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Agricultural Modelling

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In the paper models for different agricultural cultivation in Roman Tuscany are presented. By evaluating the landscape and the known Roman infrastructure in accordance with the preferences and priorities of Roman farmers as indicated by the so-called agronomists, so-called Suitability Maps have been modelled which denote more or less suitable regions for different cultivations. Since the sample size of the known Roman rural sites within the research region is slight so-called Monte Carlo simulations were carried out in order to statistically compensate this disadvantage it. In total, it can be shown that the location choices seem to be made intentionally.

Keywords: *agricultural modelling; cultivation of grain and olives; viticulture; statistics; Monte Carlo simulation*

1 Introduction

In the current study models for different agricultural cultivation in Roman Tuscany shall be presented. [1] The research area includes the valleys of the rivers Virginio, Orme, Pesa and the upper Elsa. By evaluating the landscape and the known Roman infrastructure in accordance with the preferences and priorities of Roman farmers, so-called Suitability Maps can be built which denote more or less suitable regions for different cultivations. It shall be stressed that these are theoretical models, rather than truthful reconstruction models. This approach is strongly geared to the works of Helen Goodchild who investigated the agricultural potential of the hinterland of Rome in the course of her doctoral thesis.[2]

Due to the small number of assured villas or farms within the study region at the current state of research it is not possible to create Predictive Models. Therefore, the implementation of statistical tests which could provide information about the intentionality or randomness of the sites' locational choice, would be a necessary prerequisite. But there exist alternative methods which can give a hint about the intentions of the siting and which shall be presented below. By making such observations, one must always beware following a 'self-fulfilling prophecy' to avoid biasing the sample of sites. This means that researchers must not search for new sites only in areas with similar location characteristics but also in regions of divergent appearance. Furthermore, it is essential that the study regions which are included in the model are surveyed

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1 Sources of DTM data: Regione Toscana (ed.), DTM Orografico Provincia di Firenze' (version of 18 February 2017) <http://dati.toscana.it/dataset/dem10mt/resource/94619917-2c36-4b9e-be58-bdbab367a011> (30.12.2018); all evaluations presented within this study were carried out with the geographical information system ArcGIS and the statistical computing environment RStudio.

2 Goodchild 2007.

as comprehensively as possible, with comparable methods and techniques, and that identical definitions and dating systems are used.

In the preparation of agricultural models there are many aspects which have to be considered and a lot of issues which have to be dealt with. Due to erosion and potential climate changes the landscape can have changed massively during the last 2000 years. Rivers may have followed another course and today's vegetation may differ a lot from the one of earlier times. Such transformations can be the consequence of natural changes (e.g. climate change, soil movement, seismic movement, etc.) or due to human impact. In order to develop more arable land, intensive forest clearances may have taken place, slopes may have been levelled and basins may have been filled up; thus, fertilisation may has changed the soil composition. One has always to bear these issues in mind when carrying out Land Evaluations based on modern geodata. The uncertainties can be reduced by collecting and processing different data and by taking interdisciplinary approaches (e.g. geoarchaeological surveys, archaeobotanical analyses for reconstructing former cultivation and diet, etc.).

The procedure used in this study is partially borrowed from Helen Goodchild who evaluated the hinterland of Rome and investigated its agricultural potential.[3] The purpose of the so-created models is to identify the most suitable or rather most preferred areas for the agricultural use by building so-called Suitability Maps which show the most preferred, marginally preferred and least preferred regions within the Area of Interest. All considerations included in the models are made from the perspective of an ancient Roman farmer or landowner, rather than from today's viewpoint and with the current knowledge about agriculture.

2 Area of Interest (AoI)

The investigated area includes, in accordance with the project description, the valleys of the rivers Pesa, Virginio, Orme and the Lower Elsa (fig. 1). The latter one was added, so that the whole Empoli Basin could be integrated within the evaluations. The archaeological findings in the town area of the modern Empoli indicate that there has already been a settlement during the Etruscan and Roman period.[4] In the recent research the ancient settlement is associated with the name In Portu which appears as river port between the towns *Florentia* and *Pisae* within the Tabula Peutingeriana (Segment III 2).[5] Therefore, the study region extends across an area of 867 square kilometres between Empoli, which is located at the Northern border of the Area of Interest 25 kilometres downstream of Florence, and San Gimignano, which lies 35 kilometres far south of it. As natural barrier in the North serves the river Arno, which flows into the Tyrrhenian Sea at Pisa approximately 50 kilometres to the West of it. The eastern and western edges are defined by the ridges of the hills, which border the Elsa in the West respectively the Pesa Valley in the East.

3 Goodchild 2007.

4 Archaeological and numismatic research in the area of the modern Empoli: Ferretti et al. 1995; Rustici 1998; Rastrelli 2002; Degasperi 2004; Papanti 2006; Maiuri 2006; Alderighi 2009; Cantini et al. 2014; Schreck 2018.

5 Maiuri 2006, 37-39.

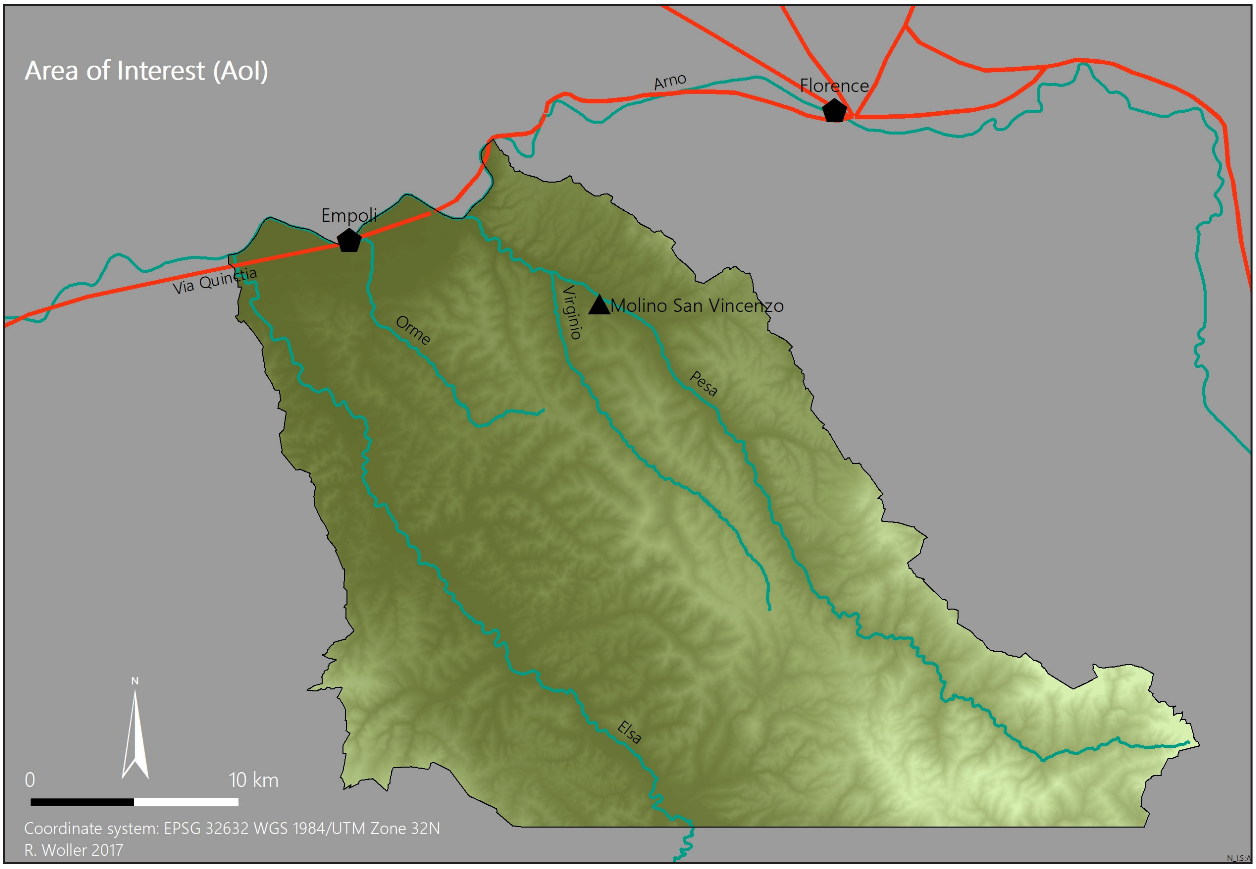

Fig. 1 Area of Interest (AoI) (R. Woller)

The highest elevations within the specified study region can be found in its Southeast in the surrounding area of Castellina in Chianti and Radda in Chianti. They reach a sea level of about 835 metres, whereas the major part of the Area of Interest (70 %) lies in areas up to 300 metres above sea level.

