Modeling Earth Systems and Environment (2022) 8:407–416
https://doi.org/10.1007/s40808-021-01104-9

ORIGINAL ARTICLE

Assessment of soil micronutrient level for vineyard production in southern Syria

Safwan Mohammed[1] · **Karam Alsafadi**[2] · **Glory O. Enaruvbe**[3] · **Endre Harsányi**[1]

Received: 31 August 2020 / Accepted: 5 January 2021 / Published online: 21 January 2021

Abstract
Availability of micronutrients is one of the important factors for the successful and economic cultivation of vineyards. The objectives of this study are to evaluate the spatial distribution of soil micronutrients (Cu, Fe, Mn, Zn, B) and their suitability for vineyard cultivation in Jabal Al Arab of Syria. To achieve the research objectives, soil samples were collected randomly from vineyard farms which cover the study area. Following this, soil analyses were conducted to determine the concentration of soil micronutrients. Results showed that soil micronutrient concentrations did not reach the minimum threshold for vineyard cultivation with 1.1, 12.06, 11.2, 2.6 and 0.3 ppm for Cu, Fe, Mn, Zn and B, respectively. Furthermore, spatial distribution showed that 63%, 39%, 34%, 76% and 74% of the study area was affected by severe deficiency of Cu, Fe, Mn, Zn, B respectively.

Keywords Micronutrient deficiency · Vineyards · Soil mapping · Syria

Introduction

The increasing population pressure and higher demand for agricultural production have led to the adoption of more intensive agricultural system and the cultivation of more rapidly growing and higher yielding plants species in many parts of the world. Studies show that the intensification of agriculture production (i.e. industrialization of agriculture), coupled with unsustainable land management is causing tremendous degradation of soil quality, environment resources, and ecosystem services (Geertsema et al. 2016; Rojas et al. 2016; Matson et al. 1997; Kahsay et al. 2018). The degradation of soil resources is leading to severe consequences including micronutrient deficiency in agricultural landscapes which can result in poor yield and low-quality crops (Alloway 2008). This is of critical concern for soil scientists, policy-makers, and conservation experts in ensuring sustainability of natural ecosystems, and food security (Rojas et al. 2016; Wubie and Assen 2020).

Arid and semi-arid regions account for more than 30% of the total earth surface (Liu et al. 2018). Agricultural intensification in this region pose a threat to agricultural systems and affects the terrestrial ecosystem especially soil quality. This has prompted various studies that aim to understand the processes affecting soil quality under agricultural practices in the region. For instance, studies have examined the impacts of salinization (Abd El-Hamid and Hong 2020; Abuelgasim and Ammad 2019); erosion (Preetha and Al-Hamdan 2019; Khademalrasoul and Amerikhah 2020), soil compaction (Abbaspour-Gilandeh and Abbaspour-Gilandeh 2019), and soil fertility reduction (Khresat et al. 2008) in the region. One commonly grown crop in arid and semi-arid regions is the grapevine which requires 16 soil nutrients to grow normally. These elements are classified as macronutrients and micronutrients (Burns 2012). Although plants require minute quantities of micronutrients, they play critical roles in different biochemical processes for healthy growth and yield. For instance, iron (Fe) is essential for multiple functions in the plant, including electron transfer and

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Safwan Mohammed and Karam Alsafadi contributed equally to this work.

✉ Safwan Mohammed
safwan@agr.unideb.hu

[1] Institute of Land Use, Technology and Regional Development, University of Debrecen, 4032 Debrecen, Hungary

[2] Department of Geography and GIS, Faculty of Arts, Alexandria University, Alexandria 25435, Egypt

[3] African Regional Institute for Geospatial Information Science and Technology, Obafemi Awolowo University, Ile-Ife, Nigeria

chlorophyll synthesis (Chen et al. 2018), zinc (Zn) is crucial for plant enzyme systems (Mahmoud and Taha 2018), while Mn is important for redox processes (Amorós et al. 2018).

