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Soil erosion estimation and the "soil footprint" for a bottle of Prosecco sparkling wine

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"Estimation of potential soil erosion in the Prosecco DOCG area (NE Italy), toward a soil footprint of bottled sparkling wine production in different land-management scenarios".
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Our study on the Prosecco is framed within the international research about soil erosion in conventional agricultural areas, more specifically in wine production areas of the called "Mediterranean vineyards". As it is extensively reported in the scientific literature of the last five decades, soil erosion in conventional agricultural areas is a world-wide phenomenon which is gaining attention due to its multiple impacts on the "environmental services", especially in hilly areas where topography and rainfall regimes are key factors in soil erosion processes (Mongomery, 2007, Verheijen et al., 2009; Beddington et al., 2012; Campbel et al., 2017). In such agro-ecosystems agricultural practices and land managements may speed erosion rates up to 1-2 order of magnitude greater than natural processes of soil formation (Mongomery, 2007). High erosion rates can compromise agricultural productivity, driving to a drastic reduction of soil organic matter, nutrients, biota and water capacity (Lollino et al., 2016). Moreover, soil erosion processes decrease quality and quantity of ecosystem services that soil system is able to guarantee (Adhikari e Hartemink 2016). Due to these issues, in Europe tolerable thresholds were established for soil erosion, with limits between 0.3-1.4 tons per hectare per year (tons ha^{-1} $year^{-1}$), which equates to the natural soil formation rates (Verheijen et al., 2009).
At present, along different crops diffused in Mediterranean regions, conventional vineyards are the most erosion-prone agricultural land (Cerdan et al., 2010; Lieskovsky e Kenderessy, 2016, Prosdocimi et al., 2016). This is mainly related both to geographical and anthropogenic factors. In *Soil Science* there are more than ninety scientific articles which study, using different approaches and methodologies, erosion rates in viticulture production areas; among them, Italian vineyards seems to show the highest erosion rates, with average values of 40 tons per hectare every year (Comino, 2018).
In a context of agricultural intensification and expansion, but also of remarkable growth of wine production, the "Prosecco Conegliano-Valdobbiadene DOCG" embodies at present a paradigmatic case: 129% of increase from 2003 to present, with about 90 million bottles yearly produced from 2016 (Annual Report Prosecco Consortium Conegliano-Valdobbiadene, 2016, 2017, 2018). However, this conspicuous wine production increase results in land use changes towards vineyards expansion: from some 4,000 hectares in 2000 to beyond 7,000 hectares in 2016 (Visentin & Vallerani, 2018). In a recent research, published on Land Use Policy Journal, only from 2007 to 2012 vineyards expansion in the Prosecco DOCG area reached 10.28% (+702 hectares) affecting other traditional crops (-361 hectares), grassland (-299 hectares), and wood (-26 hectares) (Basso, 2019). Despite the geographical dimension of wine production areas (about the 30% of the whole Prosecco DOCG surface, see Figures 1 and 2) and the dominance of vineyards on the other crops (about the 50% of monoculture, see Figure 2), scientific literature mainly focused only on economic and agronomic aspects, and on the organoleptic properties of Prosecco wine. In particular, with the exception of a technical report and maps produced by the Regional Agency for Environmental Protection and Prevention of the Veneto at regional and province scale (ARPAV, 2007, 2008), no peer-reviewed article about soil erosion estimation at Prosecco DOCG scale was found in literature. In such context our study aims to offer a scientific contribution proposing the concept of the "soil footprint" in relation the erosion estimates in the geographical area defined by the Prosecco DOCG wine production area, by modelling different land-management scenarios for wine production (see Tables 1, Figure 3). In Soil Science, different methodologies were developed and tested to estimate and to quantify soil erosion rates in vineyards: from direct/indirect measures on the field, to the use of predictive empirical models. Soil erosion analyses derived from measures are usually performed at plot-scale or field-scale and they are based un measures of erosion rate in real or simulated rainfall conditions; or they use such erosion markers *(Novara 2011, Comino 2018)*. On the contrary, predictive elaborations are based on empirical models together with geospatial data processed by Geographical Information

