundary vertices of each mound, every 1.5 m. and calculate the base surface polygon and estimate circumference values for each mound. Average mound height (m) was calculated using a stadia rods and a laser clinometer range finder. Moreover, the circumsurficial distance (distance between two points measured across the mound surface) over the major axes of each mound was measured with a calibrated cord and two standardized transects were used to make these measurements, oriented North-South and East-West. Each cord length was measured to support mound volume calculation. Combined these measured parameters were used to estimate mound volume with both semi-ovoid and hemispherical models (see formulas below).

SEMI-OVOID MODEL

For the semi-ovoid model, a set of best-fit resolved radii from the axial circumferences (length [l] and width [w]) and mound height *(h)* (Figure 3 B) were estimated for each mound by calculating the geometric centroid of vertices in ArcGIS for each RTK perimeter, and subsequently the distance from each perimeter vertex to the corresponding centroid. A circular area from the average radius of each mound was then regressed against mapped actual areas, resulting in an area-adjusted model. This area was back-transformed to arrive at best-fit radii for each mound that consisted of an area adjusted radius and corresponding to 95% confidence interval radii. The mound volume was calculated as:

$$V_m = \frac{2}{3}\pi \cdot l \cdot w \cdot h$$

HEMISPHERIC MODEL

The hemispheric model uses a similar volumetric estimation, but rather than the two resolved radii (*l*, *w*) obtained from the axial circumferences in the semi-ovoid model, it uses a single fixed radius (*w/2*) (Figure 3 A). Therefore, volumes were calculated for each mound with each best-fit radius using the formula of one-half the volume of a sphere:

$$V_m = \frac{2}{3}\pi h^3$$

MOUND DENSITY

A standardized volume (~0.08 m^3) of mound biomass was collected by cutting out random sections of the same area from 12 mounds using a plastic container to insure size consistency. Plant material in the mounds included the fractions of trunk plus cordons, roots and canes, and the way the mound elements fill out the container simulated their spatial arrangement in the mound. Samples represent a range of biomass configurations (relative ratio of biomass volume:void) found across the site. Sample contents were divided into vine biomass classes (canes, wood, and roots) dried, and weighed. Relating sample mass with the collection volume supports the calculation of mound density (47.5 kg/m^3) and C mass. Vine category proportion data were compared to the measured vine proportion data to validate the basic assumption supporting these calculations. All biomass data were multiplied by a factor of 0.47 (average C calculated for the three fractions) to estimate C mass (kg). C data were scaled up to the individual mound, unit area, and vineyard totals (Mg/ha).

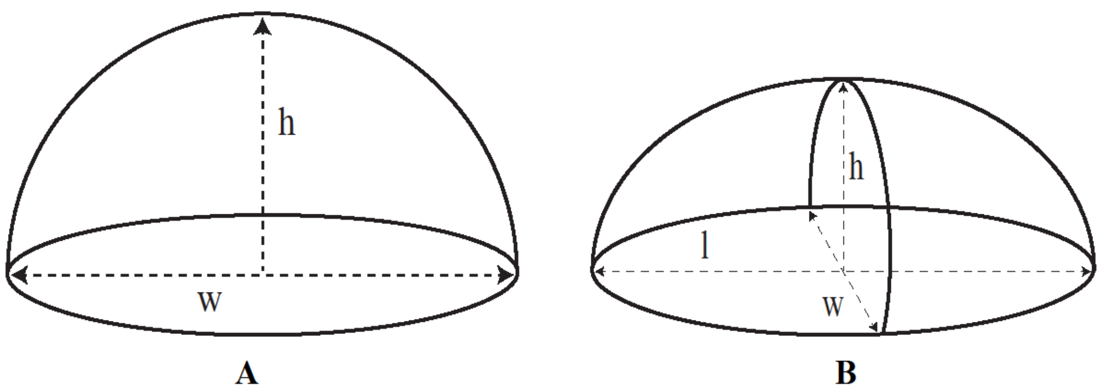

Figure 3 Diagram of mound types used in two different volumetric models for C stock estimations. **A**, Half-ellipsoid mound for semi-ovoid model where w=width, l=length and h=height. **B**, Half-sphere mound for hemispherical model. Lines N-S and E-W correspond to the cardinal point oriented transects measured to calculate w and l.

2.5 LIGHT DETECTION AND RANGING (LIDAR)

Airborne LiDAR data was collected in the summer of 2005 and processed to characterize the first returns (canopy height) and last returns (bare earth DEM) and used to estimate vine volume and biomass quantity. It was assumed since vines reach full production in year 3-4 (http://coststudies.ucdavis.edu/en/current/), that wood increment would not change dramatically cordon and trunk shape between 2005 and 2011. Biomass fractions included wood and annual biomass. Analysis of Lidar data followed a similar path to individual vine and mound biomass quantification by estimating mass of individual vines and the aggregated mass found within Thiessen polygons.

The Laserpoints were collected using an Optech ALTM 3100 LiDAR system mounted in the belly of a Cessna Caravan 208 and set to acquire points at average spacing of >7 points per square meter. The system also recorded individual return intensities (per laser return) that are used to create combined elevation models that display both elevation and surface reflectivity. Quality control real-time kinematic (RTK) GPS data points were collected within the project area using a ground based DGPS station. Data collected were then compared to the processed LiDAR data to ensure accuracies across the project area (Watershed Sciences, 2005). LiDAR volume values were calculated for the 26 Thiessen polygons from where mound volumes were obtained previously. In order to see how well aerial LiDAR quantifies aboveground biomass volume in vineyards, Lidar values were regressed to known mound values for the two models, semi-ovoid and hemispheric, and additionally to the average of the two models.

3 RESULTS

3.1 VINE C STOCKS

Results indicated an average C stock per vine of 7.7 kg (SD=2.0), which constitutes 46% of total dry biomass per vine (16.8 Kg). The partitioning of C stocks for five categories (fruit, leaf, cane, trunk plus cordons, and root) per vine is shown in Table 2. These vine-based values applied to the 1631 vines/ha density translate to an average of 12.3 Mg C/ha (92.3 Mg-C across this 7.5 ha site), with 3.4 Mg C/ha (28%) accumulated annually in canes, leaves and fruit, whereas the remaining 8.9 Mg C/ha (72%) was stored in the perennial fraction (trunk plus cordons and root) (Table 3). As expected, woody tissues (trunk plus cordons) showed the largest C pools, whereas leaves represented the lowest fraction of C.

Table 2 Average biomass and C stocks for both vine fractions and total vine in 60 samples for aboveground and 3 samples for belowground stocks.

Biomass Fractions	n	% C	Dry Biomass		C Stocks			
			Kg/vine	SD	Kg/vine	SD	Mg/ha	SD
Fruit	60	43	2.6	(2.0)	1.1	(0.8)	1.7	(1.4)
Leaves	60	45	0.9	(0.3)	0.4	(0.2)	0.6	(0.3)
Canes	60	48	1.4	(0.6)	0.7	(0.3)	1.1	(0.5)
Wood*	60	48	6.2	(2.1)	3.0	(1.0)	4.8	(1.6)
Roots	3	44	5.7	(0.9)	2.5	(0.4)	4.1	(0.6)
Total			**16.8**	**(4.4)**	**7.7**	**(2.0)**	**12.3**	**(2.5)**

*Wood = Trunk plus cordons

Similar proportions of C stocks representing ~30% each, were found in three groups: root, trunk plus cordons and leaf-fruit-cane (Figure 4). The relative variability within tissue fractions for C stocks ranged from SD = 0.2 in leaves to SD = 1.0 in trunk plus cordons. Table 2 shows the SD values of total plant C and its respective fractions. Total C stocks per plant yielded a higher variability (SD = 2) compared to fraction SD values, and showed a positively skewed distribution (Figure 5) with a similar shape as found in fruit and canes C stock distribution curves (Figure 6).

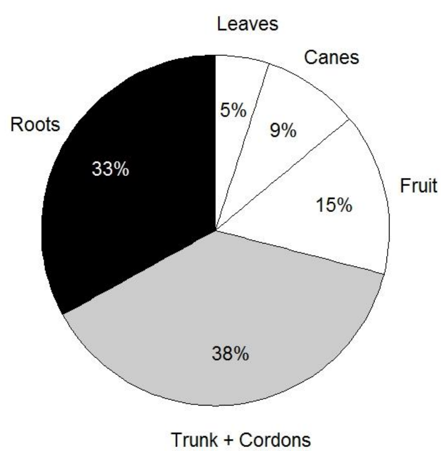

Figure 4 Average percentage distribution of fractions of vine biomass C (Kg/vine). Measurements based on 60 aboveground and 3 belowground samples of 15 year old Cabernet Sauvignon grapevines. White slices represent annual biomass C and black and grey slices indicate perennial biomass C.

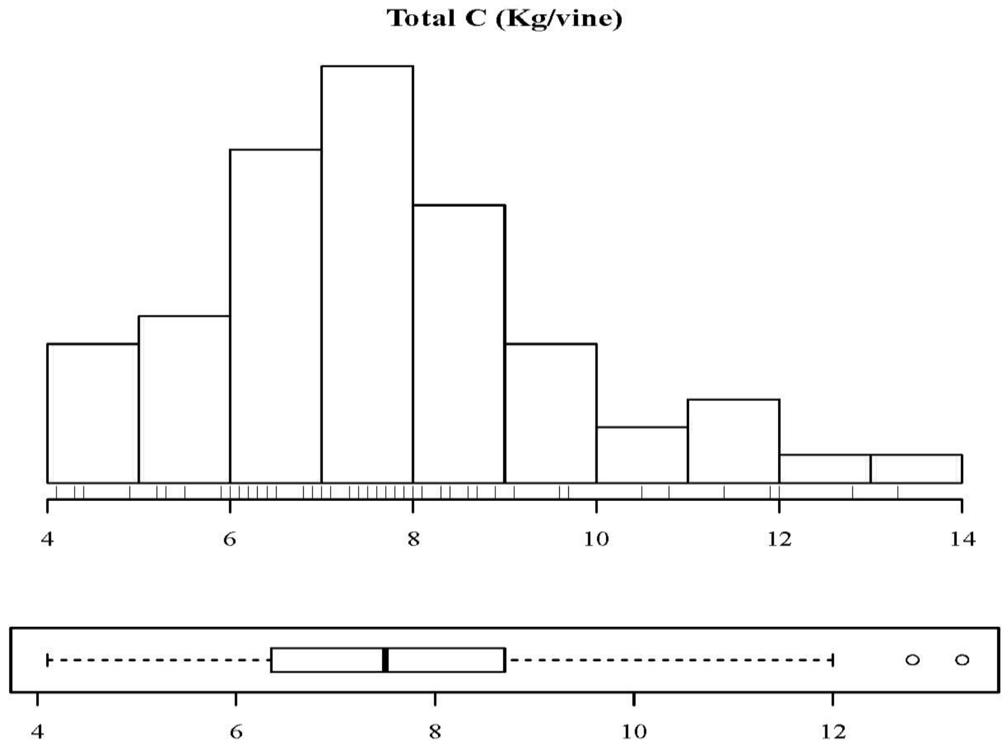

Figure 5 Distribution of total C per vine. Histogram (top) shows a right skewed distribution. Boxplot (bottom) indicates values for median, lower and upper quartiles and extreme values of the curve.

The five categories of vine biomass measured in this study enabled us to quantify C stocks in both temporal (annual vs. perennial) and spatial (aboveground vs. belowground) terms (Table 3). In the temporal domain, relative C allocation was estimated to be 28% (3.4 Mg C/ha) in annual tissues and 72% (8.9 Mg C/ha) in perennial tissues. Per ha, within the annual fraction, the highest variability was seen in fruit (SD = 1.4), whereas trunk plus cordons was the category that shown most variation in the perennial fraction (SD=1.6).

Table 3 Fractions of C sequestration in vines by Time and Space

C distribution	Biomass Fraction	Mg C/ha		%
		Partial	Total	
Temporal				
Annual	Fruit	1.7		
	Leaf	0.6	3.4	28
	Cane	1.1		
Perennial	Trunk plus cordons	4.8	8.9	72
	Root	4.1		
Spatial				
Aboveground	Fruit	1.7		
	Leaf	0.6		
	Cane	1.1	8.2	67
	Trunk plus cordons	4.8		
Belowground	Roots	4.1	4.1	33

Annual growth represents the seasonal vegetative and reproductive development starting in spring and finishing in early fall. Most fruit is removed whereas leaves and canes return to soil.

In the spatial domain, belowground C was estimated at one third of total vine C while aboveground C (trunk plus cordons, fruit, leaves, canes) accounted for 67%. The distribution of the sampled C values per plant category is illustrated in boxplots in Figure 2.