Grape cultivation is prevalent in many governorates of Syria, including Damascus, As-Suwayda, Deraa, Quneitra, Homs, Hama, Idlib and Aleppo, where it is considered an important economic crop (Al-Youssef et al. 2017, Al-Nasseer et al. 2006; Alsafadi et al. 2019). The cultivated area is about 47,000 ha with an estimated annual production of 213,000 tons in 2016, which is equivalent to 0.34% of total global production (FAO 2018; Al-Nasseer et al. 2010, MAAR 2016). Since 1997, climate change and grape phylloxera (*Daktulosphaira vitifoliae Fitch*) have played a key role in the decline of grape production and the area under grape cultivation in Syria (Makee et al. 2004, 2008, 2010; Contaldo et al. 2011). Most of the grape-growing soil in Syria is classified as calcareous soil, which is deficient in micronutrients (Cu, Fe, Mn, Zn, B). This type of soil is particularly abundant in private vineyards. Micronutrient deficiency is considered one of the most common abiotic stresses that affect Syrian grapevine production (Abu Nukta and Parkinson 2007; Sillanpää 1982; Abu Nukta 1995). For instance, Abu Nuqta and Bat'ha (2010) have reported extreme micronutrients deficiencies ranging from 14 ppm for Fe, 1.8 ppm for Cu, 2.3 ppm for Zn and 0.54 ppm for B in some private grapevine farms in the Draa governorate (S-Syria). Similarly, Jalab and Al-Sallom (2016) reported that some vineyards in the northeastern part of Syria suffer from chlorosis which is caused by iron deficiency due to a high soil content of $CaCO_3$ and active lime. This shows that availability of soil micronutrients influences the growth and yield of vineyard in Syria.

Therefore, this study seeks to characterize the soil under vineyard cultivation in the western slopes of Jabal Al Arab, Syria, and determine the availability and deficiency of micronutrient for vineyards cultivation within the study area. This is important to help soil scientists and agronomists understand the nature of the soil and develop best land management practices that can help ameliorate the impacts of soil micronutrients deficiencies in the study area.

Materials and methods

Study area

The study was conducted in the southern part of Syria, in As-Suwayda governorate (32° 28′ 15″ N, 36° 24′ 18″ E and 32° 46′ 44″ N, 36° 45′ 15″ E; Fig. 1). The study area is characterized by a Mediterranean climate with rainy cold winters and sunny summers. The mean monthly temperature range from 4 to 6 °C in January and from 28 to 30 °C in July, while average rainfall ranges between 350 mm in steep areas and 700 mm on the mountain top. The common soil orders are Vertisol, Entisols, and Inceptisols (Mohammed et al. 2020a). The main economic activity in the study area is agriculture, especially apples (*Vitis* sp.) and grapes (*Malus silvestris*). Other crops grown in the area include tomatoes (*Lycopersicum Esculentum*) and chick peas (*Cicer Arictinum*) (MAAR 2016).

Soil data collection

Data were collected based on land survey and field trips as previously reported by Mohammed et al. (2020b). Soil data were randomly collected from 55 soil profiles in soils under vineyard cultivation in the western slopes of Jabal Al-Arab (Fig. 1). Routine soil analysis was carried out using the methods outlined in Table 1.

Assessment of micronutrients suitability for grapevine production

As each soil profile consists of different horizons, and each one has a different value of micronutrient (Cu, Fe, Mn, Zn, B), we applied the weighting factor (Table 2) proposed by Sys et al. (1991) to assign each profile to a representative value for each micronutrient. This method was previously applied in the southern Syria by Mohammed et al. (2020c) and Alsafadi et al. (2019).

The recalculated values of the micronutrients were classified for vineyard suitability using Table 3 proposed by White (2009)

Multivariate and spatial analysis

Descriptive statistics (maximum, minimum, mean and slandered deviation) and principal components analysis (PCA) were analyzed using Statistical Package for The Social Science (SPSS) software (George and Mallery 2014). In this study, spatial distribution of soil micronutrient level (Cu, Fe, Mn, Zn, B) was estimated using inverse distance weighting (IDW) interpolation algorithm. Although kriging techniques is also commonly used for spatial interpolation (Bocchi et al. 2000; Diodato and Ceccarelli 2004), IDW has the lowest mean error among the commonly used interpolation methods, when applied with highly variable spatial dataset (McGregor et al. 1998). Similarly, IDW is different from stochastic method (e.g., kriging) because it does not impose strict statistical assumptions on the data. The IDW assumes that each data point influences the resulting surface up to a finite distance (Phachomphon et al. 2010) and is usually applied to highly variable data as a moving average interpolator. The IDW method calculates an unknown point as a weighted average of known data samples within the local