Today's landscape, except for the Empoli basin and the river valleys, is characterised by gentle or moderate slopes. In fact, more than 70 % of the Area of Interest show a slope steeper than 13 %. In the *Soil Survey Manual* published by the *United States Department of Agriculture*[6] such slopes are categorised as 'moderately steep' and 'very steep'. Such conditions surely meant a great challenge for the ancient agriculture as, according to Pliny the Elder, the field work on steeper slopes had to be done without the help of draught animals, so the plough could only be used in flatter areas.[7]

The Area of Interest lies midst of several great ancient settlements, for instance *Florentia* (Florence), *Faesulae* (Fiesole), *Pisae* (Pisa), *Arettium* (Arezzo), *Volaterrae* (Volterra) and of course the antique Empoli, which provided a good market for agricultural products, such as cereals, olive oil, wine, vegetables, legumes, fruits, milk and meat. Very important for the

6 Soil Survey Division Staff 1993, 51 Tab. 3-1; Soil Survey Division Staff 2017, 44 Tab. 2-3.

7 Plin.nat. 18,178.

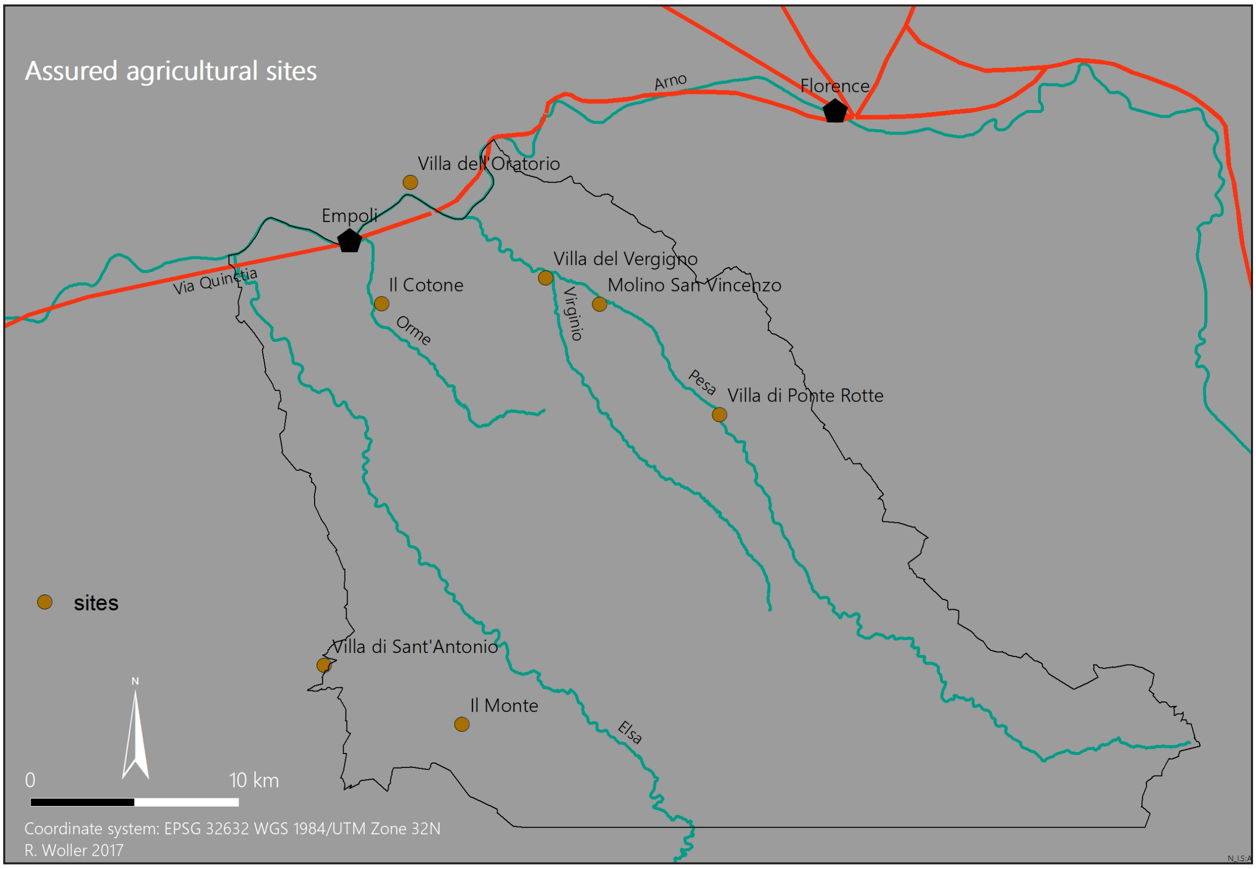

Fig. 2 Assured Roman rural sites within the Area of Interest (R. Woller)

transport of these goods, besides the streams, were paved roads or stamped trails. As the most important Roman roads of this part of the Italian peninsula the Via Quinctia, the Via Cassia and the Via Aurelia must be mentioned. The Via Quinctia ran along the riverbank of the river Arno and connected the towns *Florentia* and *Pisae*,[8] whilst the other two had Rome as their point of departure. The Via Cassia ran through the inland, passed the Lake Bolsena and *Clusium* (Chiusi) and from that point followed different routes to *Florentia* or *Faesulae*.[9] The Via Aurelia ran from Rome along the Tyrrhenian and Ligurian Coast to *Pisae* and from there continued its course to the *Gallia Cisalpina*.[10] In and around *Pisae* there existed several harbours, river ports as well as seaports, which also played a great role in the economic and transport network during the ancient times.[11]

8 Mentioned by name by bei Dion.Hal.ant. 1,14,2; for details on the first known milestone see Mosca 1992, 93-100; Uggeri 2015, 138.

9 Mosca 2002, 151-220.

10 Marcaccini – Petrini 2000, esp. 24.

11 For details on the chronology of the harbour see Bruni – Abbado 2000, 33-40; Bruni 2000; Giachi et al. 2003; Benvenuti et al. 2006.

Within the boundaries of the Area of Interest seven assured Roman rural sites can be identified (fig. 2): The agricultural production site Molino San Vincenzo in the Pesa valley, which was investigated by the VOPP research team and by excavations of the University of Vienna during the last years, is located only a few kilometres upstream from the confluence of the rivers Virginio and Pesa.[12] Not far from this lies the Villa del Vergigno which existed from the 1st century BCE to the 5th century CE. Since 2013 the University of Wyoming carries out new research activities which also include annual excavation campaigns.[13] Furthermore on the plot Il Cotone, which is located only a few kilometres from the town centre of the modern Empoli, different non-destructive investigations have been made during the last years which indicate that there has been a rural settlement during the Roman period at that place.[14] Further assured Roman rural sites in the research area are the Villa di Sant'Antonio[15] at the western border, the site of Il Monte[16] near San Gimignano, the Villa dell'Oratorio[17] – also known as Villa dei Vetti – which is located at the northern riverbank of the Arno near Montelupo and finally the imperial Villa di Ponterotto[18] near San Casciano in Val di Pesa for which several construction phases can be documented that date from the 1st to the 6th century CE.

