Quantifying Roman Laeetanian Wine Production (1st Century BC – 3rd Century AD): A Microeconomic Approach to Calculating Vineyard's Crop and Winemaking Processing Facilities Yields

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in qua terra iugerum unum denos et quinos
denos culleos fert vini, quot quaedam Italia regiones? [1]
Varro rust. 1, 2, 7

pressura una culleos XX implere debet. hic est pes iustus.
ad totidem culleos et lacus XX iugeribus unum sufficit torculum[2]
Plin. nat. 18, 317

Introduction

Viticulture played an important role in the economy of the coastal Mediterranean part of Hispania Citerior Tarraconensis between the 1st century BC and the 3rd century AD. The vineyards, wineries, and pottery workshops are usually found clustered in specific areas, such as the Laeetanian region in the north-eastern part of the Iberian Peninsula.

Their spatial and temporal distributions have been interpreted previously as a proof of the existence of an intensive and specialized winemaking economy that is associated with large-scale production and trade of wine in bulk, and that targeted predominantly overseas markets.[3]

Despite the significance of winegrowing in this territory and its relative important role in the empire-wide economy, the processes involved in the production, trade, and consumption of Laeetanian wine and their evolution over time have not been quantified using formal and empirical economic models and econometrical methods.

Here we present a first approach to a microeconomic explanatory data analysis of ancient wine production, paying particular attention to a vineyard's crops and the yields from winemaking processing facilities; values and data employed come from the Latin written sources, the archaeological record, experimentation, and ethnographic or modern viticulture data.

The main goal of this paper is to explain the different processes and factors involved in this supply chain and production function, to quantify the main values

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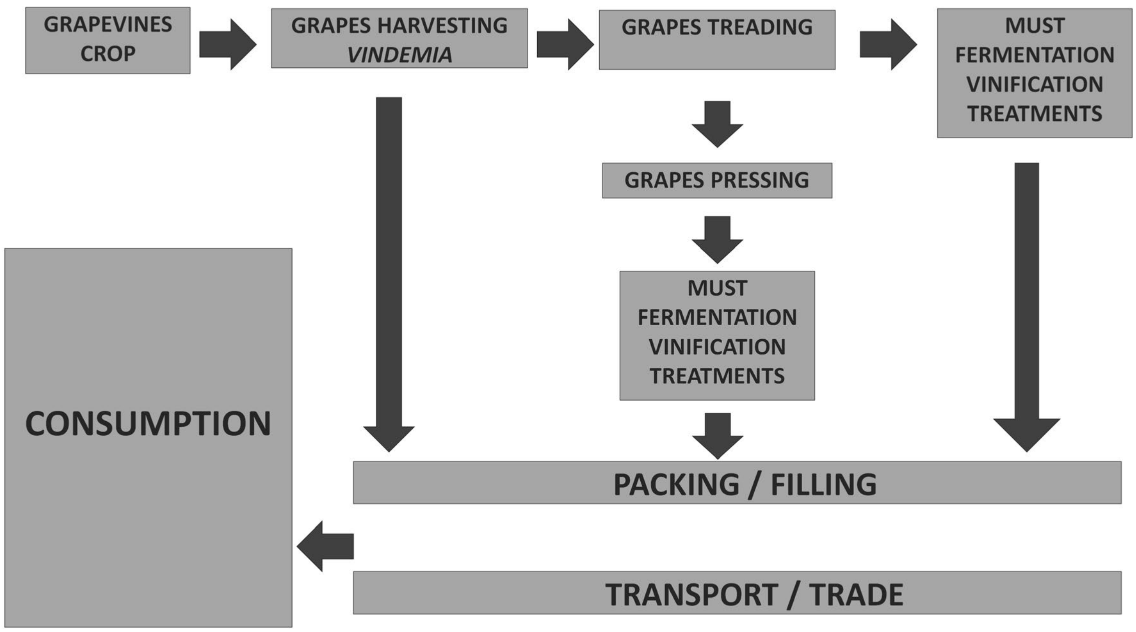

Fig. 1: Flow scheme of Roman viticulture supply chain and winegrowing production function.

and economic ratios and apply them in further geospatial econometrics models. This will assess *ab origine* the changing dynamics of the Laeetanian wine production system in a timeline dataset.

Roman Viticulture Supply Chain and Winegrowing Production Function

A supply chain is a system of resources and processes involved in the production and trade of goods or services from supplier to customer. Viticulture's supply chain involves both the production process and trade activities from its inception to its delivery to the end customer or consumer (fig. 1). The production function is the global system that characterizes a productive activity. The factors of production constitute the inputs of the economic system. A specific technology combines these inputs (e.g. raw materials, labour, machinery, tools, facilities, etc.) to obtain an optimal performance. The outputs are the finished products, the goods or services resulting from the productive activity.[4] In any type of socioeconomic organization, the production of goods and services may be in the hands of the state or in the hands of private producers. The Roman winegrowing production process is not alien to all these factors, conditions and microeconomic variables. It also has its particular production function with its own inputs intervening in the different stages of the productive chain.

Winegrowing Yields Quantification

The analysis of ancient viticulture can be approached in several ways according to different parameters of study. Its quantification is fundamental for the study of agricultural production processes, so we will try to adapt it both to the vineyard crop and to the processes of transformation, production and exploitation, for each of the different stages of viticulture's supply chain.[5] The quantification of winegrowing yields is fundamental for organizing the entire grapevine crop and winemaking production chain. This has several advantages: planning clusters and thinning needs in order to prevent excessive production and consequent poor wine quality; planning the harvest in relation to the timing of grape collection, labour needs, the configuration of the cellar, and conditioning of the equipment.[6] It is also useful for planning purchases and/or grape sales, establishing grape prices and the management of wine stocks, the management of the grape and wine market, planning investments, as well as the development of sales and trade strategies. This multiplicity of potential planning advantages makes the quantification of winegrowing yields one of the major current research topics in modern oenology. It is also one of the most interesting procedures we can use for reconstructing the productive processes of ancient viticulture.

To estimate global winegrowing yields we have to distinguish two main methods:

- Vineyard crop yields: this refers both to the crop yield itself, as regards the productive capacity of the plant, or yield per strain according to different intervening parameters and variables, and the harvesting yield (i.e. the mass of grapes collected prior to pressing, expressed in weight and produced in the whole vineyard, property, area or territory).
- Winemaking processing facilities yields: this calculates the yields from the processes of treading and pressing the grapes, its transformation into must and then into wine, as well as the maximum and average productive capacity of the processing machinery. Thus, we can determine the quantity and capacity of vats needed for collecting, ageing, and storing the wine produced.[7]

Vineyard's Crop Yields Parameters and Variables

Crop yield quantification in vineyards is important for managing vines in order to optimize growth and for controlling fruit quality over the time. If it is possible to forecast the grapevine crop yield then the planning of harvesting operations becomes easy, and optimal vineyard yields and the grape's quality goals can be achieved. Viticulture is much more effective when it is based on an accurate yield estimation. Typically, crop predictions are performed using historical data on vineyard yields, which are based on the grape cultivar, soil conditions, age of the vines, local weather patterns related with biotic and abiotic stresses, and cultural practices used by the grower. These are complimented by measurements taken manually in the field. Agronomic studies have established that a large spatial variability exists for vineyards yields across multiple regions and depending on growing conditions. Therefore, vineyard yields can display high temporal variability, either regionally or locally. Furthermore, within the same vineyard plot there can occur variability between vines, between clusters of the same vine, and between berries of the same bunch.