Systems, GIS), in order to develop spatial analyses of soil erosion processes at territory or hydrographic basin scales (Jahun et al., 2015; Lieskovsky e Kenderessy, 2016).
After a deep literature review, but also due to the lack of experimental data "on the field", we adopted for soil erosion estimation a modified and updated version of the *Universal Soil Loss Equation* (USLE Model) proposed by Wischmeier e Smith (1978). The USLE take into the model the main factors in soil erosion processes: 1) topography; 2) rainfall erosivity; 3) soil characteristics; 4) land uses. Specifically, we selected the updated *Revised Universal Soil Loss Equation* (RUSLE model) which is, together with RUSLE-derived formulas - with the limits of any model- the most adopted methodology to estimate and geo-visualize soil erosion at territory scale, as reported by more than 1,000 publication indexed in Scopus (Ashiagbor 2013; Aiello 2015; Jahun 2015; Panagos 2015a; 2015b; Yhang 2015; Zang 2017; Prosdocimi et al., 2016). RUSLE model performs soil erosion estimation in terms of tons per hectares per years (in the article measure units are Mg ha^{-1} yr^{-1}) and allow to visualize values by powerful thematic maps (see Figures 3 and 4). It is worth noting in our analyses we used public spatial data at very high temporal and spatial resolution: LiDAR topographic data at 1 m/pixel geometric resolution (Province of Treviso 2007), 10 years rainfall data (ARPAV), and local data about pedology (ARPAV-derived) and land uses (Veneto Region, 2012). RUSLE model has been previously tested and validated in different study about soil erosion in Mediterranean region, also in Italy, often by integrating experimental field measures into the RUSLE model (Bazzoffi 2007; Arpav 2008; Kinnel 2010; Jahun et al., 2015; Aiello et al., 2015; Panagos et al., 2015; Ashiagbor et al., 2013; Prosdocimi et al., 2016; Napoli et al., 2016). It is worth noting that RUSLE model, and RUSLE-based models, are adopted from European Commision to have quantitative estimation on soil erosion within the *Good Agricultural and Environmental Condition* (GAEC) and Common Agricultural Policy (CAP) (Panagos, 2015). Hence, our geographical analyses allowed to estimate and to map soil erosion at Prosecco DOCG scale in terms of magnitude (tons per hectares per year) and total erosion (tons per year), and to calculate a sort of "ecological footprint" on a single bottle of sparkling Prosecco produced (kilograms per bottle). Estimation and mapping of soil erosion were performed by simulating and by combining different land-management scenarios in order to compare results: i) conventional land-management scenario; ii) "greening scenarios" which may include mitigation measures such as buffer strips and shrubs around vineyards, and 100% grassed cover in vine inter-rows (See table 2).
Our results show that in a conventional land-management scenario, potential erosion in the Prosecco DOCG area may reach a total value of 400,000 tons per year, by an average erosion rate of 19.5 tons per hectares per year. As expected, very high of erosion rates were found along cultivated steep slopes, with values well beyond 40 tons per hectares per year (Figures 3 and 4). In such scenario, potential erosion within Prosecco vineyards may reach a total of 300,180 tons per year, with an average erosion rate of 43.7 tons per hectare every year. This estimated value is 31 times greater than the tolerable erosion limit identified for European soils. Similar results in the Prosecco DOCG area, based on RUSLE model, were found in Prosdocimi et al. (2016), and in reports and maps produced by the Regional Agency for Environmental Protection and Prevention of the Veneto (2008). Result on soil erosion estimation in the Prosecco DOCG area are quite similar to the "Chianti Classico" wine production area (Tuscany). Here, by validating data modelled by RUSLE with 566 experimental plots, Napoli et al. (2018) reported a soil erosion of 42.1 tons per hectares per year against the 43.5 we estimated in the Prosecco DOCG vineyards.
In contrast, our simulation of different greening land-management scenarios showed that soil erosion within vineyards could be drastically reduced: the 100% grassed cover vine inter-rows showed, for instance, a 3-times reduction of soil erosion (from 43.7 to 14.6 tons per hectares per year), saving about 50% of soil.
The soil footprint modelled is about 3.3 kg of soil per every Prosecco bottle produced in the conventional land-management scenario, while it could be reduced to 1.1 in the "completely green" scenario. For a better understanding of results, we invite to read the article freely accessible on line.
This study presents, for the first time in the research on soil erosion, the concept of "soil footprint" as the ecological footprint on the soil, which is related to a single unit of agricultural product, in this case a bottle of sparkling wine. As academic researcher we are aware that erosion expressed in terms of quantity of soil per surface units (tons ha^{-1} $year^{-1}$) or soil lowering (millimeters $years^{-1}$) are easily comprehensible, but mainly for experts in Soil Science. However, to facilitate the dialogue between Science and Society and to make more clear and understable also to non-experts the issue of soil erosion and the importance of environmental services provided by soil system we identify the soil footprint as a tool for visualizing and understanding erosion processes.
The present study, as the first screening of soil erosion at a very detailed scale in the Prosecco DOCG production area, aims to provide useful data and information to support a more sustainable management of soil system. Moreover, it suggests the urgent need to develop a public monitoring system of soil erosion processes in the