3 Land Evaluation in Archaeological Research

During the 1950ies Land Evaluation methods developed out of necessity to use the available arable land as efficiently as possible.[19] Due to the exponentially growing population since the 17th century and the, as a result, increasing grain requirement the farming processes had to be optimised, in order to maximise the agricultural output in the long term. Initially, Land Evaluation merely meant soil analysis but by and by further influencing factors were included in the models with the aim to achieve optimal crop yields. Since the 1990ies such methods were also applied in archaeological research in order to assess the agricultural potential of a region for a specific period of time. Mostly, this involves so-called Multi Criteria Analyses (MCA) for which it is important to choose significant and appropriate location factors. To make objective and rational choices statistical tests should be used at this point. For a sensible application and to provide a meaningful outcome it is necessary to have an adequate sample size of sites availa-

12 Reports on the annual campaigns: Alderighi 2010; Alderighi et al. 2011; Schörner – Terreni 2012; Schörner et al. 2013; Schörner – Terreni 2014; Schörner et al. 2015a; Schörner et al. 2015b.

13 For a short overview of the older campaigns of the 1990ies see Berti 2006; see here the contribution by Mackenzie Lewis; for reports on the single campaigns <www.villadelvergigno.org> (30.12.2018) and at FastiOnline: www.fastionline.org/excavation/micro_view.php?fst_cd=AIAC_3315&curcol=main_column (30.12.2018).

14 For an overview of the situation on the plot Il Cotone in general and on the findings of the first surveys see Alderighi – Terreni 2013; for actual research see the contributions of Klaus Freitag and Hadwiga Schörner in that volume.

15 Alderighi et al. 2013.

16 Schörner 2008; Schörner 2009; Schörner 2013.

17 Alderighi et al. 2010; Alderighi 2013.

18 On the Roman structures see Alderighi – Pittari 2013; on the Etruscan phases: Alderighi – Pittari 2011; see also the contribution of A. Pittri and L. Alderighi in that volume (with a new interpretation).

19 The term 'Land Evaluation' was created during a congress held in Amsterdam, see Van Baren et al. 1950. Overview of the development of 'Land Evaluation' in Verheye 2009, 2-5.

ble. In most of the cases this poses a problem in archaeological research because it is difficult to investigate an area of interest as comprehensively and intensively. Furthermore, to get a reliable and unbiased sample all the incorporated sites should be investigated in the same manner and with the same methods. Moreover, they all have to be of the same type, size and dating, otherwise they are not comparable and cannot be put into the same site category.

Within the defined Area of Interest there are seven assured Roman rural sites which unfortunately do not pose a sample large enough for statistical testing. Thus, alternative methods had to be implemented to on the one hand choose a compilation of location factors and on the other hand test which location was chosen intentionally because of special local conditions. Fortunately, the Roman agronomists, such as Pliny the Elder, Columella, Varro and Cato the Elder, provide a lot of information regarding ancient agriculture. In their texts they mention many details about preferable cultivation conditions and location conditions, about possible rates of return in different regions of the Roman Empire, about fertilisation and special cultivation techniques. On the basis of those written records it is possible to establish a catalogue of influencing factors and make assumptions about the preferred location conditions for a Roman farm or country estate.

4 Multi Criteria Analysis

Following Goodchild's approach, a Multi Criteria Analysis was carried out for three different farming systems: the cultivation cereals, olives and vines which, together with vegetables, legumes, fish and meat formed the basis of the Roman nutrition. In research literature *Puls* (Roman porridge) or bread, olive oil and wine are often called the 'Mediterranean Triad'.[20] There has been a lot of research into the Roman diet during the last decades. Researchers, such as the British archaeologists Lin Foxhall and Hamish Alexander Forbes and the American historian Thomas W. Gallant tried to reconstruct the composition of the ancient nutrition and came to the result that approximately 70% of the required energy supply were covered by cereal products, especially puls, and that 5 to 15% by meat, olive oil and wine.[21] In more recent studies, however, it gets stressed that due to different preservation methods the agricultural products lose certain parts of their nutrients.[22] Thus, whether the percentages provided by Foxhall, Forbes and Gallant actually reflect reality remains to be seen. Nowadays archaeobotanical and archaeozoological investigations make it possible to get a clearer picture of the Roman food composition. The results of recent bioarchaeological examinations of food remains in the town of Herculaneum for example confirm the information which was provided by the ancient authors regarding the composition of the Roman diet. According to these findings, the average inhabitant of a Campanian town of the 1st century CE had a balanced nutrition which consisted of cereals (especially millet and emmer, followed by bread wheat and barley), olives, grapes, figs and other fruits as well as herbs, eggs, fish and meat.[23] Following those considerations, the

[20] Term created and firstly used by Renfrew 1972, 280; recently used by Tietz 2015, 48; Witcher 2016, 462.

[21] Foxhall – Forbes 1982, 74; Gallant 1991, 68.

[22] Rowan 2014, 207-220.

[23] Rowan 2014, 185-188. 270f.

evaluations presented below were carried out with respect to the cultivation of cereals, olives and vines.

By scrutinising the written sources, one can note that in the descriptions of suitable and unsuitable conditions for the cultivation of different crops the authors focus on several location factors. The most common are slope, aspect (slope orientation), soil and the distances to a water access, to roads and to settlements. The ancient writers provide very detailed and precise instructions how and where different crops should be cultivated. Therefore, the written records were searched concerning the preferred location conditions regarding the three named cultivation systems.

Before carrying out the Multi Criteria Analysis the relevance of the different factors should be examined. As stated above, seven sites make up a sample too small for statistical testing. Helen Goodchild whose investigations in the hinterland of Rome base on the data collected in the course of the South Eturia Survey and Farfa-Survey as well as Sebastian Vogel and his team who examined the hinterland of Pompeii could show that the listed six factors apparently played a major role for the location selection of the agricultural sites within their study regions.[24] By comparing the shares of the factor categories within the Area of Interest to the distribution of the sites through the same categories[25], certain preferences can be identified. Table 1 would suggest that gentle slopes were preferred over steeper ones. At least, it can be noted that the distribution of the known sites does not follow the distribution of the whole Area of Interest regarding the slope categories. Thus, a significant location selection can be presumed which was also confirmed by a Monte-Carlo-Simulation.[26]

In accordance to the agronomists' instructions, the literal assessments had to be brought into a numerical point system. For the growing of cereals the authors recommend open and flat grounds,[27] for olive groves gently sloping hills[28] and for vineyards gentle slopes which lie beneath steeper ones and therefore collect the fertile soil sliding down the hill.[29] Tab. 1 shows the attempt of summarising these recommendations as numerical values.[30]

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24 Goodchild 2007, 121-150; Vogel et al. 2016, 129-131.

25 Therefore, instead of evaluating punctually, average values over a buffer area around each site were computed.

26 For more detailed information see the section 'Monte-Carlo-Simulation' below.

27 Cato agr. 35,1; Varro rust. 1,6,5; Colum. 1,2,4; 2,9,3.

28 Verg.georg. 2,179-181; Colum. 5,8,5; Plin.nat. 17,128.

29 Varro rust. 1,6,5; Verg.georg. 2,184-191; Colum. 3,1,8. 3,11,8.

30 All relative values in this and the following tables are rounded to 2 digits; this can cause errors in the summation to 100 % as consequence.