There are different ways to estimate potential yields in a vineyard. However, the ones based on the vineyard crop estimation components are the most used at the farm level and are conditioned by different factors that can influence in the final result.[8] These factors are:

a) Vineyard field configuration: this refers to the modulation patterns in the field, the geometry of plantation (plantation frame, vine density, row orientation and training system), and the vine architecture (plantation system, driving system and pruning methods).
   - Modulation patterns in the field: this refers to the extension, the shape of properties and the percentage of field devoted to vineyards. The ancient *agrimensores* distinguished three possibilities of modulation patterns in the fields:[9]
     – *Ager divisus et adsignatus*: this was public land assigned to *coloni* or private individuals by *catastro et centuriato.* The territorial division or cadastre featured land plots of different modules depending on the geomorphology and topography of the territory. The Roman unit of length used for land measurements was the *actus* of 120 *pedes*; the square *actus* measures 14,400 square *pede*s and one *iugerum* equals 2 *actus.* The most common land division consisted in square or rectangular plots of 100 *iugera* (≅ 62.22 ac ≅ 25.18 ha = 251,800 m^2) or 200 *iugera* (≅ 124.45 ac ≅ 50.36 ha = 503,600 m^2) called *centuria,* orthogonally organized and ascribed to a *civitas* or *municipium.*[10] This modulation of 100 or 200 *iugera* is the standard parcel module for a vineyard that we used in our calculations.
     – *Ager per extremitatem mensura comprenhibus*: this is a form of land division which seems to have followed earlier land organization patterns. It is, therefore, a system very common in provincial territories. It appears to refer to land measured only along its external boundaries; the land was normally assigned *in toto* to some pre-established community.
     – *Ager arcifinalis*: this term appears to express the division of a territory in parcels which have arbitrary boundaries not defined by specific measurement, but by natural elements such as mountain ranges, hills, woods, rivers, streams, valleys, marshy areas, maritime shores, etc. (table 1).

   In respect to the special features of the *Laeetana regio*, and considering its particular geospatial configuration, geoeconomic characteristics, and historical evolution over the time, all three possibilities of modulation patterns are represented:
     – *Ager centuriatio et catastro:* this type of land division was present in the hinterland of the colony of Barcino.[11] Perhaps a cadastral division was in place in the Vallès plain territory, where we found important secondary settlements defined as *civitas sine urbe.*[12]

ROMAN UNITS OF LENGHT AND AREA CORRESPONDANCES					
Lenght units			Area units		
digitus (1/16 *pes*)	0.728 in	18.5 mm	-	-	-
palmus (1/4 *pes*)	0.243 ft	74 mm	-	-	-
pes (pattern unit)	0.971 ft	29.6 cm	*Pes quadratus* (pattern unit)	0.94 ft²	0.0876 m²
palmipes (1 ¼ *pes*)	1.214 ft	37.0 cm	*Scrupulum* (100 *pedes quadrati*)	94.3 ft²	8.76 m²
cubitum (1 ½ *pes*)	1.456 ft	44.4 cm	*Actus minimus* (480 *pedes quadrati*)	453 ft²	42.1 m²
gradus (2 ½ *pedes*)	2.427 ft	74 cm	Clima (1/4 *actus quadrati* = 1/8 *iugerum*)	3,390 ft²	315 m²
passus (5 *pedes*)	4.854 ft	1.48 m	*Actus quadratus* (½ *iugera* =30 *actii minimus*)	0.311 a	1292 m²
pertica (10 *pedes*)	9.708 ft	2.96 m	*Iugerum*	0.623 a	2518 m²
actus (120 *pedes*)	116.496 ft	35.5 m	*Haeredium* (2 *iugera*)	1.248 a	5047 m²
stadium (625 *pedes* /125 *passi*)	202.38 yd	185 m	*Centuria* (100 *haeredia* = 200 *iugera*) ½ *centuria* (50 *haeredia*=100 *iugera)*	124.45 a 62.22 a	50.36 ha 25.18 ha
Mille/Milia passi	0,919 mi	1.48 km	*Saltus* (4 *centuriae*)	499 a	201.9 ha

Table 1: Roman units of length and area and their equivalences for measuring the extension of the fields and calculate vineyard's crop yields.

  - *Ager per extremitatem mensura comprenhibus:* this land division may have been used in the central coastal fringe between the Baetulo (Besós) and Arnum (Tordera) rivers, an area with an important pre-Roman settlement. The *ager arcifinalis* could also have been used here.
  - *Ager arcifinalis:* this was probably adopted in the lower course of the *Rubricatum* (Llobregat) River and in the short coastal fringe located between its mouth and the foothills of the Garraf massif.[13]
- Geometry of plantation: this concerns the vine's spatial disposition on the ground. There are different parameters to take into account:
  - Plantation frame: this refers to the vines layout and spacing of the vines in individual vines and rows. Different plantation systems were used in Roman times. One of the most used was the so-called standard frame of 5 *pedes* (≅ 4.85ft = 1,48m) × 4 *pedes* (≅ 3.93ft = 1.20m) = 20 *pedes quadrati* (≅19.5ft2 = 1,78m²), described by Pliny the Elder.[14] The most common layouts in the fields were rectangular, with vines in groups of two or four, or even in *quincunx* (four vines forming a square and one vine in the centre). We will use these values of a plantation's frame for our vineyard's plant density calculations.
  - Planting density: this refers to the total number of vines present in a given area. From this datum a proportional value or *ratio* of vines/acre or vines/hectare or

vitis/iugera is determined. Both the plantation frame and planting density are determined by the plantation system adopted.

- Row orientation: this refers to the maximum exposure of leaf surface to direct sunlight. This is crucial for grapevine performance in terms of yield, grape composition, and wine quality.[15] When rows are planted in north-south orientation, more leaves are exposed to direct sunlight than in the case of east-west orientation.[16] The row orientation should also take into account the direction of the prevailing summer breezes, since they have an important cooling effect on bunches and leaves.[17]
- Training system*:* this refers to how a vine is cultivated in regards to the aerial configuration of the canopy. There are three main systems of training vines: free (without support), staking (using posts) or trellising. In Laeetanian vineyards the training system was free without any kind of trellising, due to the plantation system and pruning method adopted. This growing method has a great advantage due to the savings in infrastructure costs.

• Vine architecture*:* this refers to the strain configuration, which is determined by different parameters such as:
  - Plantation system: the Roman agronomists distinguish two ways of planting a vineyard according to the ploughing system used: eeither in *scrobes* (trenches) or *alveus* (small ditches). The most common plantation system in Laetania consisted in two vines planted on both sides in a rectangular or ovoidal *alveus* of 4 *pedes* (≅ 3.93ft = 1.20m) × 1 *pes* (≅ 0.9701ft = 0.2957m) × 1 *pes* (deep).
  - Driving system: this refers to the configuration of the vines' space and their layout on the ground. This is defined by the relationship between the plantation frame and planting density as and in relation to the height of the trunk as well as the pruning system adopted.[18]
  - Pruning methods*:* different pruning methods could be used in order to favour and increase the homogeneity of fruiting. This also controlled the strain's growth, adapting it to a specific canopy's shape and improving the productivity and the quality of the grape. The vines are pruned to limit the amount of wood and delay the aging of the strain. According to the number and disposition of the different parts of the vine (trunk, branches, spurs, shoots, and buds), different levels of vine and vineyard productivity can be obtained. The common method adopted by Laeetanian growers was spur pruning, called also "goblet" or open "vase" (see fig. 2).