Root C content was estimated as 44% of dry weight. Root size classification and biomass quantification yielded interesting results to understand how biomass is distributed in the root system of vines. Almost 85% of belowground C is located in roots > 6 mm diameter, including the stump which represents ~25% of total root C. Only ~4% was found in roots < 2 mm diameter (Table 4).

Table 4 Biomass and C fractions for five different root diameter classes including the stump. Estimations per hectare are based on vine spacing = 1.83 x 3.35 (1631 vines/ha).

Root diameter classes (mm)	Root Biomass (MT/ha)	Root C (Mg C/ha)	C distribution (%)
<2	0.4	0.16	3.8
2-6	1.2	0.51	12.5
6-20	2.9	1.27	31.3
>20	2.6	1.16	28.6
Stump	2.2	0.97	23.8
Total	**9.2**	**4.1**	**100**

This study also included some spatial-measurements in plant fractions to estimate allometric relationships and possible correlations that might be used to model C stocks in vineyards elsewhere. The 60 samples provided a mean of 58.5 mm for trunk diameter and an average length of 156.8 cm. Trunk weight averaged 2,588 grams (g). Considering the overall regular shape of the trunks, it was calculated the volume of a cylinder to estimate the average trunk volume as 4,234 cubic centimeters (cc) and average wood density as 0.61 g/cc.

Correlating trunk diameter and estimated C stocks in woody tissues (trunk plus cordons) yielded higher coefficients ($r = 0.91$) than for single annual fractions (fruit: $r = 0.54$; leaves: $r = 0.78$ and canes: $r = 0.78$) (Figure 5). Considering the strong correlation mentioned above and the narrow range of trunk diameter found in this study (from 4 to 8 cm), representative of general vineyard managements, a reliable estimation of perennial C stocks can be obtained through this easy-to-measure variable.

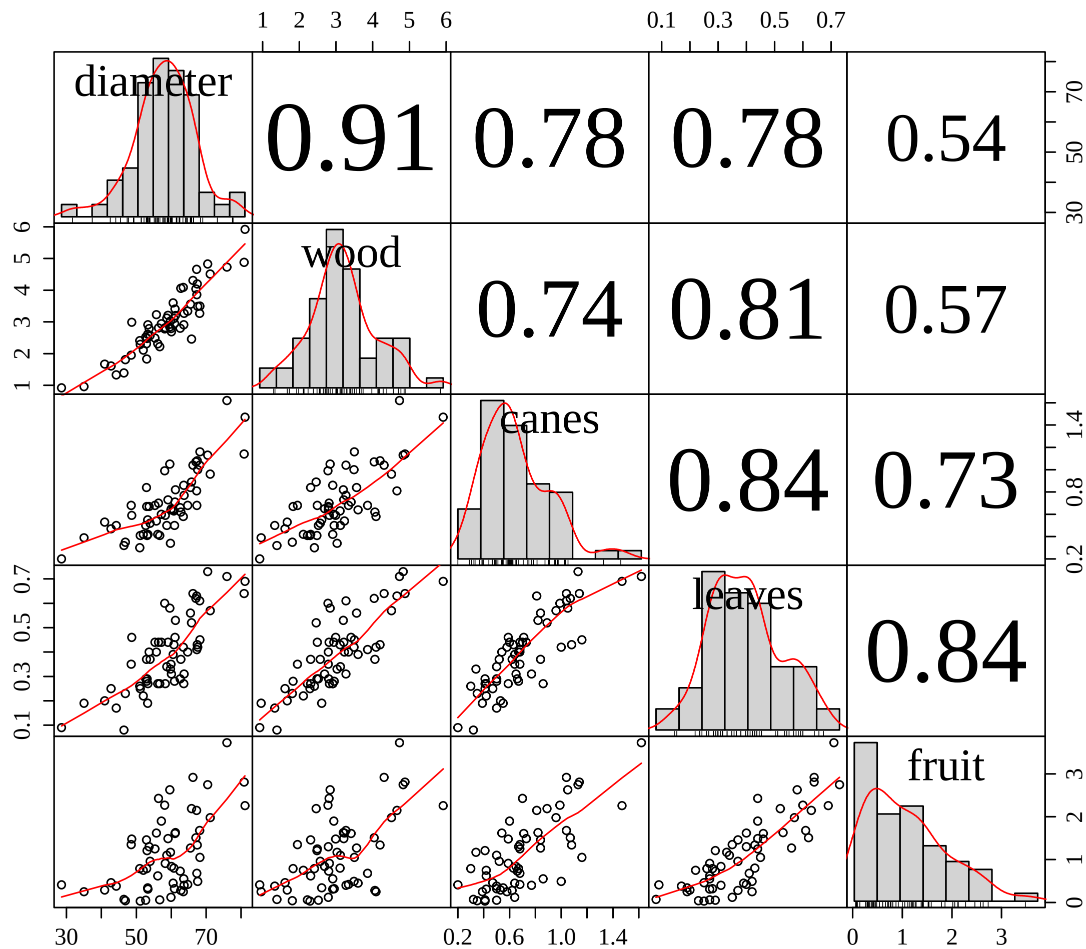

Figure 6 Scatterplot matrix showing correlations between vine C stocks fractions (kg C/vine). C stocks fractions represented by woody C (trunk plus cordons), canes, leaves and fruit (grape clusters including rachis).). The diagonal shows the frequency histograms including kernel density estimation curves (range of values for each variable represented in x axis below or above the respective column). The lower left triangle below the diagonal shows the correlation scatterplots with a loess curve line (x and y axis indicating values for each variable respectively). In the upper right triangle are Pearson correlation coefficients of linear regressions for different vine fractions with all levels of significance $p < 0.001$, (n=60).

The three allometrics evaluated, wet fruit weight, trunk diameter and pruning weight showed coefficients of determination (R^2) of 0.95, 0.84, and 0.72 when regressed to annual C, woody C and annual C, respectively.

3.2 MOUND C STOCKS AND LIDAR

MOUND MODELS

The secondary approach to estimate C stocks by fitting the regular hemispherical and semi-ovoid models produced comparable average biomass values. Our estimations of C stocks per ha quantifying mound biomass yielded an average of 9.93 ± 2.7 (semi-ovoid model) and 10.57 ± 3.6 Mg C/ha (hemispherical model), compared to 10.02 ± 1.9 Mg C/ha obtained by standing biomass considering C stocks estimations of trunk plus cordons, roots and canes (Table 5). Additionally, a paired T-test was run to compare differences between the two mound methods finding no significant differences (95% CI; $p = 0.2$).

A Welch Two Sample t-test applied to check for possible significant differences between the Standing biomass and mound methods found no significant difference (95% CI: $p = 0.72$).

Table 5 Method comparisons for measuring aboveground C stocks in a vineyard. Mounds and standing biomass include trunk plus cordons, root and cane fractions.

Method	Model	Number of samples	Mean (Mg C/ha)	Range (Mg C/ha)	SD (σ)
Standing Biomass		60	10.02	5.9 - 16.2	1.9
Mounds	Semi-ovoid	26	9.93	6.2 – 17.0	2.7
	Hemispherical		10.57	5.9 – 23.4	3.6

LIDAR STANDING BIOMASS SENSING

LiDAR data for aboveground biomass volume yielded a mean ~20 times higher than the average value obtained with mound methods in the correspondent polygons. Additionally, LiDAR showed a broader range of results (Table 6).

Table 6 Aboveground biomass volume calculated with methods LiDAR and Mounds in 26 Thiessen polygons within the vineyard.

Method	Model	Mean (m3)	Range (m3)	SD (σ)
LiDAR		2623.3	1106.4 - 4305.9	747
Mounds	Semi-ovoid	121.5	71.9 - 155.7	22.1
	Hemispherical	128.6	93.7 - 199.6	25.4
	Average	125.1	84.8 - 171.8	18.7

LiDAR data was collected during summer time scanning the biomass fractions of fruit, leaf, canes and trunk plus cordons. Mounds include canes, roots, and trunk plus cordons.

Comparing the mound model results with LiDAR calculations, linear regressions show low Pearson coefficients (Figure 6). Nevertheless, running correlations between polygon area and both volume estimation methods, Lidar yielded a higher positive correlation (R=0.5) compared to mound (R= 0.3) (Figure 7).

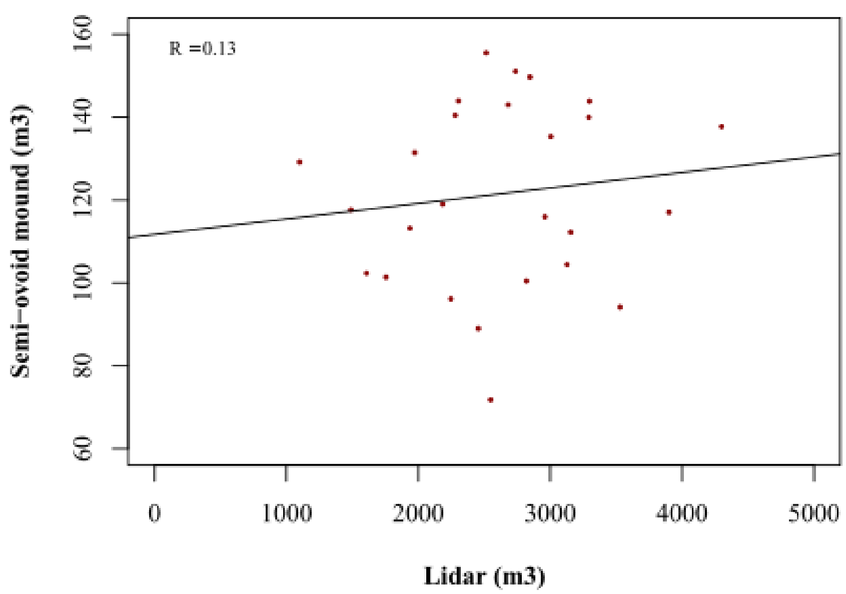

Figure 7 Vine biomass volume correlations. Linear regression between semi-ovoid mound method and Lidar method.

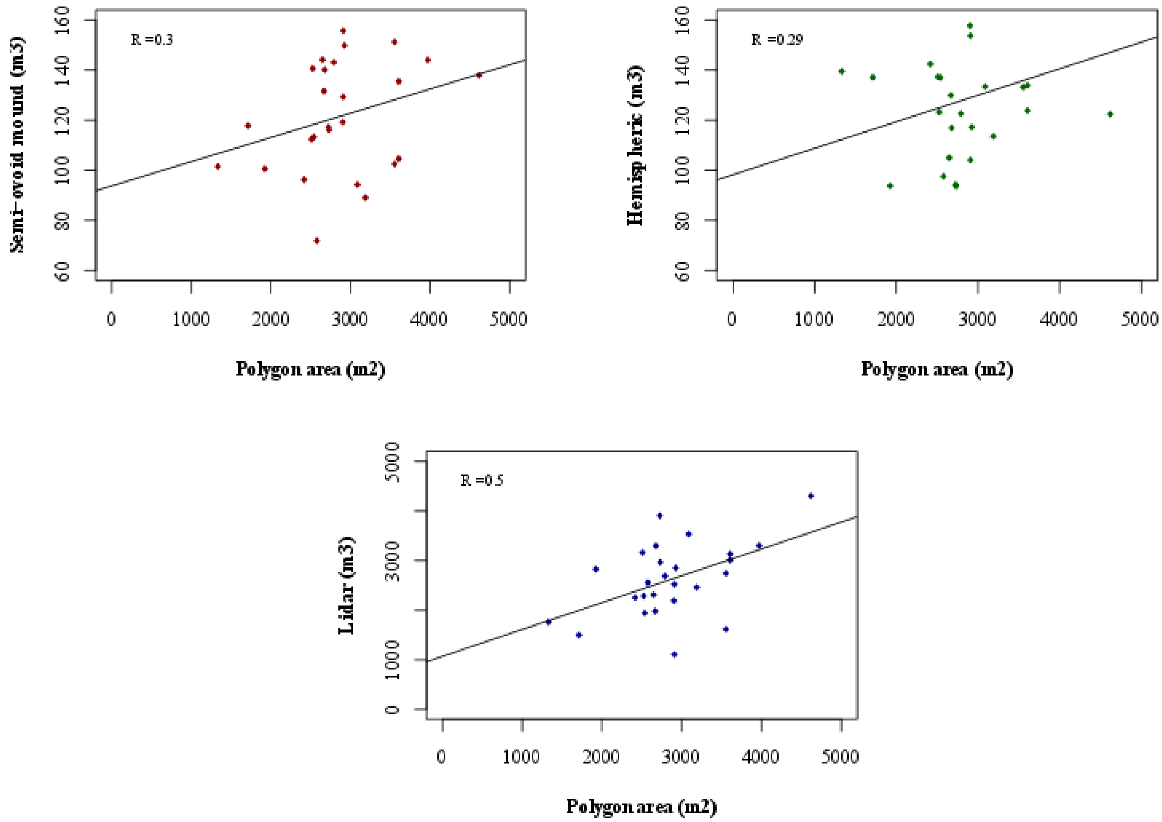

Figure 8 Correlation between vine biomass volume and Thiessen polygon area. Lidar method (bottom) yielded the highest correlation (R=0.5). Mound methods Semi-ovoid (top left) and Hemispheric (top right) showed similar R values.