Prosecco DOCG area, by integrating direct and indirect field measures with spatial analyses at wine production scale.

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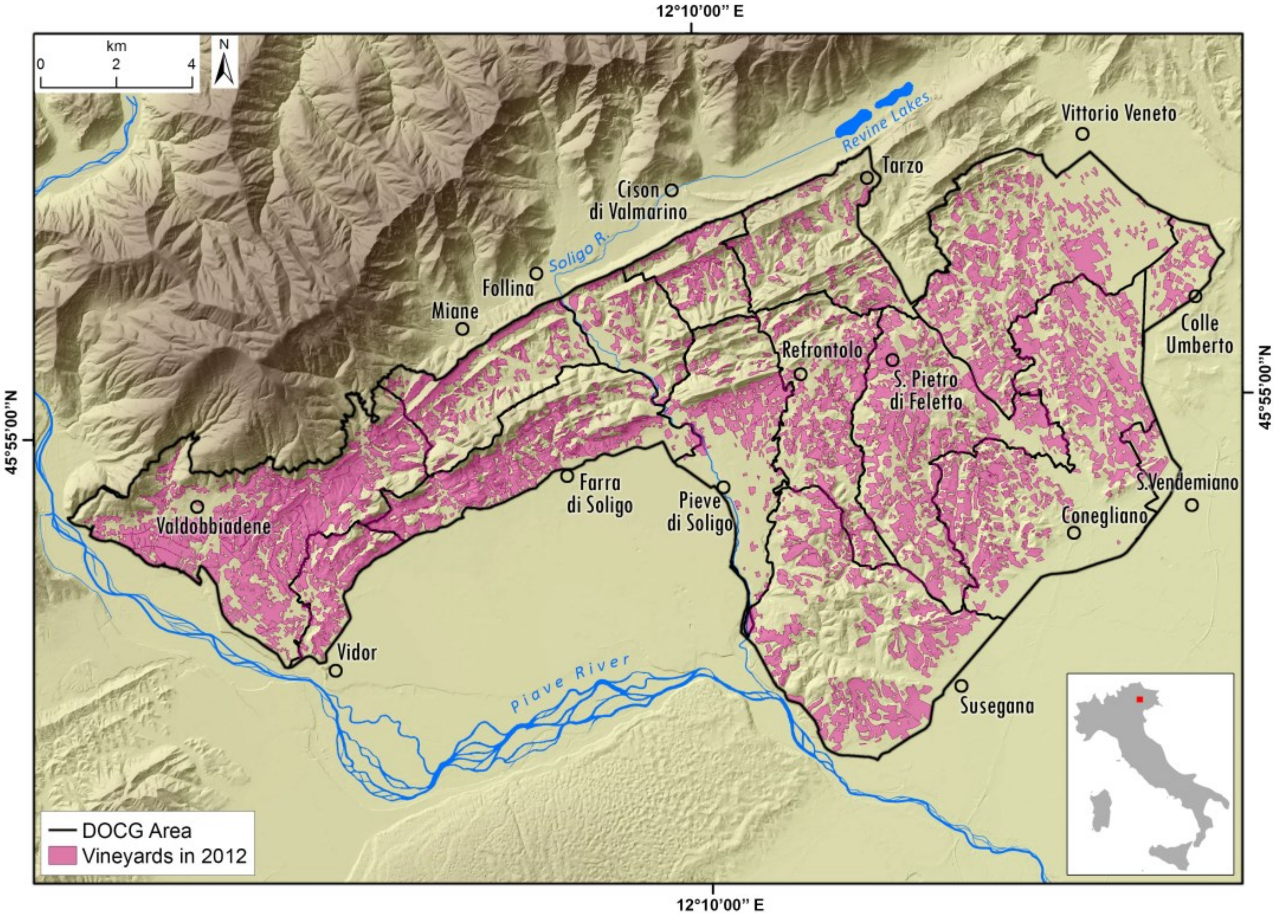

