OBJECT: manuscript ID soil-2014-43 entitled " An overview of the recent approaches for terroir functional modelling, footprinting and zoning" submitted to the SOIL journal.

Firstly, we would like to thank Anonymous Referee#1 for helpful comments. We have extensively revised the paper based on his/her suggestions. The list of specific points and how we address them in the review article is given below.

Anonymous referee #1: "The authors have made a huge effort in order to try to include many aspects of soil, vine, wine, climate relationships, environmental risks, and many new tools and methods to capture and analyse data. Due to this wide range of aims, not all the objectives have been achieved in the present version. […] the topic is of importance and is addressed with a valuable interdisciplinarity."

"In my opinion, the paper tries to consider too many objectives and it is impossible to include and discuss all of them as would be desirable. It might be preferable to reduce the number of objectives and expose more clearly the relationship between the soil (terroir) and the production and / or product quality. I think that in this article, the relationship remains unclear.

I recommend the authors to reduce the number of objectives. In fact the title only mentions "An overview of the recent approaches for terroir functional modelling, footprinting and zoning". Therefore, the core of the article is the section 3. Terroir zoning at different scales using geospatial technologies They could avoid (or only mention in the introduction) the sections regarding: 2 Quantifying the influences of terroir components on plant growth, fruit composition and wine quality 2.1 Climate-soil relationships 2.3 The perspective of climate change 4 Terroir sustainability assessment and new preservation practices I don't mean that they are not important, just I think that this paper needs to focus on less themes to fulfill other important objectives: 1. New tools for assessing terroir footprints: metabolomics, metagenomic approach and microbial/chemical fingerprinting, 2. terroir zoing at different scales: mapping terroirs and using remote and proxy sensing technologies to monitor soil quality and manage the crop system for a better food quality"

Our reply to that comment:

Both anonymous referees share the critic that the paper is rather long and not well-organized because too many objectives are treated and that the reader would have expected to know more about relationships between soil and vine features. Possibly the critics come from the fact that relationship between soil and wine, which is at the basis of the terroir concept, is not yet fully acknowledged by the scientific consortium and must be further documented. For this reason and in order to clarify the reading of this paper, we followed the objectives suggested by Anonymous Referee#1.

How this is implemented in the revised manuscript:

The manuscript was reduced to the following sections corresponding to the most original objectives suggested by Anonymous Referee#1:

1/ New tools for assessing terroir footprints: metabolomics, metagenomic approach and microbial/chemical fingerprinting,

2/ terroir zoning at different scales: mapping terroirs and using remote and proxy sensing technologies to monitor soil quality and manage the crop system for a better food quality

The last section about terroir sustainability was reduced but maintained because we considered it as a perspective deriving from the new tools developed.

Section 1 was improved and restructured and updated with last recent references.

We added a new figure 1 to illustrate this first part (please see the attached supplement file).