Laeetanian vineyards adopted a configuration with a free-training and head-driving systems, with trunks between 1.5 *pes* (1.45ft = 44.4cm) and 3 *pedes* (2.90ft = 88.8cm) tall, in an *alveus* planting system and using spur pruning. This offered strong comparative advantages. It allowed for high productivity and lowered labour costs of harvesting in comparison to other competitors such as the Italic producers.[19]

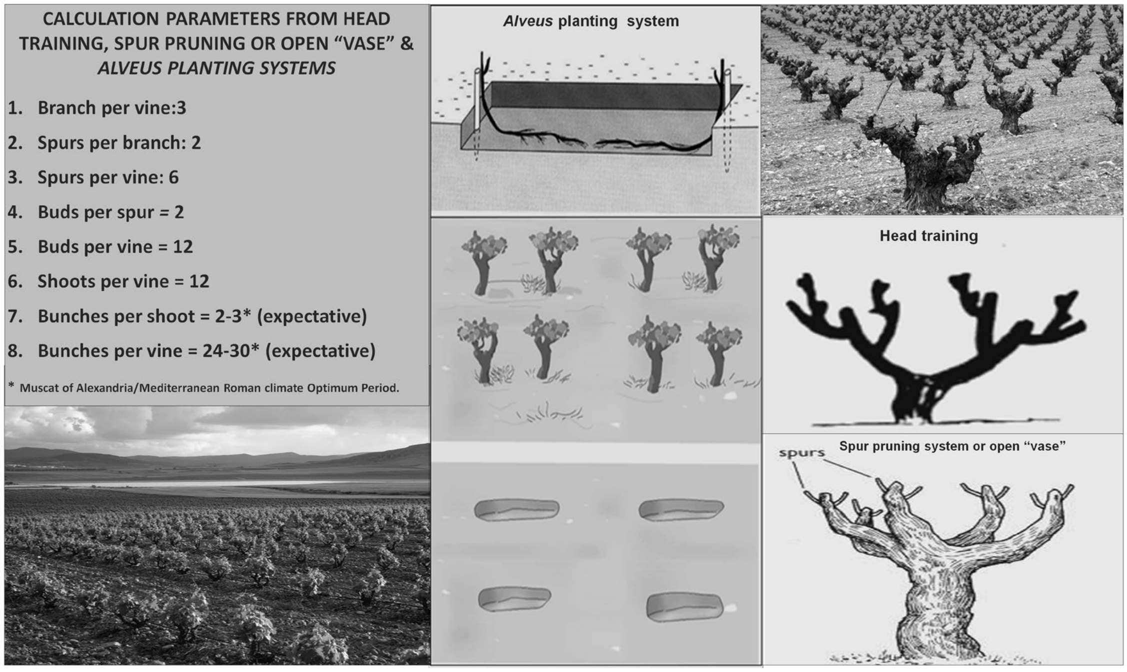

Fig. 2: Calculation parameters from head training, spur, "goblet" or open "vase" pruning, and alveus planting systems in a Laetanian vineyard.

b) Grapevine productivity: this is determined by the growth parameters of the selected vine/grape variety (e.g. vine/grape vigour and production capacity, crop load, crop level, vine balance, ripening process, mass of grapes per cultivar) and the type of canopy management chosen (e.g. trellising, thinning, fertilising and phytosanitary treatments).
   - Vine/grape variety growth parameters*:* this refers to the natural growth characteristics of the plant, clusters, and berries. They can be improved with a good management of the canopy and other care applied to the vine.
     – Vine vigour: this refers to the vine's natural capacity to increase its vegetative growth (shoots and leaf production) and its reproductive development (grapes and berries production) in specific favourable environmental circumstances. This forces the grower to find the correct balance between these two growing parameters.
     – Crop load: determines the ratio between the reproductive development (number of clusters and berries) and the vegetative development (number of exposed photosynthetically active leaves). The crop load ratio allows the grower to determine the optimal amount of fruit that can ripen on a given vine.
     – Crop level: this is analogous to crop yield but it does not imply that the entire crop will be harvestable. Therefore, crop level is a worse yield calculation parameter than crop load.[20]

  - Vine balance: is the point at which the crop load is ideally matched with vine growth. Achieving the correct crop load ratio for a balanced vine can optimize the quality of the fruit and lead to consistent production. The vine balance can vary according to the cultivar, location, training system, management practices, and overall climatic conditions.[21]
  - Ripening process*:* refers to the time period needed for the grapes to achieve the optimal point of equilibrium between sugar and acids. This period is shorter or longer depending if the cultivar ripens early or late.[22]
  - Mass of grapes per cultivar*:* refers to the ratio of the total wheight of the grapes obtained from a single vine or yield per strain and from the whole field.
  - Harvesting yield: this can be counted by plant, row or ground portion (acre, hectare, or *iugerum*).
- Canopy management: this encompasses the practices undertaken by the grower to care for the vines as well as the climatic and soil influence. This allows for an optimal balance between vine growth and its productivity. There are different tasks for the grower:
  - Trellising: it combines the training of vines and the driving actions in the canopy‘s aerial space to achieve the desired arrangement of the strains.
  - Thinning: it refers to the removal of excessive shoots, leaves, or immature grape bunches (green pruning) to ease the burden of the strains and achieve the vine balance.
  - Fertilization: a vineyard needs a regular supply of mineral and organic elements in its soil like nitrogen, phosphorus, and potassium. It is achieved by adding animal manure and mineral fertilizers that promote the healthy growth of the vines and fruits and protect them against diseases.
  - Phytosanitary treatments*:* it refers to the treatments against diseases and parasites. This includes mechanical actions, such as ploughing the soil under the vine rows to fluff and aerate the earth and also eliminate larvae, insects, and weeds that can compete with the vine roots for the soil nutrients: it also includes chemical actions, such as sulphuring the vines against parasites and fungi.

Regarding the grapevine variety productivity calculation parameters for Laeetanian wine, we chose those of the Muscat of Alexandria or Roman Muscat. This is the modern variety closest to the *coccolobis hispana* described by the Roman agronomists for this territory.[23] It is predominantly a white, sweet grape of the 4th epoch (large vegetative cycle of > 185 days), with a tardy maturation period of +55 days that should be harvested later than other similar varieties (between mid-September and mid-October).[24] It is used for wine, as a table grape, and to make raisins. This grape produces sweet and dry elegant wines with a powerful floral flavour.

Spacing Feet (m)		Between Rows									
		3 (0.9)	4 (1.2)	5 (1.5)	6 (1.8)	7 (2.1)	8 (2.4)	9 (2.7)	10 (3.0)	11 (3.4)	12 (3.7)
Between Vines	3 (0.9)	4840	3630	2904	2420	2074	1815	1613	1452	1320	1210
	4 (1.2)	3630	2723	2178	1815	1556	1361	1210	1089	990	908
	5 (1.5)	2904	2178	1742	1452	1245	1089	968	871	792	726
	6 (1.8)	2420	1815	1452	1210	1037	908	807	726	660	605
	7 (2.1)	2074	1556	1245	1037	889	778	691	622	566	519
	8 (2.4)	1815	1361	1089	908	778	681	605	545	495	454
	9 (2.7)	1613	1210	968	807	691	605	538	484	440	403

Table 2: Vines per acre based on planting spacing. Multiply by the conversion value 2.55052 to get vines/hectare.

c) Yield components calculation*:* there are three main parameters to take into account:
- Planting density calculation: refers to the ratio of vines to area. It can be expressed as number of vines/acre, vines/hectare or *vitis*/*iugerum*, depending on the surface units used or the measurement system we want to apply.
- Yield per strain: it refers to the mass of grapes per cultivar in regards to the capacity of the vine to produce a specific wheight of total grapes. This depends on different parameters, which derive from the selected vine/grape variety, the plantation system, the driving and pruning methods adopted, and the canopy management.
- Harvesting yield: it refers to the total mass of grapes, expressed in weight, produced in the whole vineyard, property, or territory.