Figure 1: Vineyards distribution in the Prosecco DOCG wine production area (NE Italy, Province of Treviso).
Pappalardo SE, Gislimberti L, Ferrarese F, De Marchi M, Mozzi P.
PLOS ONE 14(5): e0210922. https://doi.org/10.1371/journal.pone.0210922

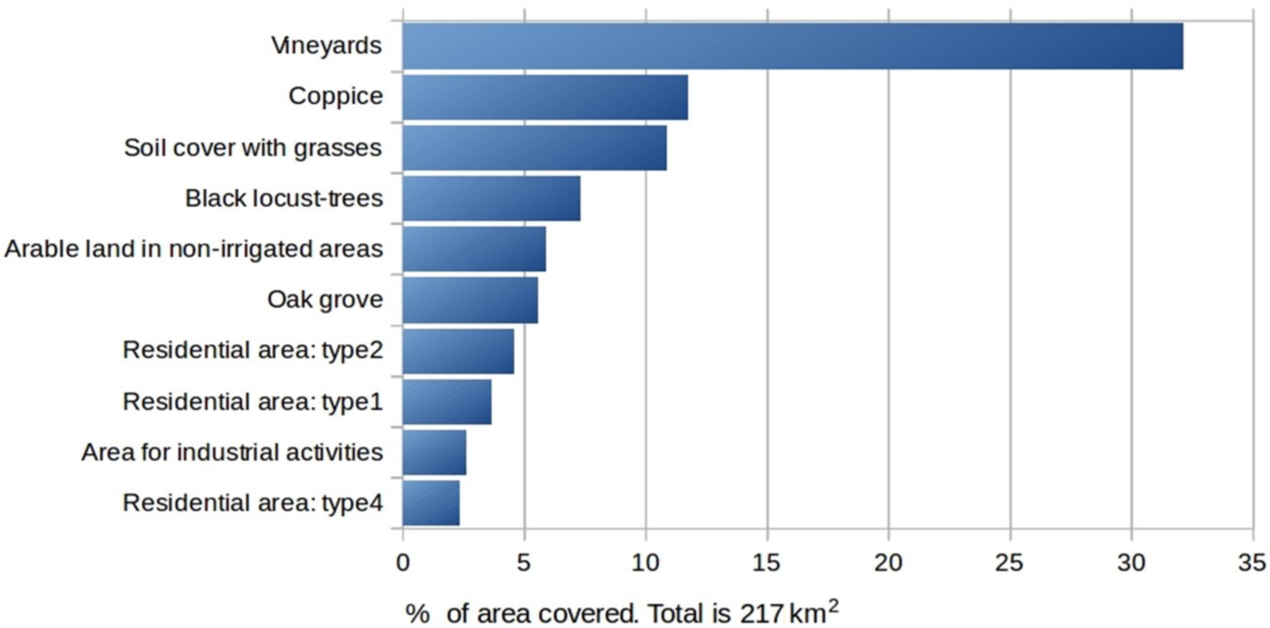

Figure 2: Percentage of area covered by principal land use classes in the Prosecco DOCG zone. More of 30% of DOCG territory is covered by vineyards.
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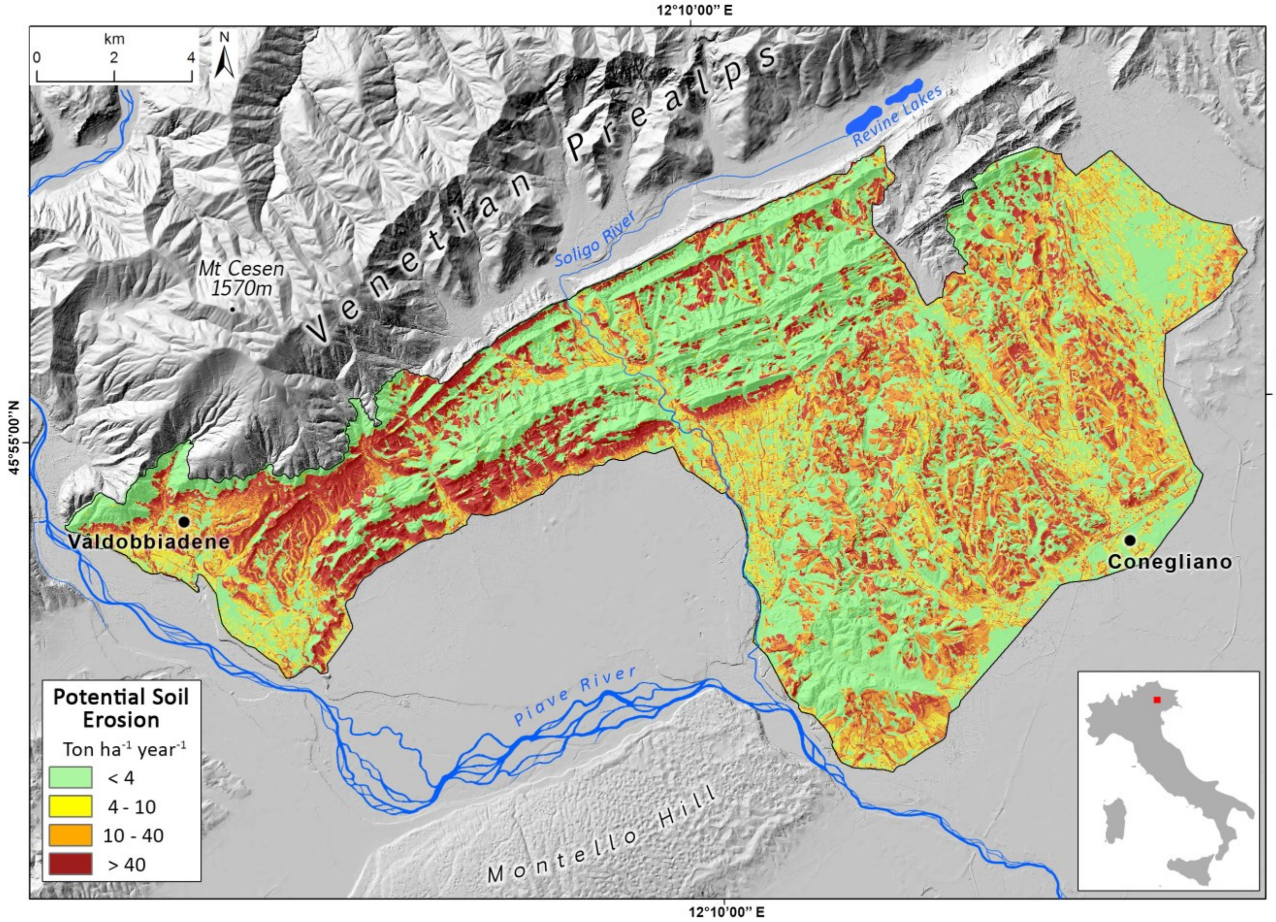

Figure 3: Map of potential soil erosion rate in the Prosecco DOCG area under conventional land-management scenario, represented in four classes. Soil erosion rate with higher intensity (>40 Mg ha^{-1} yearr^{-1}) is clustered on long and steep slopes, characterized by agricultural activities, mainly vineyards.
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Scenarios **Class and Units**	**Scenario 0 conventional vineyards management**	**Scenario 1 5 m buffer strip around stream network**	**Scenario 2 3.5 m buffer hedgerow strips around vineyards**	**Scenario 3 (Scenario 1 + Scenario 2)**	**Scenario 4 100% grass cover inter-rows**	**Scenario 5 (Scenario 3 + Scenario 4)**
DOCG surface Mg yr^{-1}	411,266	378,410	370,098	350,398	211,330	150,462
DOCG surface Mg ha-1 yr^{-1}	19.5	18.0	17.6	16.6	10.0	7.1
Vineyards Mg yr^{-1}	300,183	300,183	300,183	300,183	101,300	101,300
Vineyards Mg ha^{-1} yr^{-1}	43.7	43.7	43.7	43.7	14.6	14.6
% vineyards Mg yr^{-1}	73	73	73	73	47.4	47.4
Soil lowering in vineyards (bulk density 1.3-1.5 g/cm^3) in mm yr^{-1}	3.3-2.9	3.4-2.9	3.4-2.9	3.4-2.9	1.1-1.0	1.1-1.0
Soil footprint kg bottle^{-1} yr^{-1}	3.3	3.3	3.3	3.3	1.1	1.1