Fig. 1 The study area

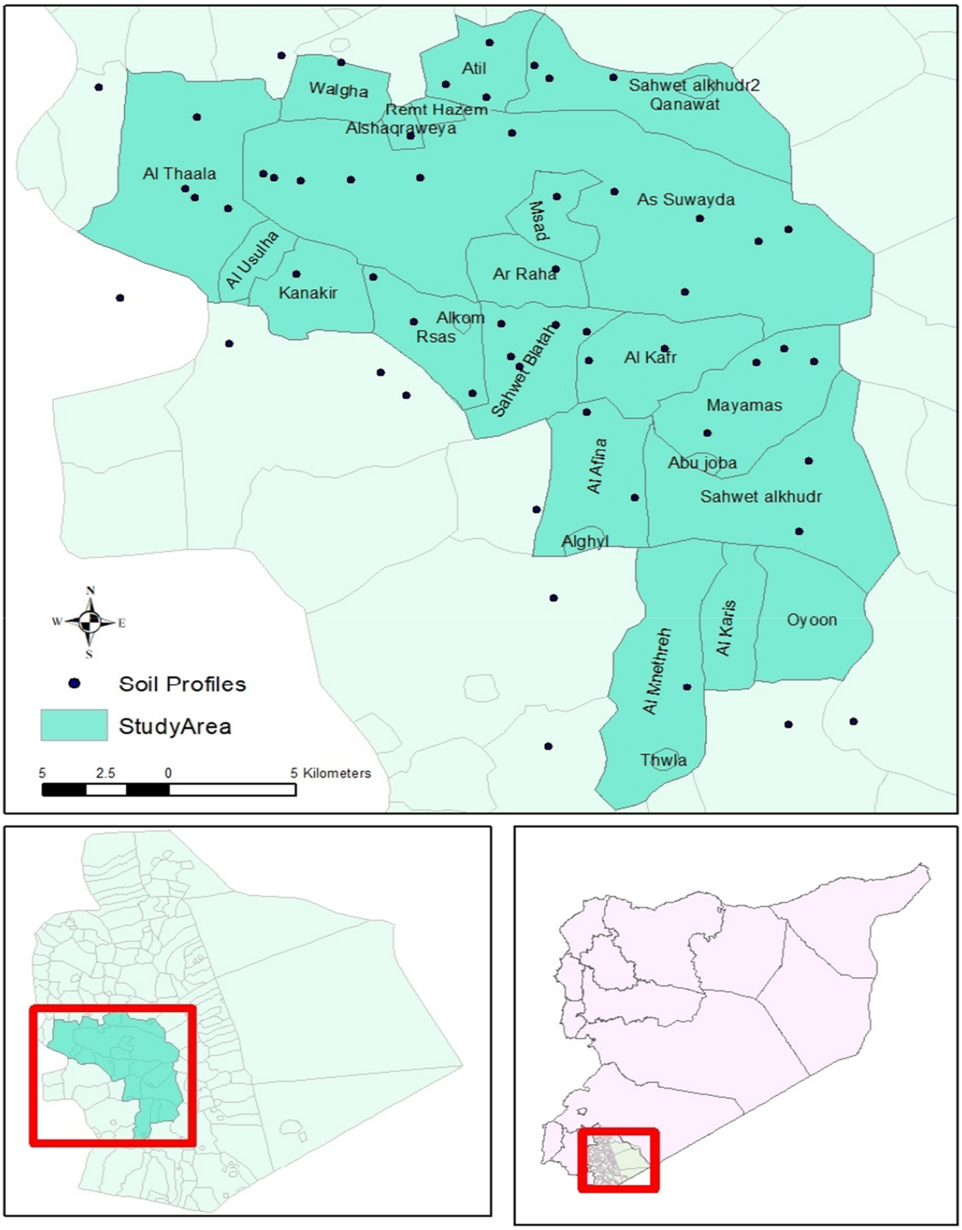

Table 1 Soil analysis methods

Soil characteristics	Method	References
Soil texture	Hydrometer method	Grossman and Reinsch (2002)
Electrical conductivity (EC)	Digital EC meter (1:5)	Rhoades (1982)
Soil pH	Digital pH meter (1:2.5)	Melan (1982)
Organic matter	Wet digestion method	Nelson and Sommers (1982)
Calcium carbonates	Calcimeter method	Loeppert and Suarez (1996) (1996
Cation exchange capacity	NH_4OAc extraction method	Polemio and Rhoades (1977)
Calcium and magnesium	Titration method	Suarez (1996)
Potassium and sodium	Flame photometer	Helmke and Sparks (1996)
Available Fe, Cu, Mn, and Zn	DTPA extraction method	Lindsay and Norvell (1978)
Available boron	Colorimetric method	Gupta (1967)

Table 2 Weighting factor classification (Sys et al. 1991)

Depth (cm)	Section number	Weighting factor
125–150	6	2–1.5–1-0.75–0.5–0.25
100–125	5	1.75–1.5–1-0.5–0.25
75–100	4	1.75–1.25–0.75–0.25
50–75	3	1.5–1-0.75
25–50	2	1.25–0.75
0–25	1	1

surrounding surface. The algorithm can be expressed by Eq. (1) below (Uygur et al. 2010; Guan et al. 2017).

$$R_x = \frac{\sum_{l=1}^{m} z(x) d_{ij}^{-r}}{\sum_{l=1}^{m} d_{ij}^{-r}}, \qquad (1)$$

where $z(x)$ is known data samples within a chosen neighborhood, r is the weight and d_{ij} is the distance between the predicted point and the measured point, m is the number of the neighboring observations samples used for prediction. In this study, data of 16 points samples and the weight power of 1 were used because the weight power of one has been shown to perform better than powers of 2, 3 and 4 if the skewness is below than 1 value (Liu et al. 2012; Robinson and Metternicht 2006; Guan et al. 2017). The inverse distance weighting (IDW) was applied via a GIS environment using the geostatistical analyst tool of ArcGIS 10.8 to generate spatial distribution patterns of the soil micronutrients.

Results

Soil characteristics in the study area