Slope [%]	**Share in AoI** [%]	**Distribution of sites (n=7)**	**Rating value Cereals**	**Rating value Olives**	**Rating value Vine**
0-2	7.29	0	255	1	1
2-8	10.89	28.57	255	255	170
8-13	11.45	42.86	191	255	170
13-25	40.64	14.29	127	255	170
25-55	28.06	14.29	63	127	85
> 55	1.67	0	1	1	1
Buffer	33.48	-	-	-	85

Tab. 1 Numerical rating system for the factor slope (R. Woller)

Aspect	**Share in AoI** [%]	**Distribution of sites (n=7)**	**Rating value Cereals**	**Rating value Olives**	**Rating value Vine**
Flat	0.11	0	1	1	1
N	12.10	14.29	1	127	1
NO	11.29	28.57	127	1	127
O	11.14	0	255	1	1
SO	12.19	14.29	255	1	127
S	11.52	14.29	255	127	255
SW	12.52	14.29	127	255	255
W	14.31	14.29	1	255	255
NW	14.83	0	1	255	127

Tab. 2 Numerical rating system for the factor aspect (R. Woller)

The categorisation of slopes is adopted from the above-mentioned *Soil Survey Manual* of the *United States Department of Agriculture* which declares the first class (0-2 %) as nearly level, the second one (2-8 %) as gently sloping, the third one (8-13 %) as moderately sloping etc.

Within their handbooks the ancient agronomists make also many recommendations regarding the orientation of slopes.[31] In their opinion, southward or eastward facing slopes are to be preferred in general for a country estate. They stress that for a profitable cultivation of grain the sun should shine on the farmland as directly and long as possible, whereas olive groves should be exposed to the westerly wind for cooling during the hot summer months. For the cultivation of vine their positions are not consistent but mainly they recommend westward and southward facing slopes. According to those statements and to resulting considerations regarding Etruria's geographical position the numerical rating of the factor *aspect* is set (tab. 2). Furthermore, the ancient agronomists refer in several passages to the presumed optimal soil types for a profitable Roman country estate. As this factor is very difficult to evaluate due to the high transformation risk of the topmost soil layers, it is assigned the lowest weighting and rated very roughly and superficially.

After having set this rating system for the first three factors, a 10 x 10 metres grid gets placed over the Area of Interest. For every 10 x 10 metres cell one data point for each cultivation system and for every factor is generated and assigned to it as rating value. This means that in each calculation step nearly 9 million data points are generated for the whole Area of Interest, which extends over 867 square kilometres. After this, the three distance factors need to be evaluated. This happens by calculating so-called cost distances from each cell to the 'nearest' water access, road or settlement.

Since the 1970ies Cost Distance Analysis has been used in archaeology.[32] Thereby, instead of calculating a linear distance between two points A and B, you search for the path which requires the least effort to get from one to the other based on a certain cost surface. Therefore, measures like calories for modelling the afforded energy or minutes for modelling the needed expenditure of time are used, rather than units of length like kilometres. The challenge is to find a suitable cost function which describes the required effort in an appropriate way. Many archaeologists simply use the absolute value of the slope which means that, for instance, a doubled slope would require a doubled effort. Such assumptions are not sustainable. Furthermore, this function makes no difference between going downhill or uphill. Over the years researchers of different sciences tried to invent appropriate cost functions for moving through free terrain. Although they mostly used the slope as explanatory variable for the function, they developed different versions depending on the means of transport, the prevailing underground, etc.[33]

31 Cato agr. 1,3; 6,2; 34,2-35,1; Varro rust. 1,12,1; 1,24,1; Verg.georg. 2,298; Colum. 1,2,3; 1,5,5.8; 2,9,3; 4,22,8; 5,8,5; 5,9,7; Plin.nat. 17,19-21; 18,33.328.

32 First application in archaeology, see Vita-Finzi et al. 1970, 27-29; several case studies in White – Surface-Evans 2012.

33 One of the best-known cost function is probably the 'Tobler's Hiking Function', for more information on this see Tobler 1993; for other examples see Pandolf et al. 1977; Minetti et al. 2002, 1041; Herzog 2013, 377.

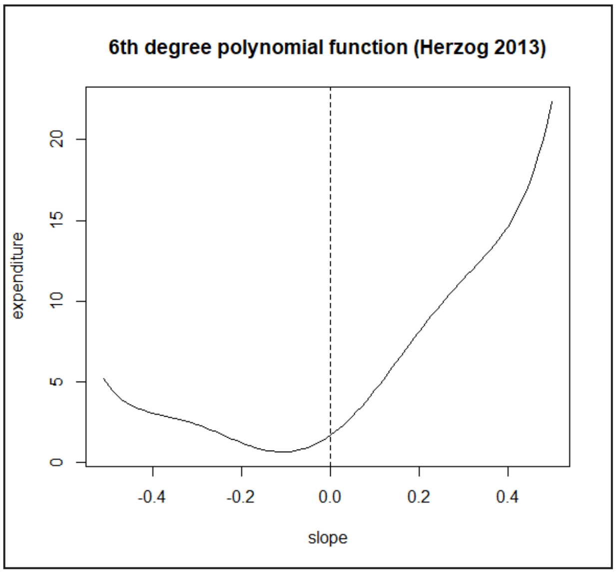


Fig. 3 Graph of Herzog's polynomial cost function of sixth degree (R. Woller)

In this study the polynomial function of sixth degree invented by Imela Herzog was used.[34] It is the further development of a cost function which was designed by a team of physiologists in 2002 to describe the effort of a normal walker. One can read from the diagram (fig. 3) that walking slightly downhill means the least effort for a hiker but that it increases for a steeper decline and that by walking uphill the expenditure raises massively. This curve seems to describe a walker's expenditure quite plausibly, whereas other functions show logical errors. The mentioned polynomial function of fifth degree, for instance returns a negative expenditure for a very sharp decline which is not plausible.

Fig. 4 shows the cost distances from each cell of the raster to the 'nearest' water access. It can be seen that in the flat river valleys it is very easy for a walker and involves only little effort to reach a stream, whereas in the hilly areas of the Chianti region in the Southeast of the Area of Interest or in the region between Certaldo and San Barberino Val d'Elsa in the centre of the research area it is pretty energy-intensive.

After having evaluated and rated the nature factors (slope, aspect, soil) and after having computed the three different cost distance factors for the whole study area, an average value needs to be calculated. As, according to the written sources, the six factors were not equally relevant for the ancient Roman agriculture this average has to be weighted in some way. Helen Goodchild therefore used the so-called Analytical Hierarchy Process which was invented by the American mathematician Thomas Saaty in 1977.[35] Therefore, first of all a comparison matrix has to be constructed. Each of its entries stands for a pairwise comparison of the importance of a factor-tuple. Due to the frequency of references within the ancient texts, their descriptions and the data quality, the following order of importance was determined: slope =