Table 1: Estimation of potential soil erosion in different land management scenarios and metric units.
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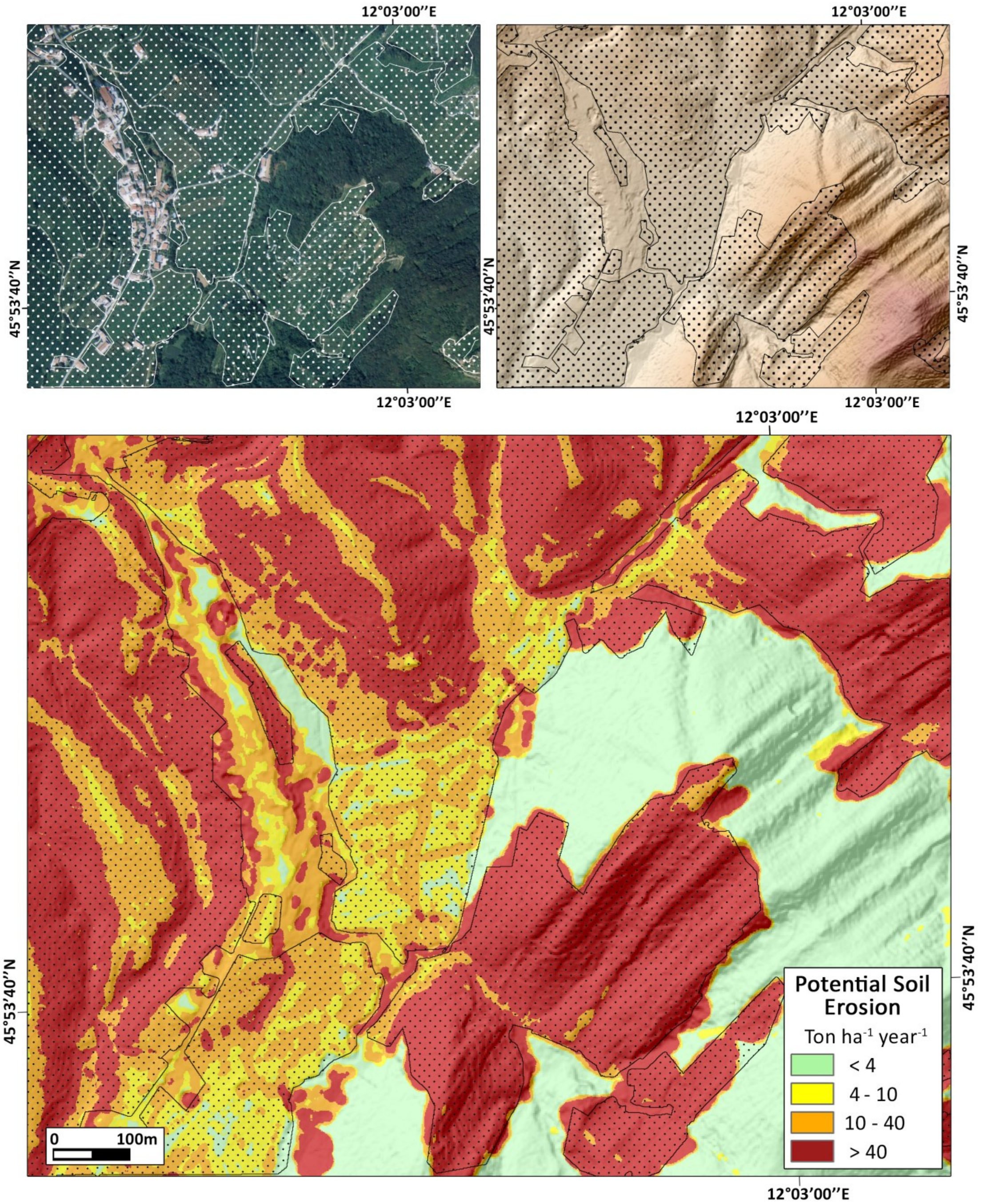

Figure 4: Sample area of soil erosion estimation in conventional land-management scenario in S. Stefano di Barbozza (Valdobbiadene Municipality).

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