Soil characteristics reflect soil development stage, which could help to determine the suitability of soil for agricultural purposes. In the study area, the soil depth was mostly less than 150 cm, depending on the geographical position of the soil profile (backslope, foot-slope). Soil texture ranged between clay and silty clay in most of the studied profiles, where clay content increasing gradually with depth. This could be due to in situ clay formation or due clay migration (Mohammed et al. 2020a). Calcium carbonates did not exceed 18.4% in the majority of the studied locations; similarly, EC did not exceed 2.8 ds/m, which indicates low soil salinity in the study area (Table 4).

Furthermore, the studied profile was characterized by low organic matter content because of intensive land use and high mineralization of plant residue. The soil reaction (pH) ranged between moderate (pH 6.5) and weak alkalinity (pH 8.1), which can be explained by the moderate calcium carbonate content, low organic matter content (OM%), and domination of smectite clay minerals. The cation exchange capacity (CEC) was relatively high, reflecting the high clay content of the soil which reached an average of 50 mmeq/100 g soil. Among the exchangeable cations, Ca dominates in the soil adsorption complex, followed by Mg, K, and Na in that order.

The soils were relatively poor in micronutrients (B, Fe, Zn, Mn and Cu) and their concentration decreased with depth. This is attributed to the low levels of these nutrients in the parent material, fixation in the soil, and plant uptake (Table 4).

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Table 4 Statistical analyze of some soil properties in the study area

Soil characteristics	n	$\bar{x}$	S_x	Max	Min
Depth (cm)	56	93.66	22.59	150	20
pH_{H_2O}	56	7.44	0.376	8.1	6.5
EC (ds/m)	56	0.16	0.38	2.8	0
OM%	56	0.96	0.89	6.8	0.3
$CaCO_3$%	56	3.87	4.36	18.4	0
CEC (m meq/100gsoil)	56	42.3	6.7	55.8	19.4
Sum[a] (ppm)	56	37.98	6.46	50.70	6.40
B (ppm)	56	0.37	0.43	1.66	0.02
Fe (ppm)	56	12.06	10.63	75.5	2.82
Zn (ppm)	56	2.61	1.54	6.986	0.10
Mn(ppm)	56	11.20	11.60	73.6	1.61
Cu (ppm)	56	1.18	0.66	4.15	0.19