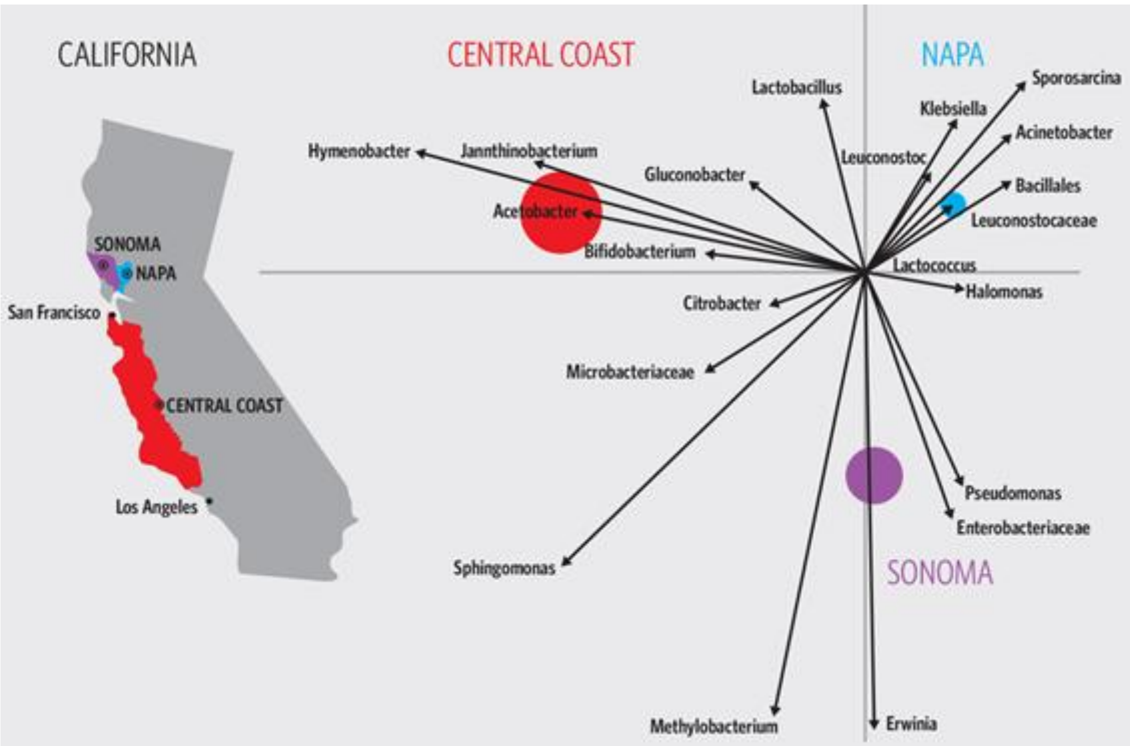

Figure 1. Differences in grape surface microbial communities present between wine regions of

California. From: https://cosmosmagazine.com/earth-sciences/winemaking-art-or-science

`Anonymous referee #1:` "I like the section 3. I think that the authors put together the last methods to study soil (or terroirs) providing updated and organised information. I think that a general table with methods, pros, cons, examples and references would be useful."

Our reply to that comment and how this is implemented in the revised manuscript:
We provided such a table (new table 2, please see the attached supplement file, page 5) and added some comments in the text.
" Table 2 puts together the main last combination of methods, pros, cons, and references examples to study grape characteristics, canopy/yield/biomass/trunk circumference and/or enological parameters, vineyard identification, vine rows and vineyard characteristics, vineyard soil properties (or management zones or terroir units), soil surface condition, erosion and evapotranspiration.[…] Most approaches combine several data sources, methods (geostatistical/statistical/image processing/computer vision/mechanistical models)and remote or proxy sensors (Table 2). All approaches use geopositioning devices (not detailed in Table 2) the error positioning requirements of which need to be compatible with the study objectives (i.e. accurate positioning of individual sampled vines) and the spatial resolution of the acquired imagery."

In addition to Table 2 and its comments, section 2 (former 3) was improved with some additional references and sentences.

`Anonymous referee #1:` "I think that conclusions could be improved if the paper focus only in the questions mentioned in the title. The influence of terroir in grapes/wines and the sustainable land management are not included in the title."

Our reply to that comment:
The revised paper mainly focuses in the questions mentioned in the title, but we consider the

sustainable management as perspectives enabled by the new zoning approaches and already emerging through them.

How this is implemented in the revised manuscript:
Conclusion was reshaped and developed as follows : "Recent studies based either on metabolomics or on the Sr isotopic ratio lead to a strengthening of the assumption that geographical origin does leave a footprint in wines and that both soil and substrate, in interaction with climate and cultural choices, influence the shaping of grapevine phenology and grape and wine quality. Furthermore, the use of the current "omics" technologies seems to confirm the existence of a 'microbial terroir' as a key factor in regional variation among wine grapes. Despite the role of soil microbial communities on terroir is still unclear, in the next future the combination of the omics techniques and traditional approaches could give further insights on activity and composition of vine-associated microbes, especially those living on the grape or leaf surface (phyllosphere) and root surfaces (rhizosphere) but also within the plant tissues (endophytes), and their interactions with plant and soil.

Differentiation and mapping of viticultural terroirs meant as homogeneous regions of grape/wine quality need comprehensive spatial modelling of soil, agronomical and climatic properties, including their changes through time. As such the development of a myriad of either remote or proxy sensing techniques and the corollary challenge of processing large quantities of data acquired at a very fine spatial resolution and/or at several spatial resolutions, scales, and organisational levels. These techniques in data collection and processing are needed to produce easy-to-update decision maps with associated uncertainties that allow users to make appropriate and timely management decisions. This is a revolution in the spatial management of terroir units, as the managed zones will be updatable and the effects of viticultural and/or soil management practices might be easier to control. The perspective of facilitated terroir spatial monitoring makes it possible to address another great challenge in the years to come: the issue of terroir sustainability and the construction of efficient strategies for assessing and applying them across numerous scales. These include the design of efficient soil restoration practices along with crop and/or intercrop management plans, and/or agroforestry viticultural systems, that take into account the possible effects of climate change. Therefore, terroirs are more and more likely to be addressed through the concept of ecosystem services, as viticultural agro-ecosystems, the services of which need to be constantly evaluated and rationalized."