These three parameters are the most used to calculate vineyard crop and grapevine yields in respect to two main productivity values: Maximum and Average (table 5).

Vineyard Crop and Grapevine Yields Calculation

There are two main parameters for calculating the total harvesting yield of a single vineyard, a property or *fundus*, and area or territory (region, province, etc.). These are also used to obtain the corresponding ratio for predicting a potential vineyard crop after considering planting density, cultivar chosen, environmental conditions, and the mass of grapes per cultivar and per field.

a) Vineyard crop yield: the most common way to predict a potential vineyard crop yield is the so-called traditional method. To do this, some data are needed:

First, the planting density, which equals the total number of vines per acre/hectare/*iugera*. There are modern tables of vineyard planting densities that estimate the vines based on the plantation frame and calculated from the distances between rows and vine spacing (table 2).

	1 m	1,10 m	1,15 m	1,20 m	1,25 m	1,30 m	1,40 m	1,50 m	1,75 m	2 m	2,25 m	2,50 m	2,75 m	3 m
1 m	10.000	9.090	8.695	8.333	8.000	7.692	7.142	6.666	5.714	5.000	4.444	4.000	3.636	3.333
1,10 m		8.264	7.905	7.575	7,272	6.993	6.493	6.060	5.194	4.545	4.040	3.636	3.305	3.030
1,15 m			7.561	7.246	6.956	6.688	6.211	5.797	4.968	4.347	3.864	3.478	3.162	2.898
1,20 m				6.944	6.666	6.410	5.952	5.555	4.761	4.166	3.703	3.333	3.030	2.777
1,25 m					6.400	6.153	5.714	5.333	4.571	4.000	3.555	3.200	2.909	2.666
1,30 m						5.917	5.494	5.128	4.335	3.846	3.418	3.076	2.797	2.564
1,40 m							5.102	4.761	4.081	3.571	3.174	2.857	2.597	2.380
1,50 m								4.444	3.809	3.333	2.962	2.666	2.424	2.222
1,75 m									3.265	2.857	2.539	2.285	2.077	1.904
2 m										2.500	2.222	2.000	1.818	1.666
2,25 m											1.975	1.777	1.616	1.481
2,50 m												1.600	1.454	1.333
2,75 m													1.322	1.212
3 m														1.111

Table 3: Vines per hectare based on planting spacing. Divide by the conversion value 2.55052 to get vines/acre.

The highlighted vine density value in table 2 is associated with common vine spacing in the Laeetanian region in Roman times:

4 *pedes* × 5 *pede*s ≅ 4/5 vines/frame ≅ 2178 vines/acre

A 10 % reduction in vine numbers ought to be considered due to the use of land for margins and roads:[25]

2178 vines/acre × 10 % = 217.8 vines/acre

2178 vines/acre − 217.8 vines/acre ≅ 1960 vines /acre (table 2)

The values of vines highlighted in Table 3 is associated with the common vine spacing in the Laeetanian region in Roman times:

4 *pedes* per 5 *pedes* ≅ 4/5 vines/frame ≅ 5,555 vines/ha.

When considering the 10 % reduction due to the need for roads and margins, we have:

5,555 vines/ha × 10 % = 555 vines/ha

5,555 vines/hectare − 555 vines/hectare ≅ 5,000 vines /ha.

We can transform these values by converting the units of measure:

1 acre ≅ 0,405 ha / 1 hectare ≅ 2.47 acres

1 *iugerum* ≅ 0.620 acres / 1 *iugerum* ≅ 0.2518 ha.

The calculation for both values of surface measurements is:

1,960 vines/acre × 0.620 acres = 1,215.2 *vitis*/*iugerum*

5,000 vines/hectare × 0.2518 hectare = 1,259 *vitis/iugerum.*

The resulting average value is:

1,960 vines/acre ≅ 5,000 vines/ha ≅ 1,237.1 *vitis*/*iugerum.*[26]

Then we can calculate the plant density for a vineyard of 100 *iugera* or 200 *iugera*:

1,237.1 *vitis/iugerum* × 100 *iugera* = 123,710 *vitis/½ centuria*

1,237.1 *vitis/iugerum* × 200 *iugera* = 247,420 *vitis/centuria.*

Row width (m)	Number of rows per ha	Number of bearers/ha[1]	Mass of grapes[2] for cultivars with							
			120 g/bunch[3]		150 g/bunch[4]		200 g/bunch[5]		250 g/bunch[6]	
			Per bearer (g)	Per ha (t)	Per bearer (g)	Per ha (t)	Per bearer (g)	Per ha (t)	Per bearer (g)	Per ha (t)
3,0	33	33 000	360	11,8	450	14,9	600	19,8	750	24,8
2,7	37	37 000	360	13,3	450	16,7	600	22,2	750	27,8
2,5	40	40 000	360	14,4	450	18,0	600	24,0	750	30,0
2,2	45	45 000	360	16,2	450	20,3	600	27,0	750	33,8
2,0	50	50 000	360	18,0	450	22,5	600	30,0	750	37,5

[1] With a bearer spacing of 10 cm between bearers
[2] For an average of 3 bunches per spur
[3] E.g. Cabernet Sauvignon, Cabernet franc, Pinot noir
[4] E.g. Merlot, Pinotage
[5] E.g. Crouchen blanc, Morio Muscat, Sauvignon blanc
[6] E.g. Carignan, Colombar, Mourvèdre

Table 4: Mass of grapes for cultivars on different plantation frames and grapevine varieties (footnote 26).

Second, we need the number of clusters per vine to calculate the yield per strain value. This is estimated either based on the buds left at pruning (and therefore, potential shoots/ vine) or the typical cluster count/shoot for the grape variety. It can also be estimated in-season by doing cluster counts on selected vines within a block. Often, it is done at both times, particularly in years where winter damage has resulted in significant bud damage, or when early frosts have damaged emerging shoots. (fig. 2)

Third and finally, we need an estimated mass of grapes for cultivars of an average cluster weight. This is taken from historical records (and thus, a grower should keep yearly records). If calculating the potential yield just before harvest, a grower can sample a few clusters and use their average weight as this estimate. The traditional equations also allow us to determine the number of clusters they should leave per vine, if they have a target yield in mind. There are some tables of correspondence between mass of grapes for cultivars and average cluster weights for different grapevine varieties: (table 4)

With all this information, we can calculate the potential yield in tons/acre or in tons/hectare or in *librae/ iugerum* by applying this simple formula:[27] (fig. 3)

b) Grapevine crop yield: this has to adapt to the grapevine variety chosen. For Laeetanian wine, we have used the parameters from Muscat of Alexandria / Roman Muscat variety in a standard vineyard of 100 *iugera*. The calculation parameters have been calculated for both the maximum and average productivity levels: (table 5)
We can convert these values:
1 Roman *libra* ≅ 0.7109 lb /1 Roman *libra* ≅ 0.32245 kg
1 ton (UK) = 2,240 lb / 1 metric ton = 1,000 kg
1 Roman wine *amphora* ≅ 81 Roman *librae.*

$$PY(t/a) = \frac{ANV \times NC \times CW}{2000}$$

PY(t/a): Potential yield, in tons per acre
ANV: Number of producing vines per acre
NC: Number of clusters per vine
CW: Cluster weight in pounds

$$PY(kg/ha) = \frac{ANV \times NC \times CW}{1000}$$

PY(kg/ha): Potential yield, in kilograms per hectare
ANV: Number of producing vines per hectare
NC: Number of clusters per vine
CW: Cluster weight in grams

$$PY(lib/iug) = \frac{ANV \times NC \times CW}{12}$$

PY(*lb*/*iug*): Potential yield, in *librae* per *iugerum*
ANV: Number of producing vines per *iugerum*
NC: Number of clusters per vine
CW: Cluster weight in *unciae*

Fig. 3: Formula for calculation of potential yields in different measurement magnitudes.