$\bar{x}$: average,S_x: standard deviation

[a] Sum of basic cations ($Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}$)

Table 3 Micronutrient level classification for grapevines (White 2009)

Micronutrient	Deficient (ppm)	Low to marginal (ppm)	Adequate (ppm)	High to excessive (ppm)
Fe	–	< 25–30	> 30	–
Cu	< 3	3–5	6–11	> 40
Zn	< 15	15–25	26–150	> 450
Mn	< 20	20–29	30–60	> 500
B	< 25	25–34	35–70	> 100

Table 5 Correlation matrix between studied micronutrients

	Cu	Fe	Mn	Zn	*B*
Cu	1				
Fe	0.688**	1			
Mn	0.604**	0.876**	1		
Zn	0.260	− 0.095	− 0.117	1	
B	− 0.267*	0.129	0.313*	− 0.377**	1

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

To further investigate the relationship between micronutrients, multivariate data analysis was carried out (Table 5). There was a significant positive correlation ($p < 0.01$) between Fe soil content and both of Cu (0.68) and Mn soil content (0.87). Also, there was a significant positive correlation between *B* soil content and Mn (0.31) ($p < 0.05$). Interestingly, the study showed a negative significant correlation between B and both of Cu (0.26) ($p < 0.05$), and Zn (0.37) ($p < 0.01$).

Furthermore, principal components analysis (PCA) was applied to extract the type of correlation structure among micronutrients (Table 6). The first three component explained 92% of the total variance. The first principle component (PC1) explained 49.248% of the total variance which was dominated by Fe, Mn and Cu (Table 7). While the second principle component (PC2) explained 31.753% and dominated by B and Zn (Table 7).

Availability and deficiency of micronutrient for vineyards cultivation

By applying IDW method, Fig. 2 depicts the spatial distribution of the evaluated micronutrients within the study area. The concentration of B was higher in the southern part (1–1.5 ppm); while the concentration did not exceed 0.25 ppm in the northern part (Fig. 2a). Similarly, the concentration of available Fe was higher in the southern part (7.5–25 ppm) (Fig. 2b). Zinc and Manganese show similar spatial pattern with the highest concentration occurring in the eastern portion of the study area (Fig. 2c, d). The northern part of the study area, however, shows a higher concentration of copper (5–6.98 ppm) than the northern part which was mostly less than 2 ppm (Fig. 2e).

Table 3 showed that the soil is deficient in micronutrients, which makes it unsuitable for vineyard cultivation, as can be seen in Fig. 3.

Discussion

In this study, 55 soil profiles were investigated in the southern part of Syria to assess the suitability of micronutrient level for vineyard cultivation. Results reveal that micronutrient levels were not adequate for vineyard production (Table 4). The spatial distribution of micronutrient level suitability for vineyards showed that most of the western and southern parts of the study area were affected by severe deficiencies of Cu, Fe, Mn, Zn, B (63%, 39%, 34%, 76%, and 74%, respectively) (Fig. 3). This result is consistent with findings reported by Abu Nukta (1995) who observed that iron, zinc, and boron were especially deficient in soils under vineyards in southwestern Syrian.

Table 6 Total variance explained by factor analysis

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	Variance %	Cumulative %	Total	Variance %	Cumulative %
1	2.462	49.248	49.248	2.462	49.248	49.248
2	1.588	31.753	81.001	1.588	31.753	81.001
3	0.639	12.787	93.788			
4	0.208	4.169	97.957			
5	0.102	2.043	100			

Table 7 The micronutrients and factors using varimax rotation method

Elements	Before rotation			After rotation		
	1	2	3	1	2	3
Fe	0.955	− 0.050	− 0.070	0.951	0.073	− 0.097
Mn	0.938	− 0.194	0.098	0.916	0.290	− 0.068
Cu	0.804	0.471	− 0.099	0.840	− 0.345	0.233
B	0.147	− 0.836	0.499	0.062	0.964	− 0.191
Zn	− 0.032	0.791	0.605	− 0.005	− 0.184	0.980