34 Herzog 2013, 377.

35 Saaty 1977.

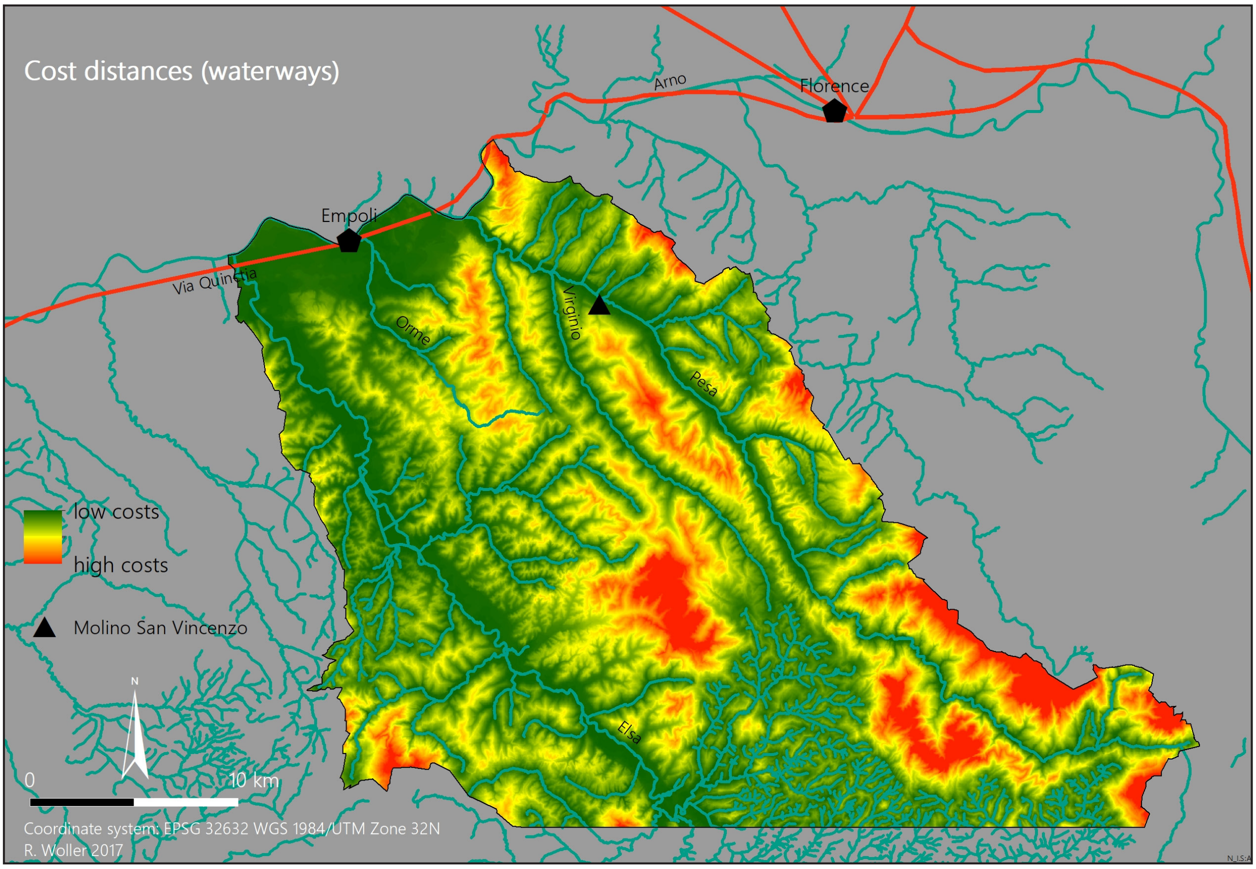


Fig. 4 Cost distances to the 'nearest' water access, computed with Herzog's polynomial cost function of sixth degree (R. Woller)

aspect > cost distance to water access > cost distance to roads = cost distance to settlements > soil. The lowest value was assigned to the factor 'soil' because of the reason that the soil composition may have changed to a certain degree during the last 2000 years; therefore, the factor shall have the lowest impact on the model. In accordance to the stated order of importance the comparison matrix gets set up, a weighting vector is computed by special algorithm and subsequently used for calculating the weighted averages (form. 1):

$$\begin{pmatrix} w_{slope} \\ w_{aspect} \\ w_{soil} \\ w_{CostDist\ water} \\ w_{CostDist\ road} \\ w_{CostDist\ town} \end{pmatrix} = \begin{pmatrix} 0.3358 \\ 0.3358 \\ 0.1564 \\ 0.0691 \\ 0.0691 \\ 0.0336 \end{pmatrix}.$$

Form. 1 Comparison matrix for weighting factors (R. Woller)

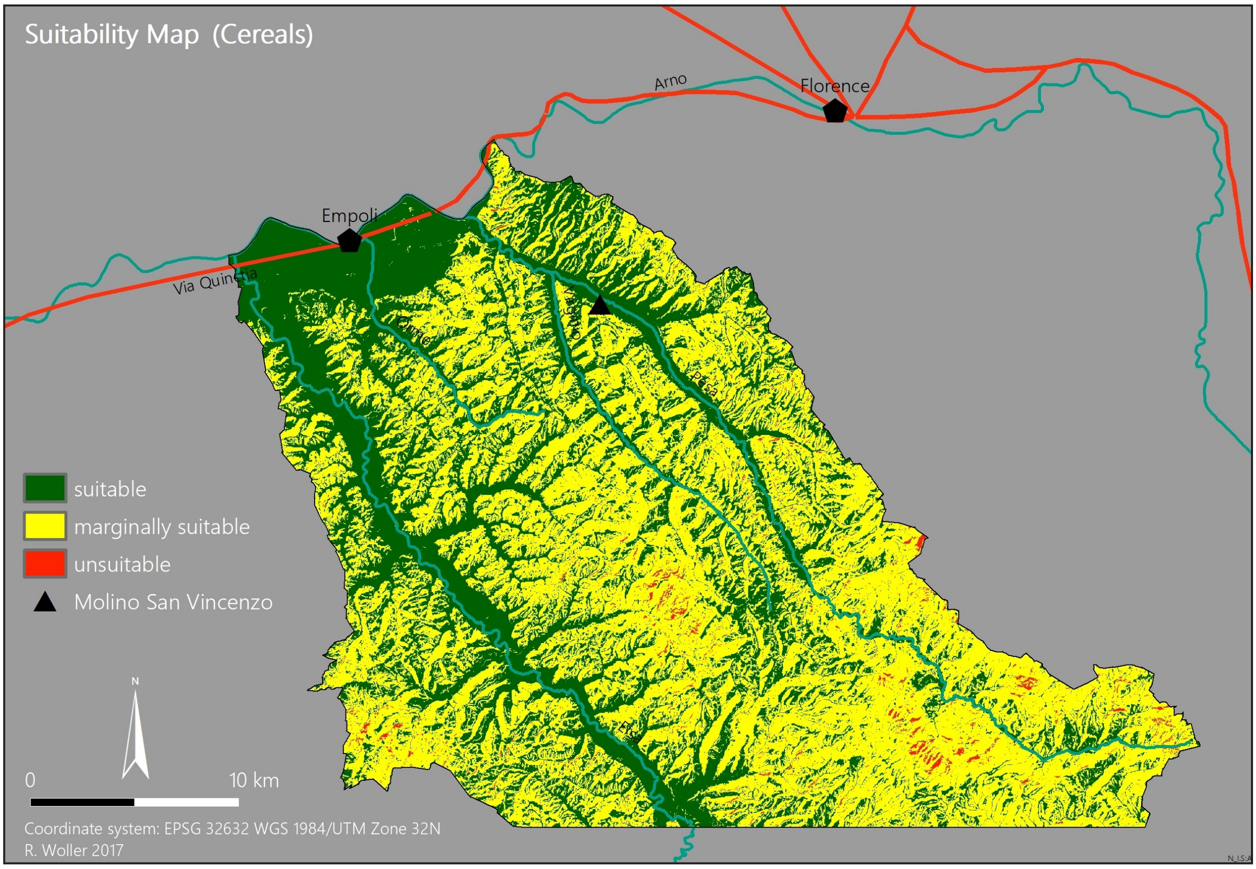


Fig. 5 Suitability Map for the monocultivation of cereals (R. Woller)

All the described evaluations finally culminate in so-called Suitability Maps which shall show the tendencies of the Roman preferences for the site selection of agricultural production units. Fig. 5 shows the Suitability Map for the monocultivation of grain.

At first glance, it can be noted that due to the model the Empoli Plain and the river valleys are the preferred regions for the cultivation of cereals, whereas the high and steep region between Certaldo and Barberino Val d'Elsa, the area south of Gambassi Terme in the Southwest of the Area of Interest and the hills north of Castellina in Chianti are identified as the least suitable spots. More than a third of the investigation area is marked as suitable for such a kind of cultivation but the major part of it as marginally suitable. Despite this fact, six of the seven known agricultural sites (85.7 %) are located within areas characterised as most suitable.

According to the Multi Criteria Analysis for the cultivation of olives, the major part of the examined area was rated as suitable (fig. 6). This evaluation result is due to the fact that a large share of the Area of Interest fulfils the criteria for a profitable olive grove as required by the agronomists, regarding the factors slope and aspect which were assigned the strongest weighting. Firstly, 60 % of the study region are gently but not steeply sloping and secondly, 40 % of the whole area are orientated westwards.