4 DISCUSSION

Vineyards represent an economically important crop as well as a significant land use in Mediterranean ecosystems around the globe. Besides the Mediterranean basin, this biome also includes Australia, Chile, South Africa, and the Californias (California, USA, and Baja California, Mexico) and is of particular interest in those areas because of their high potential for vineyard expansion (Viers *et al.*, 2013). All together sum ~7M acres of wine grape which represents ~44% of world's surface where this crop is grown. California's wine grape surface represents ~59% of national wine grape surface and 3.3% of the world's (FAO, 2012) with 258.2 M cases sold in 2013, with an estimated retail value of $23.1 billion (Institute, 2014).

Despite being a perennial cropping system where significant fractions of the crop's biomass sequester C in woody tissue for years to decades, there has been no systematic effort to quantify their C storage dynamics. To our knowledge, this study represents one of the first approaches to conduct a comprehensive above and belowground assessment of C storage in both perennial and annual tissues. No vineyard C budgets have been published that consider above and belowground assimilation of C (Wolff, 2011).

Our findings for a 15 years old vineyard yielded a total average C estimation of 12.3 Mg C/ha from which 72% is stored in perennial woody biomass and the remaining 28% in annual growing structures (Table 3). Interestingly, similar proportions were found in spatial fractions where above and belowground structures represented 67% and 33% of total C respectively. Breaking down perennial C in roots and trunk plus cordons' fractions, a fairly even biomass C distribution is observed in the three groups: annual (28%) trunk plus cordons (39%) and roots (33%) (Figure 4).

Among the allometrics studied, trunk diameter (TD) represents a good model (R^2=0.85) and practical tool for woody C (trunk plus cordons) estimations per vine:

$$\text{Woody C} = 0.0031*TD + 0.00081*TD^2$$ (TD: average trunk diameter in mm)

Likewise, wet fruit weight (FW) represents a reliable measurement (R^2=0.96) to estimate annual C storage in vines:

$$\text{Annual C} = 0.65 + 0.14 * FW$$ (FW: average total wet fruit weight per vine in kg)

A third measurement, pruning weight (PW) or cane biomass, is also highly correlated to annual C estimations per vine (R^2= 0.72), constituting another simple-to-measure variable that can be used for this purpose.

$$\text{Annual C} = 1.6 * PW$$ (PW: average total dry cane weight per vine in kg)

In addition to C per vine, reliable models for C estimations per ha were obtained from this representative California vineyard (Figure 8 D,E,F). After acquiring allometrics and C estimations per vine, these data can be easily scaled up to quantify C stocks per surface unit according to any particular situation (different vine densities and training systems).

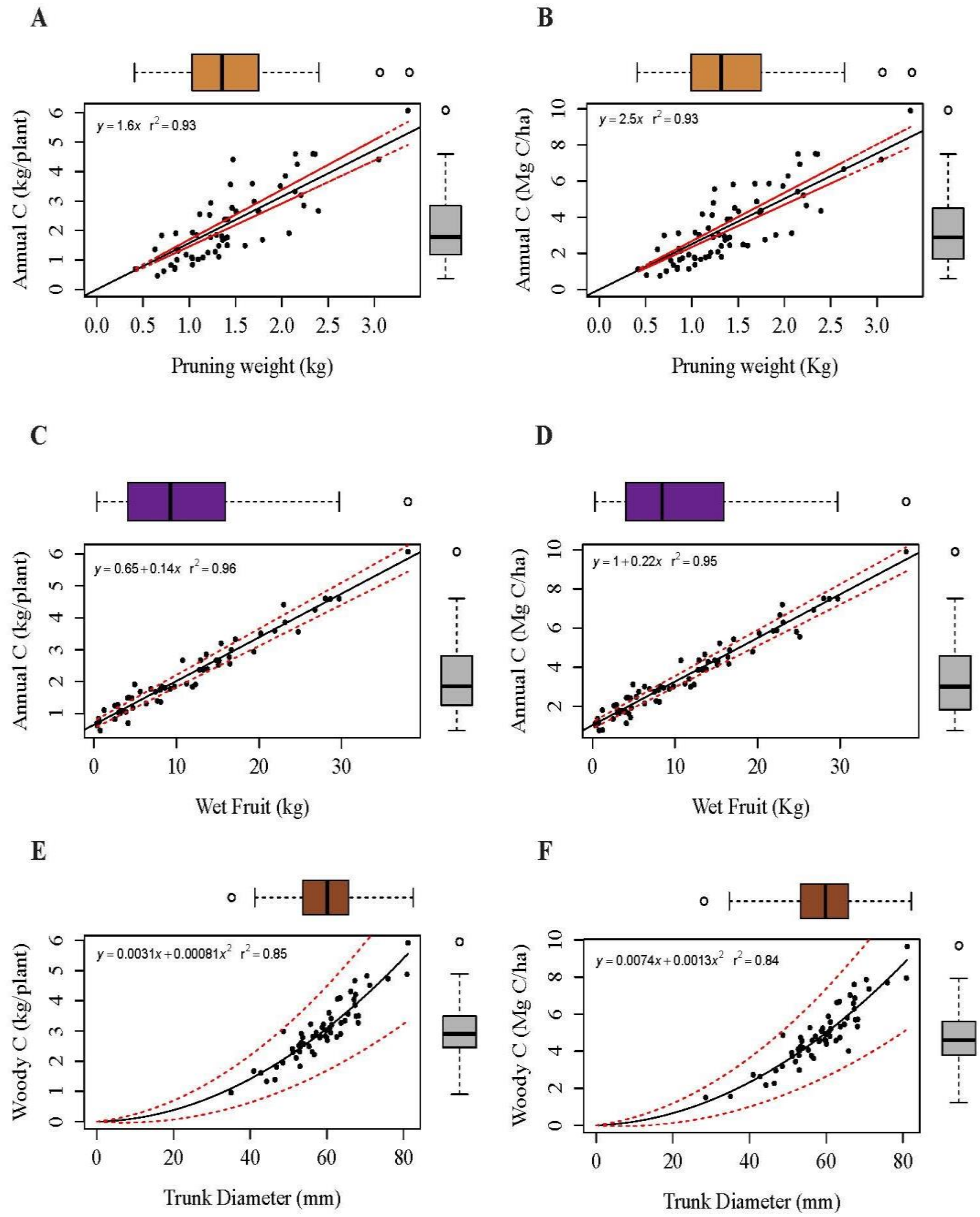

Figure 9 Linear and quadratic regression curves for three vine allometrics. 95% confidence interval indicated by red dotted line. Left column: Estimations in Kg C per plant. **Right column:** Estimations in Mg C per ha. (A, D) Pruning weight and Annual C stocks (R^2 = 0.93 and 0.93 respectively, $p < 0.05$), (B, E) Fresh fruit weight and Annual C stocks (R^2 = 0.96 and 0.95 respectively, $p < 0.05$), (C,F) Trunk diameter and Woody C stocks (R^2 = 0.85 and 0.84 respectively, $p < 0.05$). Annual C stock represents the C content of

Canes, Leaves and Fruit together. Woody C stock expresses the C content of Trunk plus cordons. Boxplots show the distribution of C stock values (y axis-right) and the measured variable (X axis-top).

The main contribution provided by these positive-correlated allometric relationships is that they represent simple-manageable tools that both table and wine grape growers can implement as part of the actual management plan with low extra operational costs. In point of fact, two of them, fruit and pruning weights represent bound practices for all vine orchards when they are harvested and pruned, respectively. In addition, it is important to consider the spatio-temporal scale for the application of these allometrics. Regarding spatial scale applications, this study provides evidence for good estimations at small-medium size orchards levels with relatively small variability in vine's anatomy. There are techniques of developing terrestrial C budget by measuring above and belowground components and a consideration in using this approach is the large-scale spatial variability and poor statistical sensitivity in both components (Homann *et al.*, 2001). In terms of temporal dimensions, since grapes constitute a perennial deciduous species, seasonal (annual) C sequestration is easier to be delimited from perennial C, compared to ever-green perennial crops. Annual C stocks accounted for roughly one third of total C in this study, and they represent the plant categories that are removed partial or totally via natural or human-induced processes in a vineyard (Leaf, Fruit, Cane). However, there is an additional fraction captured annually by wood and roots that it is considered in the perennial C fraction.

A study run in grapevines in California in the late 1990s found net primary productivity (NPP) values between 550 g C/m^2 (5.5 Mg C/ha) and 1100 g C/m^2 (11 Mg C/ha) (Christensen, 2000) which are comparable to our average estimation of 12.3 Mg C/ha. In terms of spatial distribution, Kroodsma et al. (Kroodsma and Field, 2006) data of standing biomass (1.0 to 1.3 Mg C/ha woody C for nuts and stone fruit species, and 0.2 to 0.4 Mg C/ha for vineyards) are significantly lower than our estimates for vineyards (4.8 Mg C/ha). Additionally, our results in vineyards yielded an average of 53% of the total annual biomass C to harvested clusters which is comparable to the range of 35-50% reported by Williams (Williams, 2000). This 53% would be lower if we quantify annual growth in wood and roots. For vineyard pruning weight, our results of 1.1 Mg C/ha (2.3 Mg biomass/ha) are comparable to the estimated 2.5 Mg of pruned biomass per ha for both almonds (Holtz *et al.*, 2004) and vineyards (Christensen, 2000).

Our study includes the characterization of root sizes in vineyards whose average estimation of C content yielded 3.1 Mg C/ha (25% total vine C, not considering stump) (Table 4), which lies between the range of 20-30% yielded by some studies (Elderfield, 1998).

Predictive functions for aboveground biomass derived from allometric equations (based on trunk diameter) in natural systems obtained by Saatchi (Saatchi *et al.*, 2011) yielded similar predictive power (R^2 = 0.73 to 0.86, P < 0.001) to our trunk diameter-woody C (R^2 = 0.85, P < 0.05). This provides an insight on how well this approach could be applied to other crops managed under a diverse range of planting designs. The high coefficient of determination (0.85) in our results may be explained by the higher structural homogeneity in the vine system compared to natural ones.

The integration between crops and naturals systems has been manifested as an interesting alternative to offset potential net annual loss of aboveground C. Our results contribute to obtain more accurate calculations of the C sequestration by the crop component of these systems, taking into account the importance of considering vineyards both as crops and in the context of natural vegetation and the Mediterranean habitats in which they occur.

Vineyards are considered one of the most promising systems in California and this study provides not only a quantification of the C stocks but also simple methods to estimate them temporal and spatially under different training systems. The importance of these results and methodologies lies in its novel informative value and simple applicability by winegrape growers, respectively. Incentives offered to the wine industry, might be extended to other types of both annual and perennial cropping systems, to which this study certainly confers valuable information. In the case of table grapes, for instance, estimating C employing the allometrics may provide a good approach even though the training system and final product differ significantly to the wine grape's. Higher trunk diameter and larger fruit harvest are expected in this system, which would support prediction of higher values of woody and annual C respectively. The biomass fractions values will likely change as well, according to table grape train systems that seek higher yields and denser canopies for larger photosynthetic area and partially shady conditions for the fruit. Similar situation would be expected for other fruit crops such as citrus, pommes, stone fruit, nuts and even some systems of perennial berries, where this study provides wide applicable methods that subsequently need to be adapted to each particular cropping system's situation to be implemented successfully.

The mound's approach implemented in this study yielded C estimations significantly similar to standing biomass (Table 5), which makes the first a reliable tool for spatial characterization in orchards. Spatially, mounds represent the biomass of a unit surface area (Thiessen polygon) (Figures 1B, 1C), and the fact of being a destructive method makes it valuable only as a reference to validate non-invasive alternative options. The use of satellite imagery and unmanned aerial vehicles (UAV) would enable to pair methods such as remote sensing mapping (e.g., LiDAR) with our allometrics, fruit harvest, or soil sampling to deliver a robust estimation of C spatial distribution in orchards. The quantification of destructively harvest vines, thus, should be restricted to uprooted orchards.

LiDAR scanning was included in the research to see how it correlates with the accurate but expensive and time-demanding mound method. Additionally, it was intended to calculate the correlation with a specific area, which was represented by Thiessen polygons in this case. Ultimately, both approaches pursue to quantify C stocks by calculating biomass volume. Since vineyard's biomass is varying constantly due to annual growth or management decisions such as ripping vines off, LiDAR would constitute a fairly practical tool to evaluate biomass variations over time.