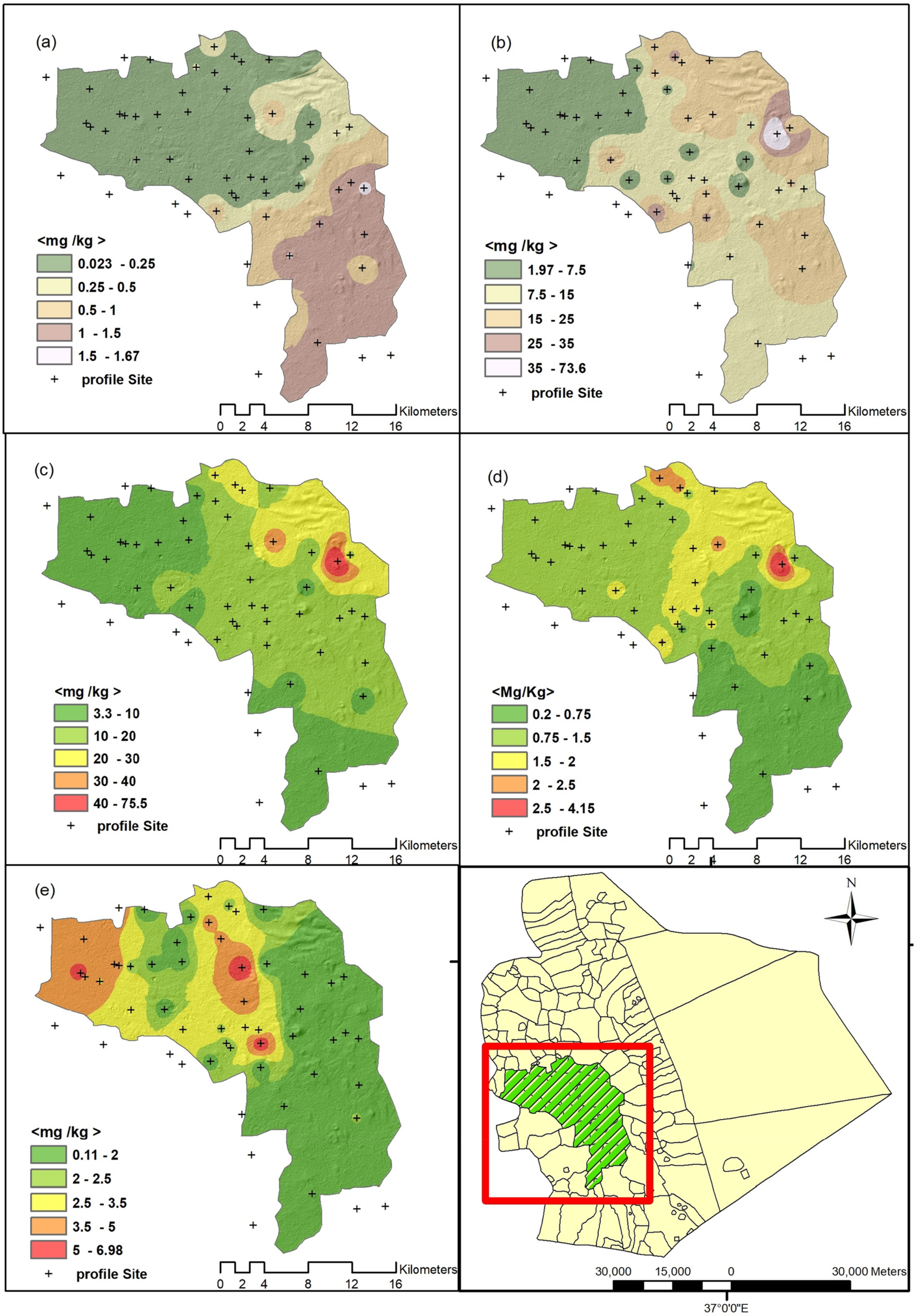

Fig. 2 Distribution maps of micronutrient concentration in the study area: **a** *B*; **b** Fe; **c** Zn; **d** Mn; **e** Cu