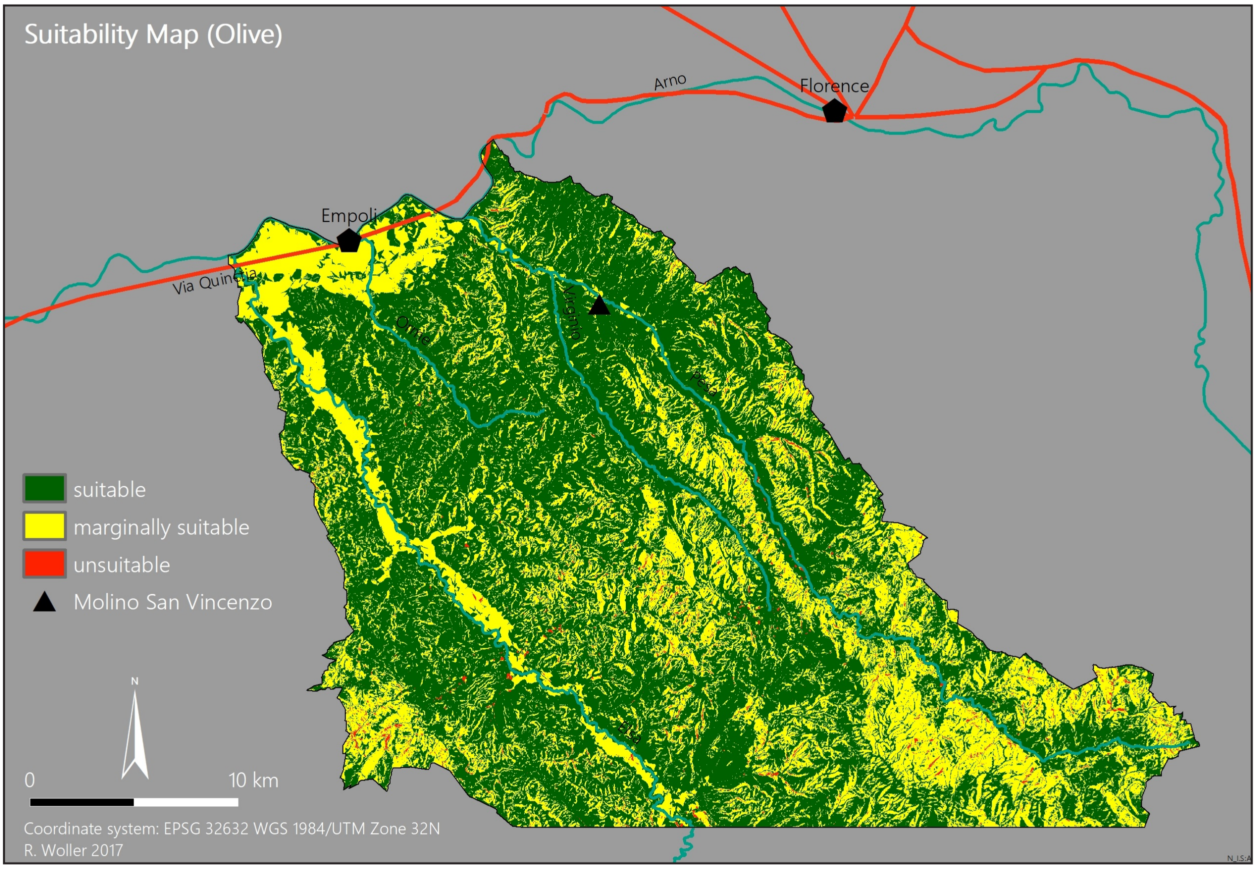


Fig. 6 Suitability Map for the monocultivation of olives (R. Woller)

The Suitability Map for the monocultivation of vine (fig. 7) perfectly reflects the parameters of the Multi Criteria Analysis. It can be seen that the gentle slopes which face south- or westwards show the highest rating, whereas very flat areas are rated very poorly.

It can be assumed that in Roman antiquity the prevalent, or at least very common, form of cultivation was intercultivation, so the farmland could be used multiply. This can either mean the cultivation of different agricultural goods in a special temporal order or a dual use of farmland at the same time. For this technique too, a lot of detailed information provided by the ancient agronomists can be found in the written sources.[36] Fig. 8 and fig. 9 show the Suitability Maps of two different forms of intercultivation: firstly, the common cultivation of grain and olives and secondly, of grain and vine. The maps were constructed by calculating averages of the rating values of the relevant two cultivation forms.

36 See Colum. 5,9,7; 13,17,3 for information on the required distance between the plants of different intercultivation systems; see Pall.agric. 18,1 for recommendations regarding the care of trees in grain fields.

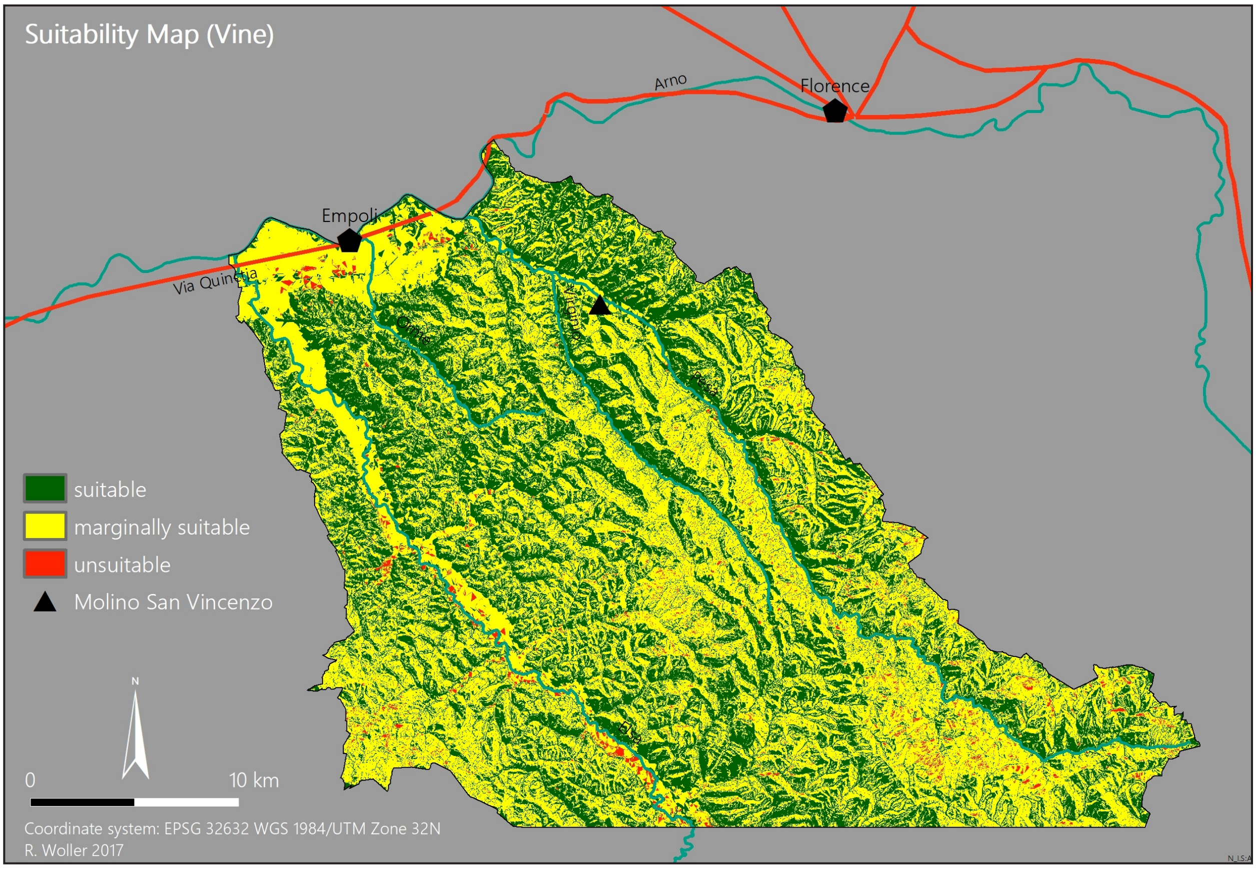


Fig. 7 Suitability Map for the monocultivation of olives (R. Woller)