The differences between LiDAR and mound volume values, can be explained in part because terrestrial LiDAR was not included in the study and provides important additional information to aerial LiDAR for vineyard volume calculations. Higher values obtained with LiDAR might have an explanation on that. Although vineyard aboveground biomass was relatively homogeneous, LiDAR yielded high variability in the results compared to both mounds and standing biomass, even though the area of the polygons did not differ significantly from each other. It is important to remark that LiDAR measurements were taken during summer season, and thus the higher biomass estimation is expected since mounds do not include neither leaves nor fruit. Additionally, empty spaces inside the canopy could have been considered as part of the volume calculated by aerial LiDAR.

Future research including terrestrial LiDAR and data collection during different seasons will be useful to complement information obtained in this research. Adding LiDAR data sensed from the ground would enable to capture elements that might be missed by aerial LiDAR, providing valuable input to refine results. Moreover, testing different seasons, varieties and/or wine locations might help to fathom what this tool can truly add to C quantification.

Although our results represent an important progress for both the information and methodologies delivered, in order to broaden the understanding of C sequestration it is necessary to replicate this study to different varietals and age classes, and even species. In wine grape, differences in aboveground C were explained by the age of the vines, which was tightly correlated with biomass and C content (Williams *et al.*, 2011b). With respect to temporal C, some of the C fraction contained in wood and roots and measured as perennial, technically constitutes annual accumulation. In order to determine this differences and fully characterize the dynamic nature of annual C storage in a vineyard, a continuous sampling schedule over years should be considered, including roots removal.

Physiologically, there are significant differences between crop species with regards to biomass growth and C allocation during the season and in the long run. Obtaining data about different crop genders (e.g., Prunus) would allow to develop C stock models for estimating C in gender-shared species (e.g., Almond, Peach, Cherry). In addition to intrinsic species characteristics, understanding which management practices and environmental variables best explain the variation in aboveground woody biomass and obtaining values for these variables at the appropriate temporal and spatial scale will improve biomass plant C estimates. Interestingly, a model developed for C acquisition and utilization by kiwifruit (*Actinidia deliciosa*) vines includes both plant physiological mechanisms and environmental elements for identify critical components of the whole plant C economy and integrate plant- environment interactions at the whole plant level (Buwalda, 1991).

Among the abiotic components involved in C storage in agricultural systems, soil plays a major role. Although it is not included in this study, it is necessary to understand SOC dynamics considering its strong linkage with aerial C and its part in C storage/emissions. The greater C proportion compared to aerial C biomass in most of the systems indicates that soil constitutes the highest storage capacity regardless the amount of C sequestered by plant biomass. Findings by Williams et al. in California vineyards showed average ratios of 3.0/84.1 Mg C/ha (Aerial woody C/Soil C). These high relative C amounts stored in the soils are, however, vulnerable to be released back to the atmosphere depending on the type of management applied to the vineyard.

Independently of the plan designed to optimize aerial C sequestration in vineyard systems, soil needs to be taken into account to minimize C losses and optimize the total C sequestration in the system. Orchards and vineyards tend to have multiple within-site farming practices for soil management that affect C cycling. Commonly, the presence of drier soils in the driveways between trees and vines in orchards and vineyards can boost methane oxidation (consumption) but may result in lower soil C retention (Hartmann *et al.*, 2011). Tillage, a regular practice among winegrape growers for controlling weeds and reducing soil compaction is expected to decrease SOC levels as a result of an increase in microbial respiration. In the other hand, alternatives such as cover crops may increase C input into soils and should thereby contribute to an increase in SOC over time in many Mediterranean systems (Kong *et al.*, 2005). C losses from agricultural soils mainly occur because of soil management practices that increase the decomposition rates of soil organic matter and the amount of organic topsoil C that is lost through erosion (Novara *et al.*, 2012).

Practices that both incorporate C and preserve them in the soil need to be implemented in vineyard systems. This includes the incorporation of biomass removed and not used for other purposes such as canes, leaves, rachis, cordon fractions, etc. and soil conservation practices like the use of cover crops and reduction of tillage.

More research is needed in vineyards and horticultural systems to integrate the elements mentioned above and obtain more accurate and reliable estimations of C sequestration. Evaluating the practices needed to achieve this purpose will provide a better understanding about their applicability and benefits for and beyond C sequestration in perennial cropping systems.

In the current scenario of threats and uncertainties associated to climate change, it is necessary to provide knowledge to dispel possible queries and bring concrete solutions to prevent and mitigate its negative effects. The wine industry and some groups in the agricultural sector are embarking in the challenge of reaching zero C balance in their respective productive processes (e.g., Carbon Accounting Protocol for the International Wine Industry). Quantifying C inputs and outputs is a "must" if C balance needs to be calculated regardless the level in the productive chain where the emissions/captures are taking place. It is common to hear about the negative impact of Agriculture emphasizing C emissions, but corrective actions cannot be taken without robust information. In addition to provide a quantitative reference for C sequestration in vineyards, the fact of simplifying aerial C stocks estimations to winegrape growers through easy methods supports those goals imposed by the wine industry. Nevertheless, if the wine industry are to get recognized for their contribution to C storage, there is a need to support C quantification in vineyards and that is not currently occurring in places like California where C accounting is becoming mandatory. This process is taking place through the implementation of the Assembly bill 32 (AB 32), the state law that requires statewide reductions of GHG emissions to 1990 levels by 2020 (CEPA, 2015). It is not yet clear what the potential impact of climate change and rising CO2 on GHG mitigation strategies will be, but it has definitely to be taken into account when implementing agricultural C sequestration.

Developing countries are required to produce robust estimates of forest C stocks for successful implementation of climate change mitigation policies related to reducing emissions from deforestation and degradation (Saatchi *et al.*, 2011), idea that fits fairly well with the role that the wine grape industry might play in recovering the degraded Mediterranean biomes.

Incentive programs supporting C sequestration practices are likely to thrive where tangible benefits are the outcomes. Offsetting current C emissions translated to economic benefits to implementers is certainly a motivation. Significant changes, however, entail a collective effort, where growers, industry leaders and policy makers need to point out to the same direction, defining clearly the future steps to successfully implement agricultural C sequestration programs.

5 CONCLUSIONS

California's wine industry is recognized worldwide and constitutes a significant economic impact at state and country level. Later concerns regarding global warming have motivated actions by the sector to seek practices that contribute to mitigate it through efforts to reduce the C footprint associated to winegrape production. This research provides simple methods, easily applicable by grape growers that enable the estimation of spatial and temporal C stocks in the diverse spectrum of vineyard systems. Strong correlations between accessible-to-measure vine traits (trunk diameter) or biomass production (fruit and pruning weight) and C stocks allow the development of allometric models that can be used for these purposes. The successful implementation of these methods in vineyards could extend its adoption by other perennial cropping systems scaling up their benefits to other areas in the agricultural sector. Finally, these methods may be supported by the use of AgTech tools especially those that quantify biomass volume remotely for which future research is encouraged.

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APPENDIX I: SUMMARY AND DESCRIPTION OF DATA

A. Vine biomass and Carbon contents

Biomass for vine fractions (Kg/plant)

Sample	Trunk	Canes	Leaves	Fruit	Roots	Total
1	8.7	2.2	1	3.1	5.7	20.7
2	5.8	1.2	0.6	2.1	5.7	15.4
3	5.6	1.4	0.7	1.9	5.7	15.3
4	5.8	1.4	0.6	1.7	5.7	15.2
5	5.4	1.1	0.4	0.8	5.7	13.4
6	6.8	1.6	0.7	0.9	5.7	15.7
7	5.8	2	1.3	5.2	5.7	20
8	5.8	1.4	0.9	3	5.7	16.8
9	8	1.4	0.9	1.6	5.7	17.6
10	6.5	1	0.7	2.5	5.7	16.4
11	6.1	1.2	1	4.4	5.7	18.4
12	12.2	3	1.5	5.2	5.7	27.6
13	9.8	3.4	1.6	8.6	5.7	29.1
14	9.3	2	1.3	4.6	5.7	22.9
15	5.9	2.2	1.3	6.1	5.7	21.2
16	5.8	1.4	1	5.6	5.7	19.5
17	7.1	1.5	1	3.7	5.7	19
18	4	1.4	0.8	3.1	5.7	15
19	3.5	1.1	0.4	0.7	5.7	11.4
20	10	2.3	1.6	6.3	5.7	25.9
21	3.3	1	0.6	1.1	5.7	11.7
22	9.6	1.7	1.4	5	5.7	23.4
23	8.5	1.2	0.9	0.6	5.7	16.9
24	8.4	1.3	0.8	0.7	5.7	16.9
25	1.9	0.4	0.2	0.9	5.7	9.1
26	7.5	1.3	0.9	1	5.7	16.4
27	6	0.9	0.6	0.7	5.7	13.9
28	10.1	2.4	1.4	6.5	5.7	26.1
29	6.7	1.1	0.9	3.7	5.7	18.1
30	5.1	0.9	0.6	2.8	5.7	15.1
31	6.4	1.3	0.9	1.9	5.7	16.2
32	5.2	1.4	1	2.9	5.7	16.2
33	8.4	2.2	1.4	3.5	5.7	21.2
34	3.8	1.4	0.6	1.8	5.7	13.3
35	5.2	1	0.6	0.1	5.7	12.6
36	4.6	0.8	0.6	0.1	5.7	11.8
37	3.7	0.7	0.5	0.1	5.7	10.7
38	4.7	0.8	0.6	0.1	5.7	11.9
39	5.8	1.3	0.8	0.3	5.7	13.9
40	5.3	1.1	0.8	2.2	5.7	15.1
41	6.3	0.7	0.7	2.7	5.7	16.1
42	5	0.6	0.6	1.8	5.7	13.7

43	6.2	1.2	1	3.4	5.7	17.5
44	4.8	0.9	0.6	1.4	5.7	13.4
45	6.1	1	0.6	0.7	5.7	14.1
46	4.4	0.9	0.5	1.7	5.7	13.2
47	6.8	2.1	1.3	3.9	5.7	19.8
48	6.6	1.7	1.2	3.8	5.7	19
49	6.7	1.5	1	3.4	5.7	18.3
50	8.9	2.1	1.4	6.7	5.7	24.8
51	2	0.8	0.4	0.6	5.7	9.5
52	7.4	1.7	1.2	2.9	5.7	18.9
53	7.2	2.4	1	2.4	5.7	18.7
54	6	1.8	0.6	1.3	5.7	15.4
55	7.2	2.1	0.9	1.1	5.7	17
56	4.8	1.7	0.8	3.4	5.7	16.4
57	2.8	1	0.4	0.9	5.7	10.8
58	2.9	0.7	0.2	0.2	5.7	9.7
59	6.9	1.4	0.9	1	5.7	15.9
60	5.1	1.8	1.1	5.1	5.7	18.8

Carbon for vine fractions (Kg Carbon/plant)

Sample	Trunk	Canes	Leaves	Fruit	Roots	Total
1	4.2	1.1	0.4	1.3	2.5	9.6
2	2.8	0.6	0.3	0.9	2.5	7.1
3	2.7	0.7	0.3	0.8	2.5	7.0
4	2.8	0.7	0.3	0.7	2.5	7.0
5	2.6	0.6	0.2	0.3	2.5	6.2
6	3.3	0.8	0.3	0.4	2.5	7.3
7	2.8	1.0	0.6	2.3	2.5	9.1
8	2.8	0.7	0.4	1.3	2.5	7.7
9	3.9	0.7	0.4	0.7	2.5	8.1
10	3.1	0.5	0.3	1.1	2.5	7.6
11	2.9	0.6	0.4	1.9	2.5	8.4
12	5.9	1.5	0.7	2.3	2.5	12.8
13	4.7	1.6	0.7	3.7	2.5	13.3
14	4.5	1.0	0.6	2.0	2.5	10.5
15	2.8	1.1	0.6	2.6	2.5	9.6
16	2.8	0.7	0.4	2.4	2.5	8.9
17	3.4	0.7	0.5	1.6	2.5	8.7
18	2.0	0.7	0.4	1.4	2.5	6.8
19	1.7	0.5	0.2	0.3	2.5	5.2
20	4.8	1.1	0.7	2.8	2.5	11.9
21	1.6	0.5	0.3	0.5	2.5	5.3
22	4.7	0.8	0.6	2.2	2.5	10.8
23	4.1	0.6	0.4	0.3	2.5	7.9
24	4.1	0.6	0.4	0.3	2.5	7.8
25	0.9	0.2	0.1	0.4	2.5	4.1
26	3.6	0.6	0.4	0.5	2.5	7.6
27	2.9	0.4	0.3	0.3	2.5	6.4