The calculations for both values of weight and surface are:
1 (mt) = 1000 (kg) = 2,204.62 (lb) /1 ha ≅ 2.47 acres/ 1 *iugerum* ≅ 0. 2518 ha
25.74 mt/ha = 25,740 kg/ha × 2.20462 (lb) = 56,747 (lb) : 2,204 (lb) = 25.74 (t)/ha
25.74 (t) /ha : 2.47 (a) = 10.42 tons/acre
25.74 (mt) × 0.2518 ha = 6.52 (mt)/*iug* = 6522 kg/*iug*: 0.32245 kg/lb = 20,226 *librae*/*iugerum.*

The calculation and conversion of these weight/surface values in volume/surface units of wine are the following:
20,226 *librae/iugerum*: 81 *librae*/*amphorae* ≅ 250 *amphorae* /*iugerum* × 22.5 litres[28] = 5,625 litres/*iug* ≅ 5.62 hl /*iugerum* × ± 4 *iugerum*/ha ≅ 22.5 hl /ha ≅ 494.93 gallons/ha: 2.47 acres/ha = 200.37 gallons/acre = 6.36 wine barrels (UK)/acre[29]
250 *amphorae*/*iugerum* ≅ 10.73 *cullei*/*iugerum*[30] × 100 *iugera* = 1,073 *cullei*/½ *centuria*
250 *amphorae*/*iugerum* ≅ 10.73 *cullei*/*iugerum* × 200 *iugera* = 2,146 *cullei*/*centuria*
This could be the average ratio of a Laeetanian vineyard crop yield obtained in volume of wine produced per field.

Yields, Parameters, and Variables of Winemaking Processing Facilities

There are two methods for quantifying the yields of a processing facility based on the four main winemaking tasks developed: extraction of the juice by treading on the grapes in the *calcatoria* (treading vats); pressing of the pomace in the *torcular* (winepresses); collection of the must in the *lacus* (collecting tanks); and transferal into the *dolia* (large fermentation jars).[31]

MUSCAT OF ALEXANDRIA / ROMAN MUSCAT **GRAPEVINE CROP YIELD COMPONENTS CALCULATION**	
Calculation parameters (maximum)	***Calculation parameters (average)***
1. Vines per ha = 5000	**1. Average Vines per ha = 4766**
2. Vines per *iugera* = 1259	**2. Average Vines per *iugera* = 1200**
3. *iugerum* in field = 100	**3. *iugerum* in field = 100**
4. Bunches per vine ≅ 27 (24-30 bunches)*	**4. Average bunches per vine ≅ 27 (24-30 bunches)***
5. Bunches weight = 450 g	**5. Average bunches weight = 200 g**
6. Berries per bunch ≅ 104	**6. Average berries per bunch = 100**
7. Berry weight = 4,32 g	**7. Average berry weight = 2,00 g**
8. Target yield kg per vine = 12.15 (kg)	**8. Average yield kg per vine = 5,4 (kg)**
9. Target yield tons per ha = 60.75 (mt)	**9. Average yield tons per ha = 25.74 (mt)**
10. Target yield tons per *iugerum*= 15.18 (mt)	**10. Average yield tons per *iugerum*= 6.52 (mt)**

Table 5: Grapevines crop yield components calculation at maximum and average productivity levels.

Thus, quantification can focus on two main operations:

a) Treading and pressing yields*:* this tries to calculate the maximum capacity of must processed during the vintage period or *vindemia* both by grape-stomping in treading vats and by pressing the pomace in winepress. This method has several advantages compared to the second one. First, practically all the harvested grapes ought to be treaded and pressed to obtain the must to be fermented into wine.[32] Second, some important values can be derived from the written sources, experimental archaeology, ethnographic data, and modern oenology.[33] Third, estimations can be subjected to mathematical and statistical analysis.[34]

b) Collection and storage yields*:* previous studies have tried to apply this method, which calculates the capacity of production from the data provided by the Latin literary sources regarding the recommended number of *dolia*.[35] It also uses archaeological data pertaining to the number and size of vats and storage structures present in production centres.[36] However, the data from the literary sources are often scarce or contradictory, and the archaeological data are often incomplete. This does not mean that we cannot use this type of calculation if sufficient data are available.[37]

A set of fixed parameters can be established from the data derived from Cato[38] about the three wine-presses necessary for processing the harvest from a 100-*iugera* vineyard (≅ 25 ha ≅ 61.77 acres), and from Pliny's description of the pressing yield capacities according to volume of must processed,[39] as c. 20 *cullei* (≅ 105 hl ≅ 2310 gal = 73 wine barrels (UK)). However, these authors do not specify how many times the presses were operated and, if the value included the volume of must extracted from treading the grapes.

To quantify the temporal variable, an average of the *vindemia* period can be calculated if we compare the values inferred from the Roman agronomists with the data taken from

Concept year	Grapes weight (tm) real	Treading must (hl) real	Pressing must (hl) real	Total must 1/2 day 6h/(hl)	Corresponding *iugera* (≅ 5.25hl)	Corresponding ha (≅ 21hl)
1995*	7,9*	23,5*	23,0*	46,5*	8,9*	2,2*
1996	5,0	16,0	14,0	30,0	5,7	1,4
1997	5,0	19,0	16,0	35,0	6,7	1,7
1998	6,0	15,5	14,0	29,5	5,6	1,4
Average	5.97(t)*/ 5.33(t)	18.5(hl)*/ 16.83(hl)	16.75(hl)*/ 14.66(hl)	35.25(hl)*/ 31.5(hl)	6.72(*iug*)*/ 6.0(*iug*)	1.6(ha)*/ 1.5(ha)

Table 6: Real yield values obtained during the Mas de Tourelles experiment.

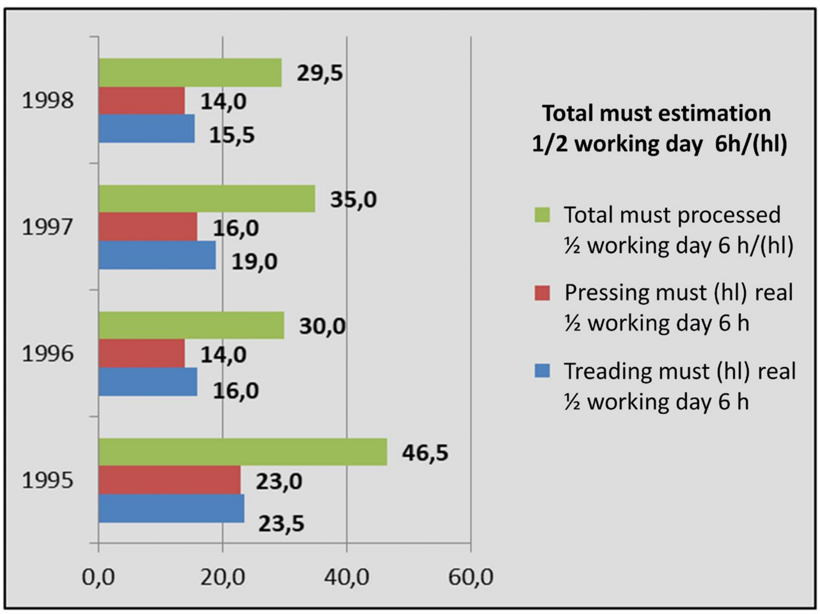

Fig. 4: Real yield values obtained during Mas de Tourelles experiment.