5 Monte-Carlo-Simulation

Finally, it would be of interest to examine the intentionality, respectively the randomness of location choice. That means to explore if the zones, which were characterised as preferred areas for the ancient agriculture by the Multi-Criteria-Analysis, indeed were given preference over the regions with a low final rating by the Roman farmers. As mentioned above, to make assumptions about such issues it would be necessary to do statistical testing which is not feasible without a sample of appropriate size. As only seven assured Roman agricultural sites are known in the Area of Interest at the current state of research, such an approach would not be reasonable. As an alternative so-called Monte-Carlo-Simulations can be carried out which were already mentioned above. Monte Carlo Simulations describe a class of numerical methods which base on a large number of random experiments that are carried out under identical conditions.

At first, a large random sample (e.g. 300 entries) has to be created, whereby, as there are seven assured Roman rural sites within the study region, every record of the sample consists of seven random points spread across the Area of Interest. The next step is to analyse for each of those 300 entries how many of the seven random points are located in suitable, marginally suitable and unsuitable regions. Furthermore, reappearing distributions are counted among

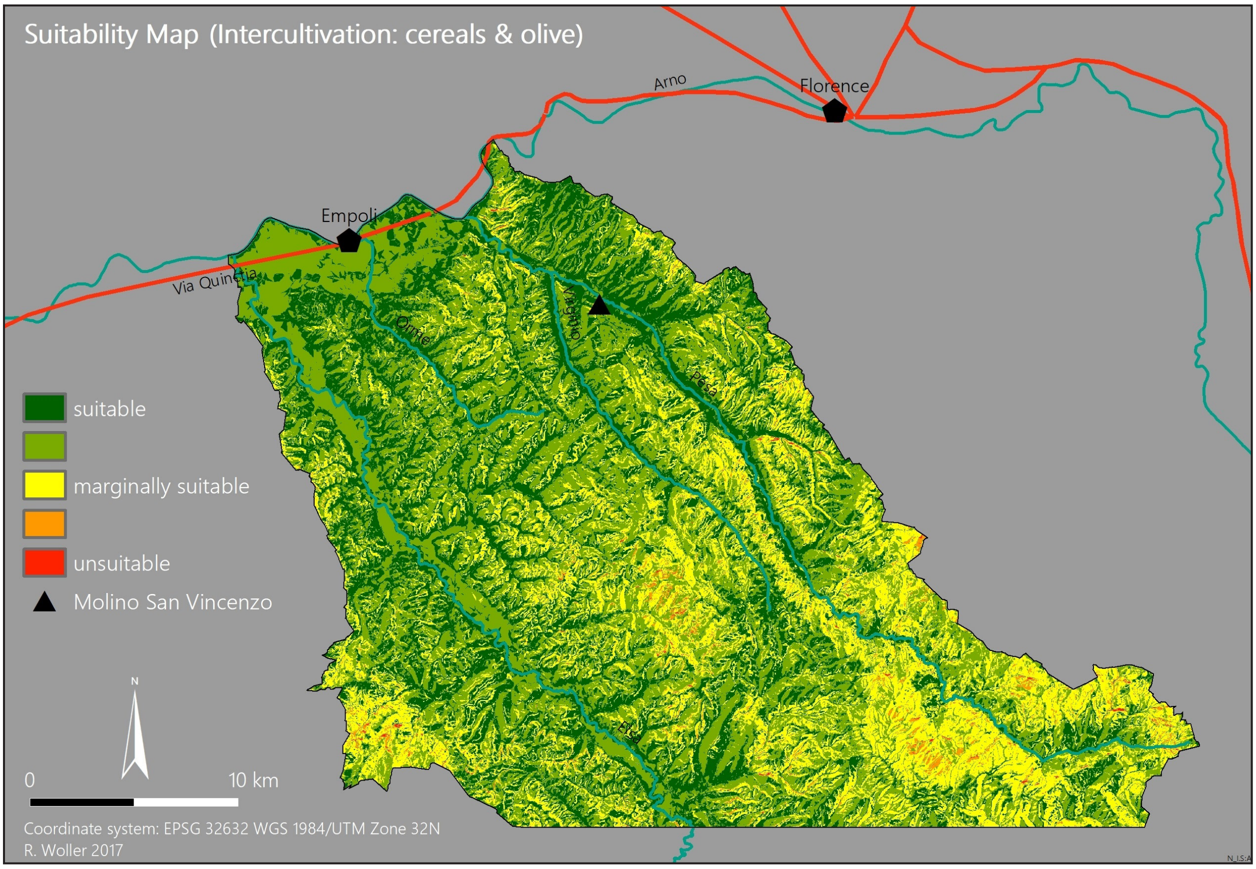


Fig. 8 Suitability Map for the intercultivation of cereals and olives (R. Woller)

the other 299 data sets.[37] The diagrams 1-3 in fig. 10 show that in most cases three of the randomly placed points lie in suitable regions and four in marginally suitable regions, whereas mostly not a single random point is dropped in an unsuitable region. In many cases there are also two or four points in suitable regions and three or five points in marginally suitable regions. This distribution naturally also corresponds to the distribution of land among the three suitability categories.

By comparing the results of the simulation to the distribution of the seven known Roman rural sites it can be seen that six of them lie in so-called suitable regions and only one in a marginally suitable region. This clearly does not fit the common distribution – neither the spatial distribution nor the result of the Monte-Carlo-Simulation. Therefore, it can be supposed that the location choice was in fact made intentionally and that the regions which were described as most suitable for the cultivation of grains by our suitability models really were indeed considered as preferred cultivation areas for Roman agriculture. As large areas of different land-

37 Similar approach used during the investigations on mesolithic sites in Northeast Belgium. See Vanacker et al. 2001, 665s.