28	4.9	1.1	0.6	2.8	2.5	12.0
29	3.2	0.5	0.4	1.6	2.5	8.3
30	2.5	0.4	0.3	1.2	2.5	6.9
31	3.1	0.6	0.4	0.8	2.5	7.5
32	2.5	0.7	0.4	1.3	2.5	7.4
33	4.0	1.1	0.6	1.5	2.5	9.7
34	1.8	0.7	0.3	0.8	2.5	6.1
35	2.5	0.5	0.3	0.1	2.5	5.9
36	2.2	0.4	0.3	0.1	2.5	5.5
37	1.8	0.4	0.2	0.0	2.5	4.9
38	2.3	0.4	0.3	0.0	2.5	5.5
39	2.8	0.6	0.4	0.1	2.5	6.4
40	2.6	0.5	0.4	1.0	2.5	6.9
41	3.0	0.3	0.3	1.2	2.5	7.4
42	2.4	0.3	0.3	0.8	2.5	6.3
43	3.0	0.6	0.5	1.5	2.5	8.0
44	2.3	0.4	0.3	0.6	2.5	6.1
45	3.0	0.5	0.3	0.3	2.5	6.5
46	2.1	0.4	0.2	0.8	2.5	6.0
47	3.3	1.0	0.6	1.7	2.5	9.1
48	3.2	0.8	0.5	1.6	2.5	8.7
49	3.2	0.7	0.4	1.5	2.5	8.4
50	4.3	1.0	0.6	2.9	2.5	11.4
51	1.0	0.4	0.2	0.3	2.5	4.3
52	3.6	0.8	0.6	1.3	2.5	8.7
53	3.5	1.2	0.5	1.1	2.5	8.7
54	2.9	0.9	0.3	0.6	2.5	7.1
55	3.5	1.0	0.4	0.5	2.5	7.9
56	2.3	0.8	0.4	1.5	2.5	7.5
57	1.3	0.5	0.2	0.4	2.5	4.9
58	1.4	0.3	0.1	0.1	2.5	4.4
59	3.3	0.7	0.4	0.4	2.5	7.3
60	2.5	0.9	0.5	2.2	2.5	8.6

Carbon for vine fractions (Mg Carbon/ha)

Sample	Trunk	Leaves	Canes	Fruit	Roots	Total
1	6.9	0.7	1.8	3.7	4.1	17.2
2	4.6	0.4	1.0	2.1	4.1	12.2
3	4.4	0.5	1.1	1.1	4.1	11.2
4	4.6	0.5	1.1	1.8	4.1	12.1
5	4.3	0.3	0.9	3.1	4.1	12.7
6	5.3	0.5	1.3	3.7	4.1	14.9
7	4.5	1.0	1.6	0.5	4.1	11.7
8	4.6	0.7	1.1	4.5	4.1	15.0
9	6.3	0.7	1.1	0.7	4.1	12.9
10	5.1	0.5	0.8	0.8	4.1	11.3
11	4.8	0.7	1.0	3.5	4.1	14.1
12	9.7	1.1	2.4	0.7	4.1	18.0
13	7.7	1.2	2.6	0.4	4.1	16.0
14	7.4	0.9	1.6	0.5	4.1	14.5
15	4.6	0.9	1.7	0.7	4.1	12.0
16	4.6	0.7	1.1	0.7	4.1	11.2
17	5.6	0.7	1.2	0.5	4.1	12.1
18	3.2	0.6	1.1	4.6	4.1	13.6
19	2.7	0.3	0.9	2.7	4.1	10.7
20	7.9	1.2	1.8	2.0	4.1	17.0
21	2.5	0.3	0.6	1.3	4.1	8.8
22	2.6	0.4	0.8	2.1	4.1	10.0
23	7.6	1.0	1.3	2.5	4.1	16.5
24	6.7	0.7	0.9	2.8	4.1	15.2
25	6.6	0.6	1.0	2.7	4.1	15.0
26	1.5	0.1	0.3	2.4	4.1	8.4
27	5.9	0.6	1.0	4.8	4.1	16.4
28	4.7	0.4	0.7	0.4	4.1	10.3
29	5.3	0.7	0.9	0.9	4.1	11.9
30	4.0	0.5	0.7	0.5	4.1	9.8
31	5.1	0.7	1.0	2.2	4.1	13.1
32	4.1	0.7	1.1	1.0	4.1	11.0
33	6.6	1.0	1.7	0.2	4.1	13.6
34	3.0	0.5	1.1	0.1	4.1	8.8
35	4.1	0.5	0.8	0.1	4.1	9.6
36	3.6	0.4	0.7	0.1	4.1	8.9
37	3.0	0.4	0.6	0.1	4.1	8.2
38	3.7	0.4	0.7	0.1	4.1	9.0
39	4.5	0.6	1.0	0.2	4.1	10.4
40	4.2	0.6	0.9	1.6	4.1	11.4
41	4.9	0.5	0.6	1.9	4.1	12.0
42	3.9	0.4	0.5	1.3	4.1	10.2
43	4.9	0.7	1.0	2.4	4.1	13.1
44	3.8	0.4	0.7	1.0	4.1	10.0
45	4.8	0.5	0.8	0.5	4.1	10.7
46	3.4	0.4	0.7	1.2	4.1	9.8
47	5.3	1.0	1.7	0.1	4.1	12.2
48	5.2	0.9	1.3	0.7	4.1	12.2
49	5.2	0.7	1.2	4.0	4.1	15.2
50	7.0	1.1	1.7	0.6	4.1	14.5
51	1.6	0.3	0.6	3.6	4.1	10.2
52	5.8	0.9	1.4	1.9	4.1	14.1
53	5.7	0.7	1.9	1.5	4.1	13.9

54	4.7	0.4	1.4	1.4	4.1	12.0
55	5.7	0.7	1.6	1.2	4.1	13.3
56	3.8	0.6	1.4	0.6	4.1	10.5
57	2.2	0.3	0.8	0.7	4.1	8.1
58	2.3	0.1	0.5	6.1	4.1	13.1
59	5.5	0.7	1.1	3.3	4.1	14.7
60	4.0	0.8	1.4	2.6	4.1	12.9

B. Wood and Annual Biomass and Carbon contents

Wood biomass per vine (g)

Sample	Trunk Biomass		Cordon Biomass		Total Wood Biomass	
	Wet	Dry	Wet	Dry	Wet	Dry
1	7842.7	3386.2	8738.8	5314.0	16581.5	8700.2
2	5035.8	2312.8	5774.2	3514.9	10810.0	5827.7
3	5179.2	2291.2	5131.7	3286.5	10310.9	5577.7
4	5745.5	2384.0	6170.4	3413.0	11915.9	5796.9
5	4908.4	2306.8	4122.8	3089.4	9031.2	5396.2
6	6050.0	2630.7	6185.8	4135.7	12235.8	6766.4
7	5559.6	2581.0	5837.3	3183.8	11396.9	5764.8
8	5158.3	2413.9	5031.7	3363.0	10190.0	5776.9
9	6856.8	3152.2	9085.1	4829.2	15941.9	7981.4
10	6213.8	2865.5	6502.8	3593.7	12716.6	6459.2
11	6234.4	2709.4	7018.6	3384.4	13253.0	6093.8
12	9926.1	4011.5	12712.2	8233.8	22638.3	12245.2
13	8754.8	3747.8	10295.4	6038.0	19050.2	9785.8
14	7075.3	3124.5	9063.1	6217.5	16138.4	9342.0
15	5801.6	2586.0	6264.2	3282.7	12065.8	5868.7
16	5698.2	2753.0	5188.1	3064.4	10886.3	5817.4
17	6200.4	2666.2	6738.4	4399.1	12938.8	7065.3
18	4163.0	1863.3	3028.9	2168.4	7191.9	4031.6
19	2603.5	1767.8	2227.7	1695.6	4831.2	3463.4
20	8905.5	4178.3	7061.4	5809.8	15966.9	9988.1
21	2748.9	1765.3	1943.2	1574.6	4692.1	3339.9
22	8473.0	4108.3	8379.4	5539.0	16852.4	9647.3
23	6285.4	3545.4	7103.7	4930.5	13389.1	8475.9
24	6694.0	3896.0	7777.2	4510.4	14471.2	8406.4
25	1560.2	1214.9	887.1	685.1	2447.3	1900.1
26	6565.2	3454.9	6374.8	4006.5	12940.0	7461.4
27	4993.7	2792.4	4939.8	3223.9	9933.5	6016.3
28	8771.1	4159.1	9580.8	5934.4	18351.9	10093.5
29	4815.3	2295.1	6645.9	4388.5	11461.2	6683.6
30	4532.7	2101.3	5124.2	3030.7	9656.9	5132.1
31	5916.6	2540.8	7434.2	3896.6	13350.8	6437.4
32	5222.1	2272.2	5626.5	2890.6	10848.6	5162.8
33	7125.4	3134.7	10333.4	5224.8	17458.8	8359.5
34	4175.2	1414.1	3928.9	2376.8	8104.1	3790.9
35	4796.7	2232.3	4249.2	2977.0	9045.9	5209.3
36	4530.6	1894.4	4501.6	2702.1	9032.2	4596.6
37	4362.8	1645.7	3836.9	2101.7	8199.7	3747.4

38	4498.6	2140.8	4170.1	2605.4	8668.7	4746.2
39	6121.1	2155.4	6326.4	3611.0	12447.5	5766.5
40	4302.3	1745.1	5058.6	3564.9	9360.9	5310.1
41	5493.2	2428.1	6822.8	3834.5	12316.0	6262.6
42	4808.9	2097.8	5793	2881.9	10601.9	4979.7
43	5658.0	2608.9	6068	3574.9	11726.0	6183.9
44	4645.3	2168.8	4700.3	2607.4	9345.6	4776.2
45	6185.7	2652.0	7675.4	3448.8	13861.1	6100.8
46	4777.1	2065.0	4349.5	2305.8	9126.6	4370.8
47	6310.8	2979.4	7704.8	3790.8	14015.6	6770.2
48	6254.3	2742.4	3304.6	3884.5	9558.9	6626.9
49	6131.2	2827.5	6692.5	3823.8	12823.7	6651.3
50	6888.0	3210.0	9843.5	5707.6	16731.5	8917.6
51	2173.3	1028.6	1657.2	954.4	3830.5	1983.0
52	7271.4	3142.6	8126	4234.3	15397.4	7376.9
53	6310.8	3123.8	8735.7	4124.0	15046.5	7247.8
54	6254.3	2542.3	6417.5	3476.8	12671.8	6019.1
55	6131.2	3026.1	7251.9	4205.3	13383.1	7231.5
56	6888.0	2241.1	4958.3	2544.5	11846.3	4785.6
57	2173.3	1341.4	2762	1413.4	4935.3	2754.8
58	7271.4	1659.5	2789.8	1217.2	10061.2	2876.7
59	6513.0	2775.2	6024.7	4144.2	12537.7	6919.4
60	6331.1	2423.5	5406.6	2670.8	11737.7	5094.4

Cordon biomass per vine (g)

Sample	Cordon 1 wet	%H2O	Cordon 2 wet	%H2O	Total Cordon dry
1	3642.0	42%	5096.8	37%	5314.0
2	2066.0	35%	1448.8	45%	3514.9
3	2492.5	31%	2639.2	41%	3286.5
4	3850.2	46%	2320.2	43%	3413.0
5	2029.0	9%	2093.8	41%	3089.4
6	2915.5	18%	3270.3	47%	4135.7
7	2293.0	45%	3544.0	46%	3183.8
8	2713.8	24%	2317.9	44%	3363.0
9	4254.9	45%	4830.2	49%	4829.2
10	3408.1	45%	3094.7	44%	3593.7
11	3563.0	53%	3455.6	50%	3384.4
12	6647.9	26%	6064.0	46%	8233.8
13	4124.6	31%	6170.8	48%	6038.0
14	4767.9	26%	4295.2	37%	6217.5
15	3011.3	50%	3252.9	45%	3282.7
16	2776.1	29%	2412.0	55%	3064.4
17	2970.0	23%	3768.4	44%	4399.1
18	1152.1	17%	1876.8	35%	2168.4
19	1032.7	22%	1195.0	25%	1695.6
20	3526.3	21%	3535.1	14%	5809.8
21	1077.1	23%	866.1	15%	1574.6
22	3482.3	38%	4897.1	31%	5539.0
23	3703.7	28%	3400.0	34%	4930.5
24	2367.2	42%	2143.1	42%	4510.4