ethnographic and experimental sources. We calculated the maximum and the average pressing capacity of one Catonian press in half of a working day (≅ 6 hours) and a complete working day (≅ 12 hours).[40]

The fixed calculation parameters and variables are:

Vindemia maximum period ≅ 30-44 days.[41]

Vindemia average period of harvesting and processing Muscat of Alexandria grapes ≅ 12–15 days.[42]

Working hours per day: 12 hours of sun (Laeetanian region/Barcelona).[43]

Vineyard extension unit: 1 *iugerum* ≅ 2,518 m^2 = 0.2518 ha ≅ 0.623 acres

Vineyard extension plot: 100 *iugera* ≅ 25.18 ha ≅ 62.3 acres,[44] or 200 *iugera* ≅ 50.36 ha ≅ 124.6 acres[45]

Concept year	Grapes weight (tm) estimation /day	Treading must (hl) estimation/day	Pressing must (hl) estimation/day	Total must estimation 1 day 12h/(hl)	Corresponding *iugera* (≅ 5.25 hl)	Corresponding ha (≅ 21hl)
1995*	15,8*	47,0*	46,0*	93,0*	17,7*	4,4*
1996	10,0	32,0	28,0	60,0	11,4	2,9
1997	10,0	38,0	32,0	70,0	13,3	3,3
1998	12,0	31,0	28,0	59,0	11,2	2,8
Average	11.95(t)*/ 10.6(t)	37(hl)*/ 33.6(hl)	33,5(hl)*/ 29.33(hl)	70.5(hl)*/ 63.0(hl)	17.82(iug)*/ 11.96(iug)	13.14 (ha)*/ 3.00 (ha)

Table 7: Estimate yield values obtained per a working day of 12 hours (our own).

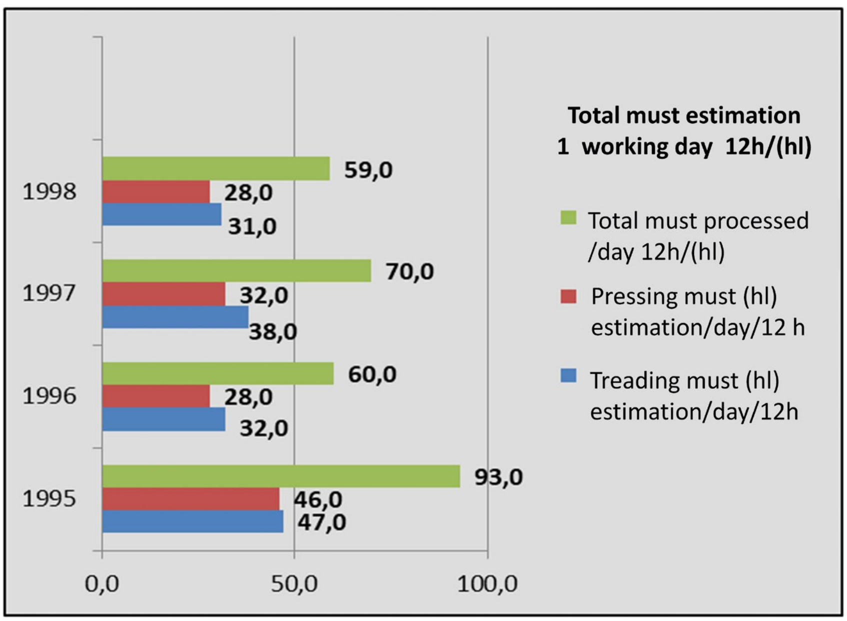

Fig. 5: Estimate yield values obtained per a working day of 12 hours (our own).

Roman liquid volume measure unit: 1 hl = 100 l ≅ 22 gal (UK)
Roman volume unit equivalence: 1 *culleus* ≅ 5.25 hl ≅ 525 l ≅ 115.3 gal (UK)
Average grapes per day (12 h) processed: ≅ 10.6 (mt) ≅ 10.38 (t)
Average grapes per *vindemia* (15 days) processed: ≅159 (mt) ≅ 155.82 (t).[46]

Winemaking Processing Facilities Yields Calculation

Our calculations take into account the data offered by A. Tchernia's and J.-P. Brun's experimental archaeology project carried out from 1995 to 1998 that used reconstructions of Roman processing facilities at Mas de Tourelles (Beaucaire, France). Moreover, we should distinguish both values (e.g. the must yields deriving from the treading process and the must yields deriving from the pressing process) when trying to obtain a production ratio of the total yield. A series of tables were developed and comparative graphs were developed that allow us to assess the average capacity of yield performance.

First, we calculate the processing yield values obtained for half of a working day (≅ 6 hours) (table 6; fig. 4),[47] followed by the values for a complete working day (≅ 12 hours) (table 7; fig. 5).

It is important to note that 1995 was the first year of the experiment, and that the experimenters themselves considered the second yield value obtained for the grape treading process to be aberrant. In order to adjust the final results, two average values are possible. The first one (total average values with asterisk) is the sum of yields for the whole period (1995–1998). The second ones are obtained from the sum of the yields for the last three years (1996–1998); this period has great coherence in terms of the final results. For the sake of accuracy, we will take the second average values as our point of comparison with our results.

Discussion

It is possible to compare the results of the calculations based on the values given in the text of the agronomists with the results obtained from experimental archaeology:

a) Data derived from the Roman agronomists:[48]

- Cato[49] gives some information about vineyard crop yield values that have been established by J.-P. Brun in a ratio ≅ 33 hl/ha. From this we can calculate other yield ratio magnitudes: 33 hl/ha = 3,300 l/ha : 0.2518 ha/*iug* ≅ 13,105 l/*iug* : 525 litres/*culleus* ≅ 24.96 *cullei*/*iugerum* × 100 *iugera* = 2,496 *cullei*/½*centuria*; 24.96 *cullei*/*iugerum* × 200 *iugera* = 4,992 *cullei/centuria.*[50]

For processing yields, J.-P. Brun established a total target of 750 hl of must processed in a facility with three presses.[51] Supposing a ratio of 250 hl per press and applying Pliny's processing yield ratio per press (20 *cullei* ≅ 105 hl ≅ 2310 gal = 73 wine barrels UK), this results in just three days of work.[52]

- Varro[53] gives an average vineyard crop yield value for Italy between 10-15 *cullei* × *iugerum* ≅ 52.5–78.75 hl ≅ 1184.84–177.26 gal = 38-57 wine barrels UK.[54]
- Pliny (nat. 18, 317), estimates that one press can produce ≅ 20 *cullei* ≅ 105 hl ≅ 2,310 gal = 73 wine barrels UK and can process ≅ 20 *iugera* ≅ 5.0 ha ≅ 12.36 acres, but does not give any temporal reference. Brun also considered that taking Pliny's ratio of 63 hl/ ha (which for Columella thought was good),[55] the total production obtained from 20 ha of vineyard ≅ 80 *iugera* would bee 240 *cullei* ≅ 1,260 hl ≅ 27,716 gal ≅ 880 wine barrels UK. A single Catonian winepress could process this amount in around 12 working days. This means that for a 25-ha vineyard ≅ 100

iugera, producing 1,575 hl ≅ 34,645 gal ≅ 1100 wine barrels UK, a single winepress would take c. 15 days to process the grape.