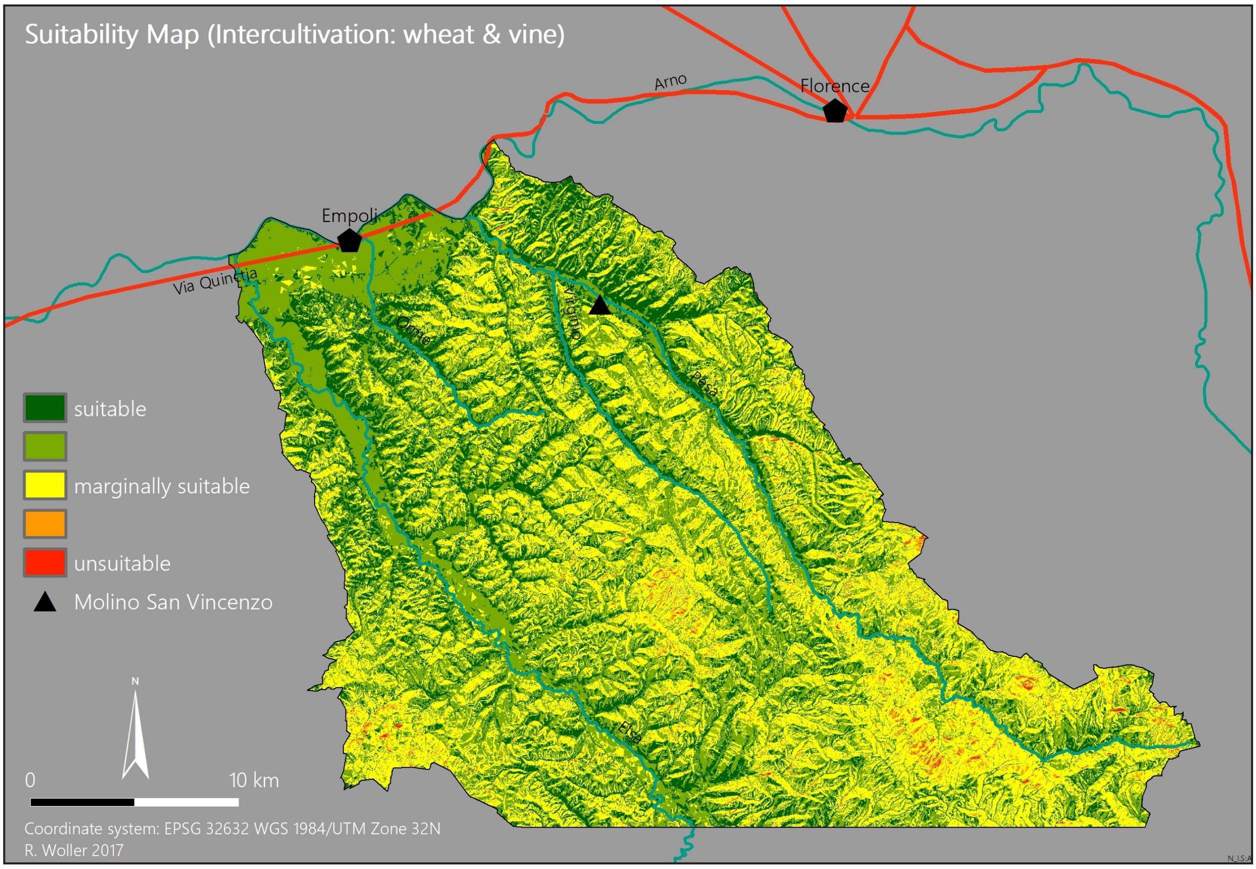


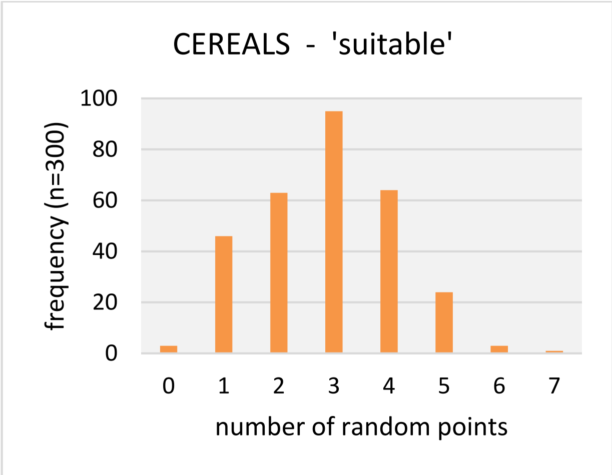
Fig. 9 *Suitability Map for the intercultivation of cereals and vine (R. Woller)*

scapes and location characteristics were surveyed in the study region during the project, it can be assumed that the seven sites form a representative and unbiased sample for the simulation.

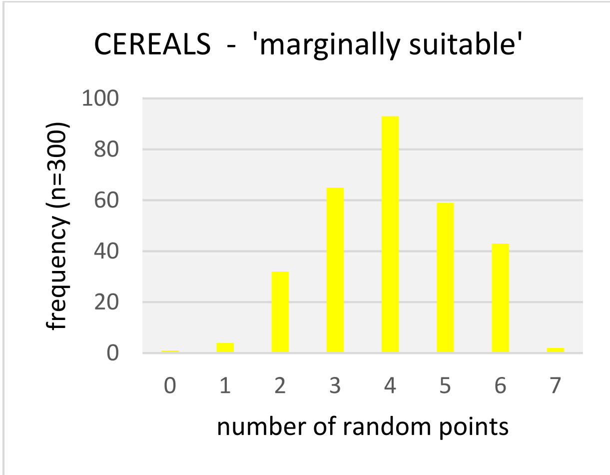
6 Outlook

It would be of great interest to make feasible estimations on the potential agricultural output of a certain area, respectively on the annual grain supply of a town as the ancient Empoli. Such observations would require a lot more verified information and data, as on living habits, population density and especially on the composition of the Roman diet. Furthermore, it probably will never be possible to verify whether the farming systems (crop rotation, intercultivation, etc.) were indeed used, as they are described within the ancient texts. But for modelling situations of uncertain circumstances some parameters have to be estimated and some assumptions have to be made, otherwise it would be a simple calculation.

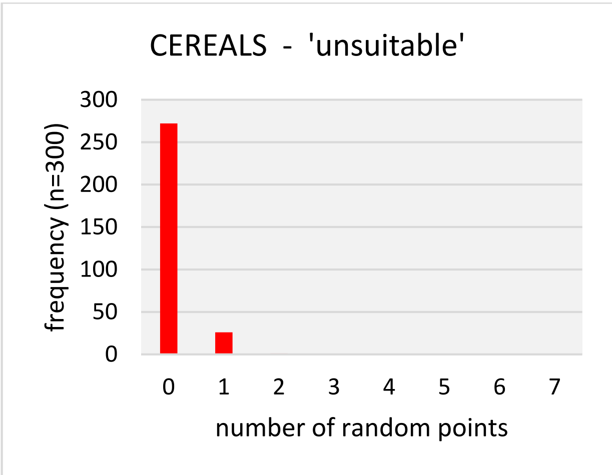
Thus, if it is assumed that the antique Empoli was of about the same size as the antique neighbouring settlements Florentiae, Pisae, Faesulae, etc., it extended approximately across 30 hectares. Regarding population size of antique towns, precise estimations were provided by Andrew Wallace-Hadrill in 1994 and Glenn R. Storey in 1997 who reconstructed a po-



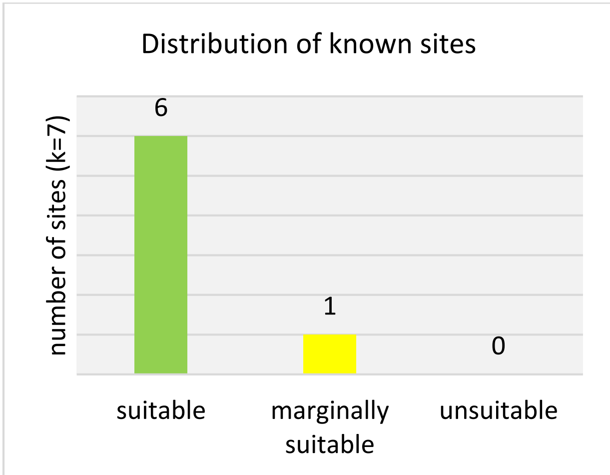
1.



2.



3.



4.

Fig. 10 Results of the Monte-Carlo-Simulation for the monocultivation of cereals (R. Woller)

pulation of 11132 for the ancient settlement of Pompeii.[38] At its date of destruction Pompeii extended across an area of 64 to 67 hectares what would mean a population density of about 166 to 175 people per hectare. Using those parameters approximately 5100 inhabitants could be reconstructed for the ancient settlement of Empoli. Such considerations in combination with the Suitability Maps presented above would invite to make further observations on the potential agricultural output of the surrounding area of Empoli.

38 Wallace-Hadrill 1994, 91-117; Storey 1997, 973f.

7 Conclusion

The Suitability Models show that for the cultivation of grain the Empoli Basin and the wide river valleys were the preferred regions. Olive groves can be expected rather in the valleys of the tributary streams than in the wider valleys. These tendencies can also be found in the agricultural use of today within this region; there is a very high overlapping of today's grain fields and the zones which were characterised as most suitable for the cultivation of cereals.

Although the sample size of the known Roman rural sites within our research region is very small it could be shown that the location choices seem to be made intentionally. Therefore, Monte-Carlo-Simulations were carried out and its results compared to the distribution of the known sites.

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