25	484.0	17%	403.1	30%	685.1
26	2996.2	35%	3378.6	39%	4006.5
27	2357.9	37%	2582.0	32%	3223.9
28	4510.3	45%	5070.5	32%	5934.4
29	2647.2	16%	3998.7	46%	4388.5
30	2580.6	29%	2543.6	53%	3030.7
31	2999.4	41%	4434.8	52%	3896.6
32	2780.2	42%	2846.3	55%	2890.6
33	6049.3	51%	4284.1	47%	5224.8
34	1765.3	28%	2163.6	49%	2376.8
35	1944.5	43%	2304.7	19%	2977.0
36	2486.8	38%	2014.8	43%	2702.1
37	1910.2	45%	1926.7	45%	2101.7
38	1754.2	27%	2418.0	45%	2605.4
39	3206.8	40%	3119.6	46%	3611.0
40	2545.0	25%	2513.6	34%	3564.9
41	3415.7	45%	3407.1	42%	3834.5
42	2530.8	15%	3262.2	78%	2881.9
43	2157.3	22%	3910.7	52%	3574.9
44	2233.6	40%	2466.7	49%	2607.4
45	3897.7	57%	3777.7	53%	3448.8
46	2062.2	43%	2323.3	51%	2305.8
47	4227.7	47%	3477.1	56%	3790.8
48	3013.8	38%	3595.4	44%	3884.5
49	3572.0	51%	3120.5	34%	3823.8
50	3885.6	48%	5957.9	38%	5707.6
51	789.6	41%	867.6	43%	954.4
52	4097.3	46%	4028.7	49%	4234.3
53	3536.8	55%	5198.9	51%	4124.0
54	3856.0	41%	5198.9	53%	3476.8
55	3077.8	51%	4174.1	35%	4205.3
56	2982.3	51%	1976.0	45%	2544.5
57	1381.2	48%	1380.8	49%	1413.4
58	1781.5	61%	1008.3	48%	1217.2
59	2654.4	7%	3370.3	50%	4144.2
60	1163.0	37%	4243.6	54%	2670.8

Woody, Annual and Total Carbon per vine (kg) and hectare (Mg)

Sample	Woody		Annual		Total*	
	Kg /vine	Mg /ha	Kg /vine	Mg /ha	Kg /vine	Mg /ha
1	4.2	6.9	2.9	6.2	9.6	17.2
2	2.8	4.6	1.8	3.5	7.1	12.2
3	2.7	4.4	1.8	2.7	7.0	11.2
4	2.8	4.6	1.7	3.4	7.0	12.1
5	2.6	4.3	1.1	4.3	6.2	12.7
6	3.3	5.3	1.5	5.5	7.3	14.9
7	2.8	4.5	3.9	3.1	9.1	11.7
8	2.8	4.6	2.4	6.3	7.7	15.0
9	3.9	6.3	1.8	2.5	8.1	12.9
10	3.1	5.1	1.9	2.1	7.6	11.3
11	2.9	4.8	2.9	5.2	8.4	14.1

12	5.9	9.7	4.4	4.2	12.8	18.0
13	4.7	7.7	6.1	4.2	13.3	16.0
14	4.5	7.4	3.5	3.0	10.5	14.5
15	2.8	4.6	4.3	3.3	9.6	12.0
16	2.8	4.6	3.6	2.5	8.9	11.2
17	3.4	5.6	2.8	2.4	8.7	12.1
18	2.0	3.2	2.4	6.3	6.8	13.6
19	1.7	2.7	1.0	3.9	5.2	10.7
20	4.8	7.9	4.6	5.0	11.9	17.0
21	1.6	2.5	1.2	2.2	5.3	8.8
22	4.7	2.6	3.6	3.3	10.8	10.0
23	4.1	7.6	1.3	4.8	7.9	16.5
24	4.1	6.7	1.3	4.4	7.8	15.2
25	0.9	6.6	0.7	4.3	4.1	15.0
26	3.6	1.5	1.5	2.8	7.6	8.4
27	2.9	5.9	1.0	6.4	6.4	16.4
28	4.9	4.7	4.6	1.5	12.0	10.3
29	3.2	5.3	2.6	2.5	8.3	11.9
30	2.5	4.0	1.9	1.7	6.9	9.8
31	3.1	5.1	1.9	3.9	7.5	13.1
32	2.5	4.1	2.4	2.8	7.4	11.0
33	4.0	6.6	3.2	2.9	9.7	13.6
34	1.8	3.0	1.7	1.7	6.1	8.8
35	2.5	4.1	0.8	1.4	5.9	9.6
36	2.2	3.6	0.7	1.2	5.5	8.9
37	1.8	3.0	0.6	1.1	4.9	8.2
38	2.3	3.7	0.7	1.2	5.5	9.0
39	2.8	4.5	1.1	1.8	6.4	10.4
40	2.6	4.2	1.9	3.1	6.9	11.4
41	3.0	4.9	1.8	3.0	7.4	12.0
42	2.4	3.9	1.4	2.2	6.3	10.2
43	3.0	4.9	2.5	4.1	8.0	13.1
44	2.3	3.8	1.3	2.1	6.1	10.0
45	3.0	4.8	1.1	1.8	6.5	10.7
46	2.1	3.4	1.4	2.3	6.0	9.8
47	3.3	5.3	3.3	2.8	9.1	12.2
48	3.2	5.2	3.0	2.9	8.7	12.2
49	3.2	5.2	2.7	5.9	8.4	15.2
50	4.3	7.0	4.6	3.4	11.4	14.5
51	1.0	1.6	0.8	4.5	4.3	10.2
52	3.6	5.8	2.7	4.2	8.7	14.1
53	3.5	5.7	2.7	4.1	8.7	13.9
54	2.9	4.7	1.7	3.2	7.1	12.0
55	3.5	5.7	1.9	3.5	7.9	13.3
56	2.3	3.8	2.7	2.6	7.5	10.5
57	1.3	2.2	1.1	1.8	4.9	8.1
58	1.4	2.3	0.5	6.7	4.4	13.1
59	3.3	5.5	1.5	5.1	7.3	14.7
60	2.5	4.0	3.6	4.8	8.6	12.9

* Including roots

Annual C breakdown per vine (kg) and hectare (Mg)

Sample	Fruit		Leaves		Canes		Total Annual C	
	Kg /vine	Mg /ha	Kg /vine	Mg /ha	Kg /vine	Mg /ha	Kg /vine	Mg /ha
1	1.3	3.7	0.4	0.7	1.1	1.8	2.9	6.2
2	0.9	2.1	0.3	0.4	0.6	1.0	1.8	3.5
3	0.8	1.1	0.3	0.5	0.7	1.1	1.8	2.7
4	0.7	1.8	0.3	0.5	0.7	1.1	1.7	3.4
5	0.3	3.1	0.2	0.3	0.6	0.9	1.1	4.3
6	0.4	3.7	0.3	0.5	0.8	1.3	1.5	5.5
7	2.3	0.5	0.6	1.0	1.0	1.6	3.9	3.1
8	1.3	4.5	0.4	0.7	0.7	1.1	2.4	6.3
9	0.7	0.7	0.4	0.7	0.7	1.1	1.8	2.5
10	1.1	0.8	0.3	0.5	0.5	0.8	1.9	2.1
11	1.9	3.5	0.4	0.7	0.6	1.0	2.9	5.2
12	2.3	0.7	0.7	1.1	1.5	2.4	4.4	4.2
13	3.7	0.4	0.7	1.2	1.6	2.6	6.1	4.2
14	2.0	0.5	0.6	0.9	1.0	1.6	3.5	3.0
15	2.6	0.7	0.6	0.9	1.1	1.7	4.3	3.3
16	2.4	0.7	0.4	0.7	0.7	1.1	3.6	2.5
17	1.6	0.5	0.5	0.7	0.7	1.2	2.8	2.4
18	1.4	4.6	0.4	0.6	0.7	1.1	2.4	6.3
19	0.3	2.7	0.2	0.3	0.5	0.9	1.0	3.9
20	2.8	2.0	0.7	1.2	1.1	1.8	4.6	5.0
21	0.5	1.3	0.3	0.3	0.5	0.6	1.2	2.2
22	2.2	2.1	0.6	0.4	0.8	0.8	3.6	3.3
23	0.3	2.5	0.4	1.0	0.6	1.3	1.3	4.8
24	0.3	2.8	0.4	0.7	0.6	0.9	1.3	4.4
25	0.4	2.7	0.1	0.6	0.2	1.0	0.7	4.3
26	0.5	2.4	0.4	0.1	0.6	0.3	1.5	2.8
27	0.3	4.8	0.3	0.6	0.4	1.0	1.0	6.4
28	2.8	0.4	0.6	0.4	1.1	0.7	4.6	1.5
29	1.6	0.9	0.4	0.7	0.5	0.9	2.6	2.5
30	1.2	0.5	0.3	0.5	0.4	0.7	1.9	1.7
31	0.8	2.2	0.4	0.7	0.6	1.0	1.9	3.9
32	1.3	1.0	0.4	0.7	0.7	1.1	2.4	2.8
33	1.5	0.2	0.6	1.0	1.1	1.7	3.2	2.9
34	0.8	0.1	0.3	0.5	0.7	1.1	1.7	1.7
35	0.1	0.1	0.3	0.5	0.5	0.8	0.8	1.4
36	0.1	0.1	0.3	0.4	0.4	0.7	0.7	1.2
37	0.0	0.1	0.2	0.4	0.4	0.6	0.6	1.1
38	0.0	0.1	0.3	0.4	0.4	0.7	0.7	1.2
39	0.1	0.2	0.4	0.6	0.6	1.0	1.1	1.8
40	1.0	1.6	0.4	0.6	0.5	0.9	1.9	3.1
41	1.2	1.9	0.3	0.5	0.3	0.6	1.8	3.0
42	0.8	1.3	0.3	0.4	0.3	0.5	1.4	2.2
43	1.5	2.4	0.5	0.7	0.6	1.0	2.5	4.1
44	0.6	1.0	0.3	0.4	0.4	0.7	1.3	2.1
45	0.3	0.5	0.3	0.5	0.5	0.8	1.1	1.8
46	0.8	1.2	0.2	0.4	0.4	0.7	1.4	2.3
47	1.7	0.1	0.6	1.0	1.0	1.7	3.3	2.8
48	1.6	0.7	0.5	0.9	0.8	1.3	3.0	2.9
49	1.5	4.0	0.4	0.7	0.7	1.2	2.7	5.9
50	2.9	0.6	0.6	1.1	1.0	1.7	4.6	3.4

51	0.3	3.6	0.2	0.3	0.4	0.6	0.8	4.5
52	1.3	1.9	0.6	0.9	0.8	1.4	2.7	4.2
53	1.1	1.5	0.5	0.7	1.2	1.9	2.7	4.1
54	0.6	1.4	0.3	0.4	0.9	1.4	1.7	3.2
55	0.5	1.2	0.4	0.7	1.0	1.6	1.9	3.5
56	1.5	0.6	0.4	0.6	0.8	1.4	2.7	2.6
57	0.4	0.7	0.2	0.3	0.5	0.8	1.1	1.8
58	0.1	6.1	0.1	0.1	0.3	0.5	0.5	6.7
59	0.4	3.3	0.4	0.7	0.7	1.1	1.5	5.1
60	2.2	2.6	0.5	0.8	0.9	1.4	3.6	4.8

Allometrics per vine for C estimations. Trunk diameter for woody C and wet fruit and pruning weight for annual C.

Sample	Trunk length (cm)	Trunk diameter (mm)	Woody C (kg)	Wet fruit weight (kg)	Pruning weight (kg)	Annual C (kg)
1	141	67.5	4.2	13.6	2.2	2.9
2	127	58.3	2.8	9.3	1.2	1.8
3	145	60.1	2.7	8.6	1.4	1.8
4	132	62.6	2.8	7.5	1.4	1.7
5	144	53.3	2.6	3.5	1.1	1.1
6	132	63.7	3.3	4.1	1.6	1.5
7	108	58.1	2.8	23.1	2.0	3.9
8	138	53.7	2.8	13.3	1.4	2.4
9	173	67.3	3.9	6.9	1.4	1.8
10	198	58.7	3.1	11.2	1.0	1.9
11	150	57.2	2.9	19.4	**1.2**	2.9
12	178	81.1	5.9	23.0	**3.0**	4.4
13	191	76.0	4.7	38.0	3.4	6.1
14	142	71.2	4.5	20.2	2.0	3.5
15	188	59.6	2.8	26.8	2.2	4.3
16	146	56.4	2.8	24.7	1.4	3.6
17	157	61.1	3.4	16.4	1.5	2.8
18	159	48.5	2.0	13.8	1.4	2.4
19	142	41.0	1.7	3.0	1.1	1.0
20	213	70.4	4.8	28.0	2.3	4.6
21	210	42.8	1.6	4.7	1.0	1.2
22	140	67.3	4.7	21.9	1.7	3.6
23	142	63.5	4.1	2.6	1.2	1.3
24	133	62.8	4.1	2.9	1.3	1.3
25	127	28.6	0.9	4.1	0.4	0.7
26	215	60.5	3.6	4.6	1.3	1.5