We also modified the second part of the abstract as follows:" This review will focus on two main areas of recent terroir research: 1) using new tools to unravel the biogeochemical cycles of both macro- and micronutrients, the biological and chemical signatures of terroirs (i.e. the metagenomic approach and the regional fingerprinting); 2) terroir zoning at different scales: mapping terroirs and using remote and proxy sensing technologies to monitor soil quality and manage the crop system for a better food quality. Both implementations of terroir chemical/biological footprinting and geospatial technologies are promising for the management of terroir units, particularly the remote and proxy data in conjunction with spatial statistics. As a matter of fact, the managed zones will be updatable and the effects of viticultural and/or soil management practices might be easier to control. The perspective of facilitated terroir spatial monitoring makes it possible to address another great challenge in the years to come: the issue of terroir sustainability and the construction of efficient strategies for assessing and applying them across numerous scales."

`Anonymous referee #1:` "Sometimes the writing is a bit disjointed. There is no clear thread in presenting different aspects: availability of water, nutrients, salinity .... Most of the work refers to oenological and biochemical aspects that occur in plants, but no clear relationship between soil and plant is stated, in spite of the fact that this is one of the objectives of the paper. One single reference or example per issue is not enough to underpin a relationship between soil and vine features."

Our reply to that comment:
That comment is related to the comment about the number of objectives, which was reduced.

How this is implemented in the revised manuscript:
This "disjointed" section was removed.

`Anonymous referee #1:` "Figures 1 and 2 could be combined, the information that they provide is redundant. Figure 3 is not sufficiently explained in the text. If the information is not really relevant, it would be better to delete it. Figure 5 is not needed."

Our reply to that comment:
In adequation with the new objectives, we agree that Figure 1 had to be removed. We followed Anonymous Referee#1's suggestions for figures.

How this is implemented in the revised manuscript:
Figure 1 was removed and Figure 2 maintained, adding a comment to it " There is therefore a gap to fill considering farm (≤ 0.1 to 1 km²), district (≤ some tens km²) to regional scales (≥ tens to thousands km²). The number of map units tends to increase with the log of study area, however its variation is higher for larger study extents than for within-field studies, jointly with the fact that regional studies focus on larger span of target properties. .."

Figure 5 was removed.

Table 2. Typology of zoning studies carried out over the 2002-2014 period

Targets	Scale	Data	Methods	Pros	Cons	References (e.g.)
Grape composition	plot	FM	BK then FA followed by Fuzzy KM	Fine-scale	Time-consuming, high sampling density (3 m)	Baluja et al. (2013)
	plot	FM, airborne NDVI	LR	Fine-scale spatially exhaustive data	Specific calibration for each plot	Lamb et al. (2004), Hall and Wilson (2013)
	plot	FM, Fluo and/or airborne NDVI, ChloM	Spectral index, CF	Replaces expensive measurements	Need of specific calibration for each plot?	Ben Ghoslen et al. (2010), Baluja et al. (2012b), Agati et al. (2013)
	district	VIS-NIR HypS airborne imagery, FM	Spectral indices, LR	Fine-scale spatially exhaustive data	Specific calibration for each plot	Martín et al. (2007), Meggio et al. (2010)
	region	FM, VIS-NIR-SWIR HR satellite imagery, TopoP and/or soil map	Multitemporal SC, SA	Large-scale spatially exhaustive data, landscape-scale relevant for unions of winegrowers	Spatial resolution of imagery appropriate if homogeneity of practices	Vaudour (2003), Vaudour et al. (2010, 2014)
Canopy characteristics, yield and grape composition	plot	FM, YM	OK then KM and/or LOGR and/or NPT	Fine-scale	Time-consuming, high sampling density (2 m)	Bramley and Hamilton (2004), 2005 ; Tisseyre et al. (2008); Bramley et al. (2011a), Arno et al. (2012)
	plot	FM (including CC), soil ECa, TopoP	NDVI, Fuzzy KM, correlations	Fine-scale	Need of further validation	Tagarakis et al. (2013)
	plot	FM, VHSR satellite NDVI	Fuzzy KM and/or GK, ANOVA and/or PCA and/or NPT	Early grape composition, definition of harvest zones	Spatial resolution of imagery not quite appropriate ?	Martinez-Casanovas et al. (2012), Urretavizcaya et al. (2013)
	plot	FM, airborne NDVI (0.3 m)	Correlations	Easy-to-use, spatially exhaustive data	Specific calibration for each plot	Hall et al. (2011)
	farm	FM (including $\delta^{13}C$) , airborne NDVI, soil ECa, TopoP	WHC, ANOVA, IDW thresholding	Relevant scale for winery, good compromise data collection/results	Need to test feasibility at the winery scale	Santesteban et al. (2013)
	farm/ district	FM (LAI), VSHR satellite NDVI	LR	Easy-to-use, spatially exhaustive data	Specific calibration for each image, spatial resolution of imagery not adapted to every viticultural system	Johnson et al. (2003)
	district	VIS-NIR HypS airborne imagery, FM (including leaf LabR spectra)	LR, spectral indices, inversion of PROSPECT-rowRCRM model for predicting leaf reflectance	Fine-scale spatially exhaustive data	Complex parameterization	Zarco-Tejada et al. (2005)