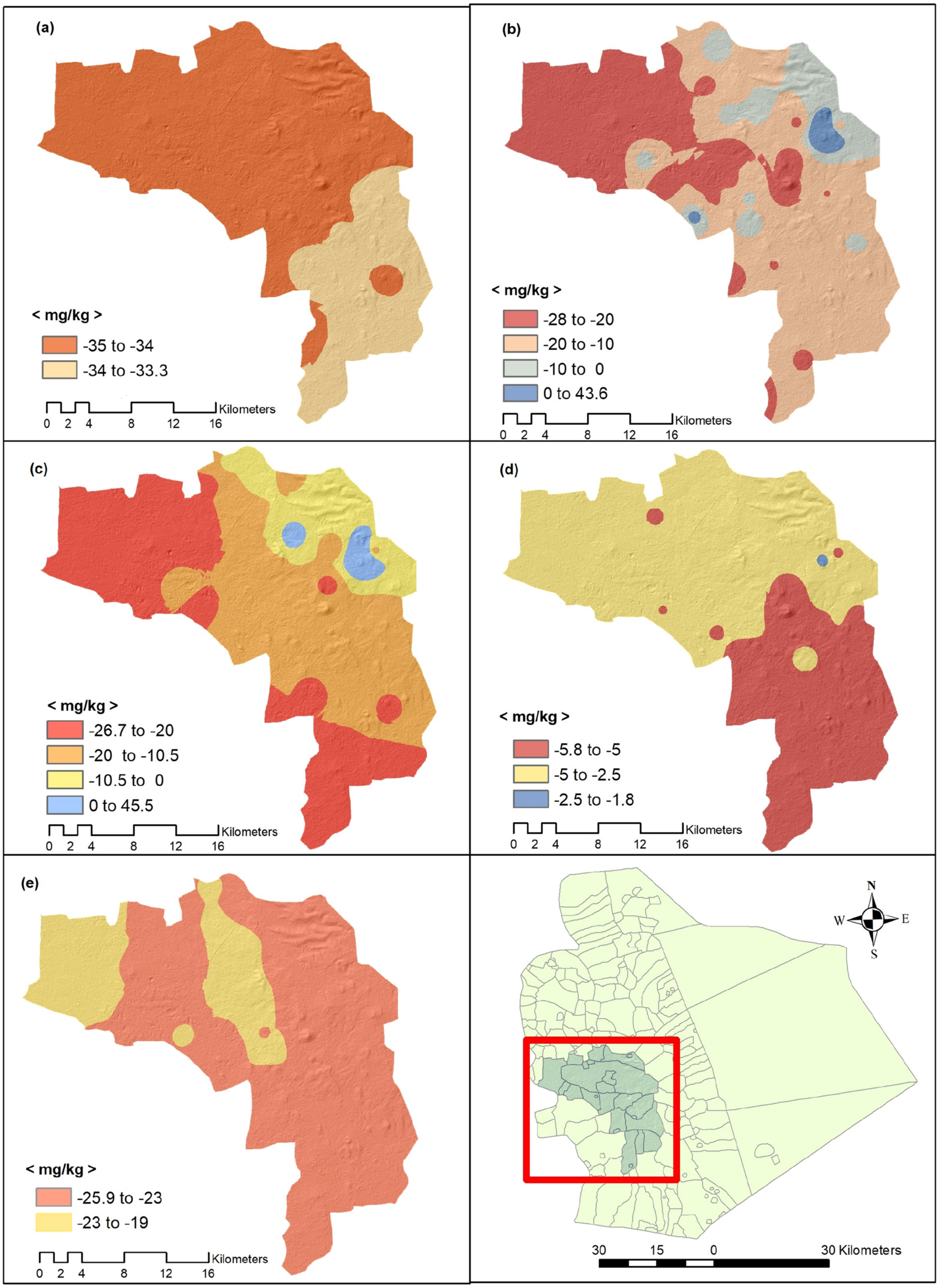

Fig. 3 Distribution maps of micronutrient deficit for vineyards cultivation in the study area: **a** *B*; **b** Fe; **c** Zn; **d** Mn; **e** Cu

Many studies show that micronutrient availability in Syrian ranges from moderate to low (Hennawi and Habib 2012; Kiwan et al. 2014). In addition, Alloway (2004) indicated that the available Zn^{2+} in the Syrian is not optimum for agricultural production. The low micronutrient concentration in Syrian soils may be because of the alkalinity of the soil (Sillanpää

1982), high calcium carbonate, the intensity of vineyard cultivation (Amorós et al. 2018), the mineralogical composition of the parent material (Kiwan et al. 2014), and topographical characteristics (Hennawi and Habib 2012).