Interpreting the productive yields values relying only on the Roman agronomists' information is difficult because the data are incomplete and the results obtained are inconsistent. However, it seems that the winemaking facilities were prepared with large harvests in mind and to obtain an optimal ratio of wine productivity.[56]

b) Results obtained by archaeological experimentation:[57]

One of the most important results achieved with the Mas de Tourelles' experiment is the ability to determine the average yield value of the treading and pressing processes per working day. These results can help to answer the question of the temporal variable missing in the written sources. Another important issue not treated in the ancient sources is how to know the must yield obtained in every process of grape treading and pressing. A third important point is to determine whether the yield values given by the Roman agronomists are coherent with the results obtained by experimental archaeology. In regard to both winemaking processes, we have obtained the following yield values according to experimental archaeology: (Table 8)

CALCATORIUM YIELD (Optimal average according to Tchernia & Brun, 1999, 104)		CATONIAN WINE PRESS YIELD (Optimal average according to Tchernia & Brun, 1999, 104)
1. Must per working day (12 h)= 33.6 (hl) ≅ 739.09 gal (UK) ≅ 23.46 wine barrels (UK) ≅ 6.4 *cullei*	+	1. Must per working day (12 h)= 29.3 (hl) ≅ 654.51 gal (UK) ≅ 20.77 wine barrels (UK) ≅ 5.6 *cullei*
2. Must per *vindemia* (10*days)= 336 (hl) ≅ 7391 gal (UK) ≅ 234.63 wine barrels (UK) ≅ 64 *cullei*		2. Must per *vindemia* (10 days*)= 293 (hl) ≅ 6445.09 gal (UK) ≅ 204.60 wine barrels(UK) ≅ 56 *cullei*
*Taking the minimum estimate time value.		*Taking the minimum estimate time value.

Table 8: Optimal average values for processing facilities (treading + pressing) obtained by archaeological experimentation.

It assumes a yield average value of 53% of must production obtained from treading and a yield average value of 47% from pressing.[58] The sum of both values gives a total average ratio per processing facilities:

The total average of must processed / working day is: ≅ 63 hl ≅ 1,385.78 gal ≅ 48 wine barrels (UK) ≅ 12 *cullei* ≅ 280 *amphorae*.[59]

The total average of must processed (treading and pressing) over a 10-day *vindemia* is: ≅ 629 hl ≅ 13,836.06 gal ≅ 439 wine barrels (UK) ≅ 120 *cullei* ≅ 2,700 *amphorae*.

The total average of must processed (treading and pressing) over a 15-day *vindemia*: ≅ 943.5 hl ≅ 20,754.09 gal ≅ 659 wine barrels (UK) ≅ 180 *cullei* ≅ 4,193 *amphorae*.

Since no experimental archaeology project was carried out on the yields of a vineyard's crop, the relevant calculations are theoretical. Nevertheless, some comparative calculations can be done between these values and dataset of yields from winemaking processing facilities that came from the experiment.

Comparing the total average results obtained from the three datasets studied (vineyard crop, Roman agronomist dataset, and experimental archaeology processing yields) is important since it clarifies ideas and gives calculation patterns that can be further applied in the analysis of winegrowing productive capacity yields in other geographic areas.

The correlations between viticulture's productive ratios and the dataset from experimental archaeology allow us to quantify Laeetanian winegrowing yields more accurately: (table 9)

Note that the average ratios ≅ 5.62 hl/*iugerum** per vineyard crop yield and ≅ 5.25 hl/*iugerum* both per Catonian wine press yield and winemaking processing facilities yield ≅ ±10 *cullei* per working day (12h) are either very similar or common in all three of the datasets.[60] Despite the different values resulting from each calculation methodology these results indicate that a statistically correlation exists between them, as shown by the common or similar average ratio obtained for the three yield calculation systems.

VINEYARD CROP YIELD
CALCULATION PARAMETERS (OBTAINED) — **Average ratio**

- **Average yield weight per vine = 5.4 (kg)**
- **Average yield weight per hectare = 25.74 (mt)**
- **Average yield weight per *iugerum* =6.52 (mt) ≅ 10.73 *cullei/iug* ≅** — **5.62 hl/*iugerum*****
- **Average yield per vineyard (100 *iug*) = 1,073 *cullei*/½ *centuria***
- **Average yield per vineyard (200 *iug*) = 2,146 *cullei*/centuria**

CATONIAN WINE PRESS YIELD
CALCULATION PARAMETERS (SUGGESTED) — **Average ratio**

- **Must processed 10 *cullei* /workday= 52.5 hl ≅ 2.5 ha ≅ 10 *iugera* ≅** — **5.25 hl/*iugerum***
- **Total *vindemia* period (+-10 days)= 525 hl ≅ 25 ha ≅ 100 *iugera* ≅ 100 *cullei* ≅ 1 press**
- **Total *vindemia* period (+-15 days)= 787.5 hl ≅ 37.5 ha ≅ 150 i*ugera*≅150 *cullei* ≅1 press**

WINEMAKING PROCESSING FACILITIES YIELDS (TREADING + PRESSING)
CALCULATION PARAMETERS (EXPERIMENT RESULTS)
(Based on Tchernia & Brun, 1999) — **Average ratio**

- **Total must estimation 1 workday (12h) ≅ 63 hl ≅ 3 ha ≅ 12 *iugera* ≅** — **5.25 hl/*iugerum***
- **Total *vindemia* period (+-10 days) ≅ 630 hl ≅ 30 ha ≅ 120 *iugera* ≅ 120 *cullei* ≅ 1 press**
- **Total *vindemia* period (+-15 days) ≅ 945 hl ≅ 45 ha ≅ 180 *iugera* ≅ 180 *cullei* ≅ 1 press**

Table 9: Comparative study of different yield calculation methodologies for assesses its correlation.

Conclusions

Changes in rural and urban settlement patterns also reflected a change in agrarian exploitation systems. Winegrowing yield calculations are crucial to the organization of the whole grapevine crop and winemaking production chain. The interaction between the potential vineyards extension and the needs of winemaking production facilities in a given area is a good way to explore the quantification of viticulture yields. To estimate global winegrowing yields we have to distinguish between two main methods:

- Vineyard's crop yield: it refers to the mass of grapes obtained (in weight) both per vine and per harvesting on the area examined.
- Winemaking processing facilities yield: it refers to the productive capacity of the processing facilities for transforming the mass of grapes into volume of must, and, with fermentation, into *cullei* of wine.

These calculations depend on a large number of variables that can affect the results, such us the agroecological environment (geomorphology, soil features, climatology and weather conditions, grape varieties, age of vines, etc.), availability of labour, transport networks, and sociocultural practices.

Comparison between vineyard crop and winemaking facilities yields (treading and pressing) is a key element for achieving this goal. It makes it possible to "reconstruct" viticulture productive units as "types" and to calculate production capacities in absolute terms. It combines the data of modern oenological studies, of the Roman agronomists, the archaeological record, ethnographic sources, and experimental archaeology.

Our explanatory data analysis has focused on obtaining some important ratios that allow us to analyse and model the scope of the Laeetanian Roman wine economy and its specific evolution over the time. This microeconomic approach also allows us to develop further predictive or reconstructive models about the productive and trading systems of the past.

In summary, combining yields' datasets obtained from experimental archaeology with available oenological, ethnographic, and historical yield datasets can be the best way to achieve an optimal knowledge (and one closer to reality) about the productive capacity of winegrowing during the Roman period. Furthermore, it is also possible to apply this method to the study of viticulture or other economic activities in other territories and periods.

Notes

[1] "In which soil does one *iugerum* produce between 10 or 15 *cullei* of wine like in the Italian regions?"(authors' transl.).

[2] "One press ought to fill (one vat of) 20 *cullei.* That is the norm. Thus, one single press should be enough for (pressing) 20 *iugera* (of vineyard) and for filling all the collecting vats (*lacus)* and wineskins (*cullei*)" (authors' transl.).