	region	FM, soil map, TopoP, daily climatic data	SWAP mechanistic model	Landscape-scale relevant for unions of winegrowers	Needs detailed data at specific sites for parameterization	Bonfante et al. (2011)
Yield, oenological parameters	plot	FM, YM, soil ER, airborne NDVI and/or topographic parameters	OK and/or PCA then KM	Fine-scale, whole soil-vine-wine chain considered	Time-consuming, high sampling density (≤ 2 m), multisensors collection, microvinifications	Bramley et al. (2011c, d), Priori et al. (2013)
Biomass, oenological parameters	plot	FM, airborne NDVI	NDVI thresholding, then LR	Fine-scale	Time-consuming, high sampling density (5 m)	Fiorillo et al. (2012)
Yield, vine trunk circumference	plot	FM, soil ER, TopoP	LR, Fuzzy KM, ANOVA	Fine-scale	Time-consuming data collection	Rossi et al. (2013)
Vine trunk circumference, management zones	farm	FM, airborne NDVI	Spatially constrained KM	Manageable zones	Need of effective testing of the aggregation-component of the algorithm	Pedroso et al. (2010)
Vine water status	plot	FM (including PLWP), airborne NDVI	NDVI thresholding, LCCAOT	Temporal stability of the zoning over 3 years	One soil type considered, specific calibration for each block required	Acevedo-Opazo et al. (2010a)
	plot	FM (including $\delta^{13}C$ and SWP)	LR, NPT, LCCAOT, IDW thresholding	High validation performance	Specific calibration for each block required	Herrero-Langreo et al. (2013)
	plot	FM (PLWP or SWP), VIS-NIR MS and thermal UAV imagery	Spectral indices, LR		Specific calibration for each plot required	Baluja et al. (2012a), Bellvert et al. (2014)
	farm	FM (including PLWP), airborne NDVI, soil ER	NDVI thresholding, PCA, NPT	Temporal stability of the zoning over 3 years	Auxiliary information on soil types needed	Acevedo-Opazo et al. (2008)
	district	FM (PLWP)	LCCAOT, LR	Easy-to-apply for winegrowers	Need of further validation	Baralon et al. (2012)
Vine rows	plot	Airborne NDVI	VineCrawler algorithm	Suited for vineyards with large rows/interrows	Not suited for dense low-vigour vineyards with missing vines	Hall et al. (2003),
Vineyard identification, vine rows, and vineyard characteristics	plot	FM (LAI), VIS multiangular UAV imagery	SfM, multiple regression	Promising ; 3D-reconstruction	Big data ; further improvements needed to improve LAI prediction	Matthews and Jensen (2013)
	district	VIS-NIR MS ULM or airborne imagery	TA, FT and/or « object-classifier »	Easy implementation, high processing speed, limited amount of parameters, export into GIS shapefile format	Further validation needed for detecting missing plants, further use of all spectral information	Rabatel et al. (2008), Delenne et al. (2010), Puletti et al. (2014)