27	211	53.3	2.9	3.2	0.9	1.0
28	128	80.9	4.9	28.7	2.4	4.6
29	140	55.8	3.2	16.5	1.1	2.6
30	149	53.1	2.5	12.3	0.9	1.9
31	130	60.8	3.1	8.2	1.3	1.9
32	140	55.3	2.5	12.8	1.4	2.4
33	133	67.1	4.0	15.4	2.2	3.2
34	235	53.0	1.8	8.0	1.4	1.7
35	177	52.7	2.5	0.6	1.0	0.8
36	132	56.7	2.2	0.7	0.8	0.7
37	165	46.9	1.8	0.4	0.7	0.6
38	178	51.1	2.3	0.3	0.8	0.7
39	141	59.9	2.8	1.2	1.3	1.1
40	150	53.9	2.6	9.8	1.1	1.9
41	139	59.8	3.0	11.9	0.7	1.8
42	195	51.0	2.4	8.1	0.6	1.4
43	202	48.7	3.0	15.1	1.2	2.5
44	123	56.2	2.3	6.3	0.9	1.3
45	146	60.9	3.0	3.2	1.0	1.1
46	131	52.0	2.1	7.7	0.9	1.4
47	124	68.2	3.3	17.1	2.1	3.3
48	214	61.2	3.2	16.6	1.7	3.0
49	192	59.1	3.2	15.2	**1.5**	2.7
50	147	66.2	4.3	29.7	**2.1**	4.6
51	139	35.0	1.0	2.5	0.8	0.8
52	190	65.5	3.6	12.9	1.7	2.7
53	193	68.2	3.5	10.7	2.4	2.7
54	113	63.6	2.9	5.6	1.8	1.7
55	158	67.6	3.5	4.9	**2.1**	1.9
56	119	52.9	2.3	14.8	**1.7**	2.7
57	191	44.3	1.3	3.9	1.0	1.1
58	182	46.5	1.4	0.8	0.7	0.5
59	112	64.7	3.3	4.3	1.4	1.5
60	120	65.8	2.5	22.3	1.8	3.6

C. Fruit cluster biomass and Carbon contents

Percentage of C and standard error in different vine biomass fractions.[1]

Biomass fraction	Components	Carbon %	Standard Error
Trunk Cordon Cane	Bark, Stem, Tendrils	48.3	0.21
Leaf	Blade, Petiole	45.3	0.42
Fruit	Berry (Skin, Seed, Pulp), Rachis	43.0	0.20-0.51-0.22*
Root	Stump, Primary roots, Lateral roots, Root hairs	44.1	0.52

1.%C Table: Stockert, C.M. 2005-2008 means from Oakville Irrigation Block Merlot and Cover Crop Cabernet on 101-14 Mgt. Rootstock
* Berry skin, seed, and rachis respectively

Fruit cluster and C partitioning

Cluster partitioning	% in Cluster	% C
Skin	2	41
Seed	3	53
Pulp soluble solids	16	42
Pulp insoluble solids	1	45
Rachis	1	42
Mean (dry weight)		43
Water	77	

Biomass in fruit and cluster components (g/vine)

Sample	Bulk fruit	Dry rachis	Dry skin	Dry seed	Insoluble solids	Soluble solids	Dry biomass
1	13,610.6	149.7	288.1	380.5	112.6	2,150.0	3,081.0
2	9,254.9	101.8	195.9	258.8	76.5	1,462.0	2,095.0
3	8,597.3	94.6	182.0	240.4	71.1	1,358.1	1,946.1
4	7,468.9	82.2	158.1	208.8	61.8	1,179.8	1,690.7
5	3,460.1	38.1	73.2	96.7	28.6	546.6	783.2
6	4,086.5	45.0	86.5	114.3	33.8	645.5	925.0
7	23,139.2	254.5	489.9	646.9	191.4	3,655.2	5,237.9
8	13,267.5	145.9	280.9	370.9	109.7	2,095.8	3,003.3
9	6,885.5	75.7	145.8	192.5	56.9	1,087.7	1,558.6
10	11,207.2	123.3	237.3	313.3	92.7	1,770.4	2,536.9
11	19,357.6	212.9	409.8	541.2	160.1	3,057.9	4,381.9
12	22,972.0	252.7	486.3	642.3	190.0	3,628.8	5,200.1
13	38,028.2	418.3	805.0	1,063.2	314.5	6,007.2	8,608.3
14	20,207.4	222.3	427.8	565.0	167.1	3,192.1	4,574.3
15	26,762.2	294.4	566.5	748.2	221.3	4,227.6	6,058.0
16	24,734.8	272.1	523.6	691.5	204.6	3,907.3	5,599.1
17	16,391.9	180.3	347.0	458.3	135.6	2,589.4	3,710.6
18	13,753.4	151.3	291.2	384.5	113.7	2,172.6	3,113.3
19	2,996.0	33.0	63.4	83.8	24.8	473.3	678.2
20	28,017.0	308.2	593.1	783.3	231.7	4,425.8	6,342.1
21	4,720.0	51.9	99.9	132.0	39.0	745.6	1,068.4
22	21,901.0	240.9	463.6	612.3	181.1	3,459.6	4,957.6
23	2,555.0	28.1	54.1	71.4	21.1	403.6	578.4
24	2,893.0	31.8	61.2	80.9	23.9	457.0	654.9
25	4,133.0	45.5	87.5	115.6	34.2	652.9	935.6
26	4,592.0	50.5	97.2	128.4	38.0	725.4	1,039.5
27	3,202.0	35.2	67.8	89.5	26.5	505.8	724.8
28	28,651.0	315.2	606.5	801.0	236.9	4,525.9	6,485.6
29	16,469.0	181.2	348.6	460.4	136.2	2,601.6	3,728.0
30	12,295.0	135.2	260.3	343.7	101.7	1,942.2	2,783.2
31	8,184.0	90.0	173.3	228.8	67.7	1,292.8	1,852.6
32	12,763.0	140.4	270.2	356.8	105.5	2,016.1	2,889.1
33	15,404.0	169.4	326.1	430.7	127.4	2,433.3	3,486.9
34	7,996.0	88.0	169.3	223.6	66.1	1,263.1	1,810.0
35	739.0	8.1	15.6	20.7	6.1	116.7	167.3
36	560.0	6.2	11.9	15.7	4.6	88.5	126.8
37	651.0	7.2	13.8	18.2	5.4	102.8	147.4
38	386.0	4.2	8.2	10.8	3.2	61.0	87.4
39	1,230.0	13.5	26.0	34.4	10.2	194.3	278.4
40	9,757.0	107.3	206.6	272.8	80.7	1,541.3	2,208.6
41	11,927.0	131.2	252.5	333.5	98.6	1,884.1	2,699.9

42	8,094.0	89.0	171.3	226.3	66.9	1,278.6	1,832.2
43	15,080.0	165.9	319.2	421.6	124.7	2,382.2	3,413.6
44	6,330.0	69.6	134.0	177.0	52.3	999.9	1,432.9
45	3,234.0	35.6	68.5	90.4	26.7	510.9	732.1
46	7,677.0	84.4	162.5	214.6	63.5	1,212.7	1,737.8
47	17,124.0	188.4	362.5	478.8	141.6	2,705.0	3,876.3
48	16,649.0	183.1	352.5	465.5	137.7	2,630.0	3,768.8
49	15,162.0	166.8	321.0	423.9	125.4	2,395.1	3,432.2
50	29,704.0	326.7	628.8	830.5	245.7	4,692.3	6,724.0
51	2,533.0	27.9	53.6	70.8	20.9	400.1	573.4
52	12,915.0	142.1	273.4	361.1	106.8	2,040.2	2,923.5
53	10,737.8	118.1	227.3	300.2	88.8	1,696.2	2,430.7
54	5,613.9	61.8	118.8	157.0	46.4	886.8	1,270.8
55	4,940.0	54.3	104.6	138.1	40.9	780.4	1,118.2
56	14,821.6	163.0	313.8	414.4	122.6	2,341.3	3,355.1
57	3,867.8	42.5	81.9	108.1	32.0	611.0	875.5
58	755.8	8.3	16.0	21.1	6.3	119.4	171.1
59	4,252.5	46.8	90.0	118.9	35.2	671.8	962.6
60	22,320.9	245.5	472.5	624.1	184.6	3,526.0	5,052.7

Total Carbon in fruit fractions (g/vine)

Sample	Dry rachis	Dry skin	Dry seed	Insoluble solids	Soluble solids	Dry biomass Carbon in Fruit*
1	62.9	118.1	201.7	50.7	903.0	1,273.5
2	42.8	80.3	137.1	34.4	614.0	865.9
3	39.7	74.6	127.4	32.0	570.4	804.4
4	34.5	64.8	110.7	27.8	495.5	698.8
5	16.0	30.0	51.3	12.9	229.6	323.7
6	18.9	35.5	60.6	15.2	271.1	382.4
7	106.9	200.8	342.9	86.1	1,535.2	2,165.0
8	61.3	115.2	196.6	49.4	880.3	1,241.4
9	31.8	59.8	102.0	25.6	456.8	644.2
10	51.8	97.3	166.1	41.7	743.6	1,048.6
11	89.4	168.0	286.8	72.0	1,284.3	1,811.2
12	106.1	199.4	340.4	85.5	1,524.1	2,149.4
13	175.7	330.1	563.5	141.5	2,523.0	3,558.1
14	93.4	175.4	299.4	75.2	1,340.7	1,890.7
15	123.6	232.3	396.6	99.6	1,775.6	2,504.0
16	114.3	214.7	366.5	92.0	1,641.1	2,314.3
17	75.7	142.3	242.9	61.0	1,087.5	1,533.7
18	63.5	119.4	203.8	51.2	912.5	1,286.8
19	13.8	26.0	44.4	11.1	198.8	280.3
20	129.4	243.2	415.2	104.3	1,858.8	2,621.4
21	21.8	41.0	69.9	17.6	313.2	441.6
22	101.2	190.1	324.5	81.5	1,453.1	2,049.2

23	11.8	22.2	37.9	9.5	169.5	239.1
24	13.4	25.1	42.9	10.8	191.9	270.7
25	19.1	35.9	61.2	15.4	274.2	386.7
26	21.2	39.9	68.0	17.1	304.7	429.7
27	14.8	27.8	47.4	11.9	212.4	299.6
28	132.4	248.7	424.5	106.6	1,900.9	2,680.7
29	76.1	142.9	244.0	61.3	1,092.7	1,540.9
30	56.8	106.7	182.2	45.8	815.7	1,150.4
31	37.8	71.0	121.3	30.5	543.0	765.7
32	59.0	110.8	189.1	47.5	846.8	1,194.2
33	71.2	133.7	228.3	57.3	1,022.0	1,441.3
34	36.9	69.4	118.5	29.8	530.5	748.1
35	3.4	6.4	11.0	2.8	49.0	69.1
36	2.6	4.9	8.3	2.1	37.2	52.4
37	3.0	5.7	9.6	2.4	43.2	60.9
38	1.8	3.4	5.7	1.4	25.6	36.1
39	5.7	10.7	18.2	4.6	81.6	115.1
40	45.1	84.7	144.6	36.3	647.3	912.9
41	55.1	103.5	176.7	44.4	791.3	1,116.0
42	37.4	70.3	119.9	30.1	537.0	757.3
43	69.7	130.9	223.5	56.1	1,000.5	1,411.0
44	29.2	54.9	93.8	23.6	420.0	592.3
45	14.9	28.1	47.9	12.0	214.6	302.6
46	35.5	66.6	113.8	28.6	509.3	718.3
47	79.1	148.6	253.7	63.7	1,136.1	1,602.2
48	76.9	144.5	246.7	62.0	1,104.6	1,557.8
49	70.0	131.6	224.7	56.4	1,005.9	1,418.6
50	137.2	257.8	440.1	110.5	1,970.8	2,779.3
51	11.7	22.0	37.5	9.4	168.1	237.0
52	59.7	112.1	191.4	48.1	856.9	1,208.4
53	49.6	93.2	159.1	40.0	712.4	1,004.7
54	25.9	48.7	83.2	20.9	372.5	525.3
55	22.8	42.9	73.2	18.4	327.8	462.2
56	68.5	128.6	219.6	55.2	983.4	1,386.8
57	17.9	33.6	57.3	14.4	256.6	361.9
58	3.5	6.6	11.2	2.8	50.1	70.7
59	19.6	36.9	63.0	15.8	282.1	397.9
60	103.1	193.7	330.7	83.1	1,480.9	2,088.5

* All fruit cluster fractions except rachis.

D. Root biomass and Carbon contents

Plot characteristics and roots remaining within sample volume

Sample	Row	Rep	Length	Width	Depth	Volume	Root Diameter (mm)				
			(m)	(m)	(m)	(m^3)	30	63	127	190	254
1	34	W	3.5	1.6	0.4	2.3		6	3		
		E	3.5	1.6	0.4	2.3		2	5		
2	24	W	3.4	1.5	0.4	2.0	3	5	2		2
		E	3.4	1.5	0.4	2.0	3	6	3	1	
3	75	W	3.0	1.5	0.4	1.8		9	3	1	2
		E	3.0	1.5	0.4	1.8		4	2		
Average			3.3	1.5	0.4	2.0	3.0	5.3	3.0	1.0	2.0

Total root biomass (g) per sample and estimations per hectare.