[3] Martín i Oliveras 2015, Martín i Oliveras – Revilla 2019, with previous bibliography.
[4] Martín i Oliveras 2015, 182.
[5] Amouretti – Brun 1993, 552.
[6] In the case of ancient viticulture, preparing the grape stock containers, cleaning the treading areas (*calcatoria*), greasing the presses (*torcularia*), proofing the must collecting tanks (*lacus*), and re-pitching the earthenware fermentation jars (*dolia*).
[7] Winemaking process in facilities yields are also called Winery's yields. Martín i Oliveras – Revilla 2019.
[8] Clingeleffer et al. 2001
[9] Frontinus "*De agrorum qualitate*" <http://www.thelatinlibrary.com/frontinus/qualitate.shtml> (30.04.2019). See also J. Murray, A Dictionary of Greek and Roman Antiquities (London 1875) s. v. Ager, 29–31. <http://penelope.uchicago.edu/Thayer/E/Roman/Texts/secondary/SMIGRA*/Ager.html> (30.04.2019) ; Castillo 2011, 83–110.
[10] Martín i Oliveras 2015, 44–50.
[11] Palet – Fiz – Orengo 2009.
[12] Oller 2015, 408–410 Map 8–12.
[13] Rivers, streams banks, and flood plains could be important constraints for settlement patterns. Mountains, marshes, and sea shores could be also conditioning factors.
[14] Plin. nat. 17, 20.
[15] Archer 2010.
[16] Champagnol 1984.
[17] Hunter – Volschenk 2008.
[18] Martin i Oliveras 2015, 71.
[19] See Tchernia 1986, 127. The author believes that this cultivation method was imported into the Iberian Peninsula by Punic colonizers and was adopted by the indigenous inhabitants in *Hispania Citerior*, this method improved productivity and lowered the production costs, making the Laetanian wine much more competitive.
[20] Stein et al. 2016, 1056–1057.
[21] Skinkis – Vance 2013.
[22] See Martin i Oliveras 2015, 39 Tab. 1. Maturation periods could be between < 5 and +55 days. Vegetative cycles could be between < 145 days and > 185 days, depending on grape varieties.
[23] Colum. 3, 2, 19; Plin. nat. 14, 29–30. See Miles et al. 2011, fig. 3: the Muscat of Alexandria is one of the most ancient and less hybrid grapevine "mother" varieties in the world.
[24] Depending on the soil typology and microclimatic conditions of the vineyard. Grape variety data come from: <http://www.vitivinicultura.net/moscatel-de-alejandria.html> (30.04.2019). Some scholars also believe that an ancient variety of *balisca* or *bilisca,* the *vitis Apiana,* cited by Pliny (Plin. nat. 14. 24. 81) as "the grapes that attract bees", and the *coccolobis hispana* were the same cultivar: García 1991, 219–221.
[25] Percentage of vines losses value taken from: <http://www.viverosmacaya.com/plantacion/> (30.04.2019).
[26] The average is obtained by adding both total quantities (vines/acres + vines/hectare) and dividing them into two.

[27] The Romans did not use weight measurements but preferred to measure by capacity. Thus a Roman cubic foot (26.26 dm3) was equivalent to a *quadrantal* or *amphora* (28 *sextarii* or 0.547 l) and one Anglo-Saxon gallon (3.785 l) would be more or less equivalent to a Roman *congius* (= 6 *sextarii* or 3.283 l). The *amphora* was equivalent to 81 Roman wine *libras*, one Roman *libra* equals 322.45 gr. which in turn are equal to 1.4 Anglo-Saxon ounces.
[28] Average capacity of Laetanian wine amphora form Pascual 1, see *Amphorae ex Hispania* database: <http://amphorae.icac.cat/amphora/pascual-1-tarraconensis-northern-coastal-area/features> (30.04.2019).
[29] 1 hl = 21.9969248299 gallons (UK) /1 gallon (UK) = 0.0454609 hl /1 barrel (UK) = 31.5 gallons (UK).
[30] 1 *culleus* ≅ 525 l ≅ 115.2639 gallons (UK) = 3.66 wine barrels (UK).
[31] In fact there are three methods if we add the vineyard crop yield calculation and its correlation with capacity units of wine produced.
[32] Except those that were sold as fruit (as grapes or raisins). According to the Food and Agriculture Organization (FAO), approximately 71 % of the world's grape production is used for wine, 27% for fresh consumption as fruit, and 2 % as raisins and juices: <http://www.fao.org/faostat/en/#data> (30.04.2019).
[33] From experimental archaeology we only have the data from the Mas de Tourelles experiment done in 1995–1998: Tchernia – Brun 1999, 102–105.
[34] Estimates are the object of debate among scholars, but have been accepted by most economic historians due to the scarcity of data and the absence of more reliable information: De Sena 2005, 2 note 7.
[35] E.g. Cato agr. 11, 1.
[36] Brun 1993, 307–342; Tchernia 2013, 153–166.
[37] Mainly to be able to contrast them with the results obtained by other quantification methodologies (vineyard crop yields and winemaking processing facilities yields).
[38] Cato agr. 11.
[39] Plin. nat. 18, 317.
[40] The Romans divided the day into twelve *horae* or hours starting at sunrise and ending at sunset. The night was divided into four watches. Sunlight parameters for the months of August/September/October in the Barcelona area are from: <https://meteogram.es/sol/espana/barcelona/> (30.4.2019).
[41] Varro rust. 1, 34, 2; Plin. nat. 18, 319.
[42] Assuming a vineyard of Muscat of Alexandria variety in the Laetanian region's agro-ecological conditions (i.e. soil, slope, weather, temperatures, planting system, head-spur pruning, etc.), with an extension of 100 *iugera* (≅ 62.3 acres ≅ 25.18 ha) and also considering the average temporal values for processing (treading and pressing) as deduced from Pliny's dataset (see discussion section).
[43] Op. cit. note 32.
[44] Cato agr. 10, 1.
[45] Colum. 2, 12.
[46] Average grape values taken from Mas de Tourelles experiment: Tchernia – Brun 1999, 102–105.
[47] Corresponds to the real values obtained in the 6 hours of work / day during the experiment in France.
[48] All data are from Brun 2004, 20.
[49] Cato agr. 11.

[50] These values appear too optimistic.
[51] We have not been able to deduce from where the total processing yield target of 750 hl arises, since if we take the ratio of 33 hl/ha previously established and multiply it per 25 ha (≅ 100 iugera), the result obtained is 825 hl.
[52] We think the temporal ratio of almost three days is deduced by assuming Pliny's processing yield value of 20 *cullei* for one single press in one single working day adding the treading yield as well. In any case, the result obtained is oversized.
[53] Varro rust. 1, 2, 7.
[54] These values are coherent with Pliny's processing yields ratio of 20 *cullei* / *iugerum* but also are oversized.
[55] Colum. 3, 3,1.
[56] Note that we speak of optimal results, not maximal; achieving a good balance between vineyard's crops and processing facilities yields was the main objective pursued by the winegrowers.
[57] All data from Tchernia – Brun 1999, 104–109 and our own study.
[58] Percentages from Tchernia – Brun 1999, 104.
[59] Op. cit. note 25.
[60] Considering the bias resulting from the conversion between weight and volume for liquids values.

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Fig. 1–5: by authors. – Table 1: by authors. – Table 2: from Komm & Moyer 2015, table 2; Moyer, 2015, table 1. – Table 3: from <http://www.viverosmacaya.com/plantacion/> (30.04.2019). – Table 4–9: by authors.

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