Micronutrient availability in the soil is generally affected by many factors, including pH, OM%, adsorption forces on soil colloids (humus and clay), $CaCO_3$%, and the P concentration in the soil solution, as well as the cropping system and other agricultural practices (Viets 1962; Wei et al. 2006; Li et al. 2007; Ben-Yin et al. 2010; Sachan and Krishna 2018; Das et al. 2017). Soil pH plays a major role in the availability of micronutrients. For instance, high pH level is associated with the occurrence of phosphate, lead to iron fixation resulting in iron deficiency symptoms known as iron chlorosis (Mengel 1994). Thus, Fe changes from Fe^{2+}, which is soluble and suitable for vineyards, to Fe^{3+}, which is unsuitable for vineyards cultivation. Similarly, high concentration of manganese, zinc or copper have been linked to weak absorption of iron, especially in acid soils (Mortvedt 1991). Moderate to alkaline pH levels also affect the availability of Mn^{2+} in the soil. Alkaline pH transforms Mn^{2+} into insoluble Mn^{3+} (Welch 2003). Zinc (Zn^{2+}) availability for vineyards is also related to pH, and many researchers have indicated that zinc deficiency symptoms appear when the soil reaction ranges between 4 and 8 (Barrow 1986); due to precipitation of zinc in the soil. In alkaline soil zinc can be fixed or precipitated by calcium carbonates or iron oxides, while it is fixed by iron and aluminum in low pH soils. Alloway (2004) reported that the available Zn^{2+} in the Syrian soil ranges between 0.3 and 3.5 ppm. In a similar vein, Cu^{2+} availability in the studied soil did not exceed the limiting value in most of the profiles, which can be explained by the effect of the pH level. An inverse relationship was observed between the increased pH and the availability of Boron in the soil. This finding aligns with Sillanpää (1982), who noted the limited availability of Boron for vineyards in the study area (Table 8).

Mapping of soil properties as well as analyzing the spatial distribution of micronutrient level suitability for vineyards or other crops is essential for achieving sustainable use of soil in vineyards (Barakat et al. 2017). This is because soil mapping helps decision-makers, planners and soil scientists better understand the distribution of these nutrients for them to determine the best management strategies to be adopted in ensuring sustainability of the soil. This is important for the enhancement of crop productivity by identifying areas of deficiency and planning intervention strategies.

Conclusions

Micronutrient availability for vineyard cultivation was determined on the western slopes of Jabal Al Arab in Syria. The results showed a concentration of micronutrients below the critical deficiency level in most of the studied soil profiles.

Table 8 Distribution of limiting value for micronutrient in the study area

Micronutrient	Limiting value (ppm)	Area km^2
B (ppm)	− 35 to − 34	385.381
	− 34 to − 33.3	133.202
Fe (ppm)	− 26.7 to − 20	204.48
	− 20 to − 10.5	224.89
	− 10.5 to 0	75.52
	0 to 45.5	13.68
Zn (ppm)	− 25.9 to − 23	395.8
	− 23 to − 19	122.7
Mn(ppm)	− 28 to − 20	175.85
	− 20 to − 10	272.29
	− 10 to 0	61.78
	0 to 43.6	8.65
Cu (ppm)	− 5.8 to − 5	189.89
	− 5 to − 2.5	327.94
	− 2.5 to 1.8	0.74

Maps of micronutrient distribution indicate that most of the study area suffers from an acute level of micronutrients for vineyards cultivation. For sustainable agriculture within the study area, organic fertilizer, as well as humic substances, accompanied by micronutrient fertilizers should be added to the soil, to ensure sufficient amounts for economic vineyard production. However, further research is required to determine other factors that may exacerbate micronutrients deficiency in vineyards within the study area.

Funding Open Access funding provided by University of Debrecen.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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