Sample	Root length categories (mm)				Total root weight (g)	Root stump weight (g)	Volume (m^3)	Area (m^2)	Kg/ha	MT/ha	MT C/ha
	<2	2-6	6-20	>20							
1	423.9	1143.4	2882.7	3298.5	7748.5	2541.3	4.5	11.2	9187.3	9.2	4.04
2	290.1	1278.0	3587.0	2347.3	7502.4	2178.5	6.5	9.0	10756.6	10.8	4.73
3	362.5	1018.3	2120.4	2393.4	5894.6	1900.6	5.5	10.1	7756.4	7.8	3.41

E. Mound description and biomass-C estimates

Semi-ovoid mound model measurements and C estimates

Mound	North-South transect(m)	Radius 1 (m)	East-West transect (m)	Radius 2 (m)	Height (m)	Volume (m3)	Mound biomass (Kg)[1]	Mg C/mound [2]	Thiessen Polygon Area (m2)	Carbon estimates (Mg C/ha)
1	13.3	4.2	12.0	3.8	4.0	135.5	6435.0	3.0	3607.5	8.4
2	12.5	4.0	12.0	3.8	3.7	117.8	5594.3	2.6	1711.9	15.4
3	10.0	3.2	12.0	3.8	3.5	89.1	4233.5	2.0	3188.5	6.2
4	12.3	3.9	13.8	4.4	4.0	144.1	6843.8	3.2	2648.0	12.1
5	11.5	3.7	12.9	4.1	3.6	113.3	5383.2	2.5	2537.9	10.0
6	14.0	4.5	13.1	4.2	4.0	155.7	7394.6	3.5	2907.8	12.0
7	11.9	3.8	13.0	4.1	4.2	137.9	6549.3	3.1	4619.8	6.7
8	12.3	3.9	11.9	3.8	3.1	96.3	4573.7	2.1	2415.7	8.9
9	13.6	4.3	11.6	3.7	4.2	140.6	6678.8	3.1	2524.2	12.4
10	11.6	3.7	12.5	4.0	3.3	101.5	4823.2	2.3	1331.8	17.0
11	13.2	4.2	10.2	3.2	3.3	94.3	4478.6	2.1	3088.4	6.8
12	11.4	3.6	10.4	3.3	4.0	100.6	4780.3	2.2	1923.3	11.7
13	11.7	3.7	11.8	3.8	4.0	117.2	5566.5	2.6	2725.0	9.6
14	12.4	3.9	12.2	3.9	3.5	112.4	5337.1	2.5	2508.7	10.0
15	13.1	4.2	12.6	4.0	4.0	140.1	6655.1	3.1	2676.6	11.7
16	13.6	4.3	13.1	4.2	4.0	151.2	7183.3	3.4	3554.1	9.5
17	11.6	3.7	11.8	3.8	3.6	104.6	4967.0	2.3	3606.4	6.5
18	12.4	3.9	13.6	4.3	4.0	143.1	6799.4	3.2	2791.6	11.4
19	12.0	3.8	14.5	4.6	3.9	144.0	6840.2	3.2	3973.3	8.1
20	12.3	3.9	14.0	4.5	4.1	149.8	7116.5	3.3	2924.7	11.4
21	12.9	4.1	11.7	3.7	3.2	102.5	4868.3	2.3	3554.2	6.4
22	12.5	4.0	12.5	4.0	3.9	129.3	6142.4	2.9	2907.5	9.9
23	12.5	4.0	12.1	3.9	4.1	131.6	6250.7	2.9	2667.0	11.0
24	12.0	3.8	13.0	4.1	3.6	119.2	5660.8	2.7	2902.3	9.2
25	11.3	3.6	10.0	3.2	3.0	71.9	3417.1	1.6	2576.2	6.2
26	12.0	3.8	11.4	3.6	4.0	116.1	5515.7	2.6	2731.2	9.5

[1] Mound average density = 47.5 Kg/m3

[2] Carbon percentage = 47 (considers wood, roots and canes)

Hemispheric mound measurements and C estimates per mound

Mound	Model Radius	Model Lower 95 CI Radius	Model Upper 95 CI Radius	Model Average Volume	Model Lower 95 CI Volume	Mod Upper 95 CI Volume	Mg biomass Lower 95 CI	Mg biomass Upper 95 CI
1	4.00	3.85	4.31	133.93	119.81	167.25	5.69	7.94
2	4.03	3.81	4.42	137.09	115.43	180.68	5.48	8.58
3	3.79	3.51	4.20	113.63	90.86	155.44	4.32	7.38
4	3.69	3.52	3.99	104.98	91.21	133.30	4.33	6.33
5	4.03	3.85	4.37	136.97	119.44	175.11	5.67	8.32
6	3.68	3.61	3.87	104.07	98.89	121.80	4.70	5.79
7	3.88	3.63	4.28	122.44	100.35	164.51	4.77	7.81
8	4.08	3.64	4.69	142.42	101.05	216.19	4.80	10.27
9	3.89	3.71	4.22	123.19	107.07	157.36	5.09	7.47
10	4.05	3.71	4.57	139.54	106.53	199.73	5.06	9.49
11	3.99	3.67	4.48	133.40	103.79	187.73	4.93	8.92
12	3.55	3.37	3.86	93.78	80.07	120.31	3.80	5.71
13	3.56	3.25	3.99	94.26	71.68	133.35	3.41	6.33
14	4.03	3.81	4.42	137.31	115.74	180.83	5.50	8.59
15	3.82	3.53	4.26	116.95	92.09	162.21	4.37	7.71
16	4.42	4.19	4.83	180.29	154.23	236.40	7.33	11.23
17	3.90	3.69	4.26	123.84	105.23	161.36	5.00	7.66
18	3.88	3.45	4.47	122.57	85.84	187.01	4.08	8.88
19	4.57	4.12	5.22	199.60	146.99	297.10	6.98	14.11
20	3.82	3.59	4.21	117.15	96.52	156.44	4.58	7.43
21	3.99	3.34	4.81	133.18	77.94	232.38	3.70	11.04
22	4.19	4.00	4.55	153.70	133.91	197.39	6.36	9.38
23	3.96	3.60	4.48	129.92	97.34	188.34	4.62	8.95
24	4.22	3.93	4.70	157.66	126.92	216.85	6.03	10.30
25	3.60	3.22	4.11	97.57	69.66	145.39	3.31	6.91
26	3.55	3.37	3.85	93.71	80.44	119.67	3.82	5.68

Hemispheric model C estimates

Model Average Volume (m3)	Mean Mound biomass (Kg)[1]	Mg C/mound [2]	Thiessen Polygon Area (m2)	Carbon estimates (Mg C/ha)
133.9	6361.7	3.0	3607.5	8.3
137.1	6511.7	3.1	1711.9	17.9
113.6	5397.6	2.5	3188.5	8.0
105.0	4986.3	2.3	2648.0	8.9
137.0	6506.1	3.1	2537.9	12.0
104.1	4943.2	2.3	2907.8	8.0
122.4	5816.0	2.7	4619.8	5.9
142.4	6765.0	3.2	2415.7	13.2
123.2	5851.5	2.8	2524.2	10.9
139.5	6628.1	3.1	1331.8	23.4
133.4	6336.4	3.0	3088.4	9.6
93.8	4454.3	2.1	1923.3	10.9
94.3	4477.1	2.1	2725.0	7.7
137.3	6522.4	3.1	2508.7	12.2
116.9	5555.0	2.6	2676.6	9.8
180.3	8563.7	4.0	3554.1	11.3
123.8	5882.4	2.8	3606.4	7.7
122.6	5822.1	2.7	2791.6	9.8
199.6	9481.0	4.5	3973.3	11.2
117.2	5564.6	2.6	2924.7	8.9
133.2	6325.9	3.0	3554.2	8.4
153.7	7300.9	3.4	2907.5	11.8
129.9	6171.2	2.9	2667.0	10.9
157.7	7489.0	3.5	2902.3	12.1
97.6	4634.5	2.2	2576.2	8.5
93.7	4451.1	2.1	2731.2	7.7

[1] Mound average density = 47.5 Kg/m3

[2] Carbon percentage = 47 (considers wood, roots and canes)

F. Lidar method and biomass volume estimates

Lidar data for biomass volume estimation

Mound	Shape Polygon Area (m2)	Minimum Height[1] (m)	Maximum Height[2] (m)	Range (m)	Mean Height (m)	Standard deviation	Volume (m3)
1	3607.53	1.01	2.41	1.40	1.72	0.31	3010.28
2	1711.91	1.01	2.33	1.32	1.71	0.33	1496.19
3	3188.52	1.01	2.49	1.48	1.69	0.34	2460.31
4	2647.99	1.01	2.52	1.51	1.72	0.32	2310.49
5	2537.88	1.01	2.59	1.58	1.70	0.31	1942.53
6	2907.77	1.01	2.26	1.25	1.70	0.30	2521.17
7	4619.83	1.01	2.59	1.58	1.72	0.33	4305.92
8	2415.74	1.01	2.27	1.26	1.68	0.30	2253.20
9	2524.16	1.01	2.60	1.59	1.71	0.31	2286.24
10	1331.80	1.01	2.31	1.30	1.78	0.29	1760.50
11	3088.40	1.01	2.54	1.53	1.80	0.32	3536.44
12	1923.25	1.01	2.43	1.42	1.85	0.29	2825.80
13	2724.99	1.01	2.64	1.63	1.86	0.31	3905.84
14	2508.74	1.01	2.63	1.62	1.77	0.30	3162.38
15	2676.61	1.01	2.46	1.45	1.77	0.29	3298.13
16	3554.09	1.01	2.40	1.39	1.68	0.31	2742.90
17	3606.42	1.01	2.54	1.53	1.73	0.32	3133.51
18	2791.61	1.01	2.56	1.55	1.76	0.32	2687.69
19	3973.31	1.01	2.42	1.41	1.74	0.32	3303.51
20	2924.72	1.01	2.46	1.45	1.75	0.34	2852.07
21	3554.25	1.01	2.59	1.58	1.66	0.34	1613.76
22	2907.46	1.01	2.60	1.59	1.56	0.30	1106.36
23	2666.97	1.01	2.48	1.47	1.68	0.31	1978.97
24	2902.26	1.01	2.46	1.45	1.71	0.33	2191.09
25	2576.23	1.01	2.43	1.42	1.73	0.32	2553.98
26	2731.20	1.01	2.44	1.43	1.75	0.30	2966.04

[1] Mean minimum height set to sum every point > 1 m.

[2] Maximum height of a pixel within a polygon

Biomass volume estimations per Thiessen polygon from LiDAR and Mound methods (cubic meters)

Polygon (mound-number)	Aerial Lidar (m3)	Semi-ovoid mound (m3)	Hemispheric mound (m3)	Mound Average (m3)
1	3010.3	135.5	133.9	134.7
2	1496.2	117.8	137.1	127.4
3	2460.3	89.1	113.6	101.4
4	2310.5	144.1	105.0	124.5
5	1942.5	113.3	137.0	125.2
6	2521.2	155.7	104.1	129.9
7	4305.9	137.9	122.4	130.2
8	2253.2	96.3	142.4	119.4
9	2286.2	140.6	123.2	131.9
10	1760.5	101.5	139.5	120.5
11	3536.4	94.3	133.4	113.8
12	2825.8	100.6	93.8	97.2
13	3905.8	117.2	94.3	105.7
14	3162.4	112.4	137.3	124.8
15	3298.1	140.1	116.9	128.5
16	2742.9	151.2	180.3	165.8
17	3133.5	104.6	123.8	114.2
18	2687.7	143.1	122.6	132.9
19	3303.5	144.0	199.6	171.8
20	2852.1	149.8	117.2	133.5
21	1613.8	102.5	133.2	117.8
22	1106.4	129.3	153.7	141.5
23	1979.0	131.6	129.9	130.8
24	2191.1	119.2	157.7	138.4
25	2554.0	71.9	97.6	84.8
26	2966.0	116.1	93.7	104.9

APPENDIX II: T TESTS

A. Paired t-test (n=26): Mound models Semi-ovoid and Hemispheric (C estimates)

```
t = -1.3213, df = 25, p-value = 0.1984
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -1.6729924  0.3653001
sample estimates:
mean of the differences
             -0.6538462

No significant differences between the two methods
```

B. Welch Two Sample t-test: Standing biomass (n=60) and Average Mound (n=26) model (C estimates)

```
t = 0.36476, df = 35.331, p-value = 0.7175
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -1.039697  1.495338
sample estimates:
mean of x mean of y
 10.24615  10.01833

No significant differences between the two methods
```