	district	FM, airborne LIDAR	Georeferencing, LR and/or KM, TA	Performing, 3D-reconstruction	Need of further test on complex viticultural landscapes with several training modes? Cost-prohibitive repeated acquisitions	Llorens et al. (2011), Matthews and Jensen (2012)
	region	VIS MS helicopter imagery	FT, TA	Robust recognition of vineyards	Ambiguities in identifying training modes	Wassenaar et al. (2002)
	region	VHSR MS satellite imagery	TA, autocorrelogram pattern	Robust recognition of vineyards	Better adapted to equally spaced vineyards with large rows	Warner and Steinmaus (2005)
	region	MR MS satellite imagery	Multitemporal SC	Fast unexpensive landscape-scale map	Not accurate enough at the farm/plot scales	Lanjeri et al. (2004), Rodriguez-Perez et al. (2008)
Soil properties, potential management zones	plot	Soil ECa and/or ER, FM (soil analysis) and/or airborne/satellite NDVI	FKA, KM	Additional description of residual variation within classes provided	Ground-truth soil samples mandatory to understand + interpret EMI mapping	Morari et al. (2009), André et al. (2012), Andrenelli et al. (2013), Martini et al. (2013), Priori et al. (2013a)
	farm	Soil ECa, soil map	Geostatistical descriptors, FA	Satisfactory discrimination between soil types	Reference soil map needed in addition to ECa	Taylor et al. (2009)
	region	FM (clay content), airborne VIS-NIR-SWIR HypS imagery	CR, coK, BcoK	Spatially validated	Further test on other soil types/cultural practices	Lagacherie et al. (2012)
	region	FM (soil types, analyses), TopoP, geological map, soil map and/or climatic data	GIS combination of raster layers and/or PCA and/or KM	Landscape-scale relevant for unions of winegrowers ;	Need of further spatial validation; potential high number of output map units	Carey et al. (2008), Herrera-Nuñez et al. (2011)
	region	FM (soil types, analyses), TopoP and/or satellite HR imagery	Different geostatistical models, SC, PCA, fuzzy KM	Landscape-scale relevant for unions of winegrowers ; spatially validated	Need of further viticultural characterization + validation	Hugues et al. (2012), Malone et al. (2014), Priori et al. (2014)
Soil surface condition	plot	FM (soil infiltration rate, clod sizes), VIS UAV imagery	SC, multiscale « object-classifier »	Enables to avoid time-consuming field descriptions	Possible improvements considering NIR and SWIR ranges	Corbane et al. (2008)
	region	FM (BRDF), VIS helicopter imagery	TA, BRDF model	Extraction of bare soil inter-rows	Possible improvements considering NIR and SWIR ranges; need of further validation	Wassenaar et al. (2005)

Erosion	plot	FM (SUM), TopoP, historical landuse maps and/or soil ER,and/or VIS UAV imagery	KM, multitemporal SA	Fine-scale spatially exhaustive data	Further developments at a higher scale; time-consuming observations	Brénot et al. (2008), Paroissien et al. (2010), Chevigny et al. (2014), Quiquerez et al. (2014)
	region	FM (SUM), TopoP, historical landuse information	multitemporal SA	Variability of multi-decennial erosion across local and regional scales with acceptable investigation costs	Time-consuming observations	Paroissien et al. (2010)
Evapotranspiration	region	FM (EdCov, soil water), VIS-NIR-SWIR-thermal satellite imagery	HYDRUS-1D model, S-SEBI and WBI models	accuracies between 0.8 $mm.d^{-1}$ and 1.1 $mm.d^{-1}$ compatible with applications	Further need to address model sensitivities , inclusion of row orientation, landscape characterization	Galleguillos et al. (2011a, b)

Legend: BcoK, block co-kriging; BK, Block kriging; CC, crop circle sensor canopy measurements; BRDF, bidirectional reflectance distribution function; CF, curve fitting; ChloM, chlorophyll content measurements on leaves (chlorophyll meter) ; CoK, co-kriging; CR, continuum removal; Eca, apparent electrical conductivity; EdCov, eddy covariance measurements; EMI, electro-magnetic induction; ER, electrical resistivity; FA, factorial analysis; Fluo, fluorescence proxy measurements in the field; FKA, factorial kriging analysis; FM, field measurements at point locations; FT, Fourier Transform; GK, global kriging; GPR, ground penetrating radar; IDW, inverse distance weighting; HR, high spatial resolution; HypS, hyperspectral; KM, k-means clustering of interpolated values; LabR, laboratory reflectance spectra; LAI, leaf area index; LCCAOT, linear coefficient of correlation analysis and covariance analysis between sites over time; LR, linear regression; LOGR, Logistic regression; MR, medium resolution; MS, multispectral; NPT, non-parametric test; OK, ordinary kriging; PCA, Principal Components Analysis; PLWP, predawn leaf water potential; rowRCRM, Markov-Chain Canopy Reflectance Model; SA, spatial analysis; SfM, structure from motion; SPE, stereoscopic photograph examination; SUM, stock unearthing measurement; SWIR, shortwave infrared; SC, supervised image classifiers (such as regression trees, support vector machines, Bayesian Maximum Likelihood); SWAP, soil-water-atmosphere plant model; SWP, stem water potential; TA, textural analysis; TopoP, topographic parameters (mainly elevation, slope and/or topographic wetness index); UAV, Unmanned aerial vehicle; ULM, ultra-light motorized; VHSR, very high spatial resolution; VIS-NIR, visible and near infrared; WHC, Ward's Hierarchical Clustering; YM, yield maps from grape harvester equipped with yield monitor.