INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No II/1/2019, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 39-51
Commission of Technical Rural Infrastructure

DOI: https://doi.org/10.14597/INFRAECO.2019.2.1.004

USING OF WIND EROSION EQUATION IN GIS

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Abstract

The vulnerability of soil by wind erosion using the wind erosion equation (WEQ) in geographic information systems (GIS) was demonstrated on the cadastral area of Přísnotice, southeast of the Czech Republic. Raster layers were created for input factors of WEQ and potential soil loss by wind was calculated using the Raster Calculator. Subsequently, map outputs showing the potential vulnerability of soil to wind erosion were made. In the first variant, where the protective effect of the barriers was not taken into account, the wind erosion intensity reached 47.6 t.ha^{-1}.year^{-1}. In the second variant, where the protective effect of the barrier was assumed, the loss of soil was lower, the maximum value was 4.7 t.ha^{-1}.year^{-1}. The soil loss limit was exceeded, even in a situation where a relatively high protective barrier effect has been proposed. The advantage of determining of wind erosion vulnerability using ArcGIS is that it is possible to identify particular parts of soil blocks from the map outputs, which are the most vulnerable. Similarly, it is possible to design a windbreak network and simulate its protective effect using ArcGIS.

Key words: land consolidation, soil erodibility, non-erodible soil particles, climatic factor, unsheltered distance, wind barriers

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INTRODUCTION

The vulnerability of soil by wind erosion using the geographic information systems (GIS) was demonstrated in the cadastral area (c.a.) of Přísnotice, Czech Republic. The fact, that no land consolidation has yet been implemented in this territory, was the reason for choosing of this area. Owner of most land in the c.a. is the agriculture enterprise Žabčice (UAE), which belongs to the Mendel University in Brno (MENDELU).

Large land plots, including of both own and rented land managed by UAE, provide excellent conditions for the development of wind erosion processes. Since no one has ever calculated how large the soil loss in this area could be, we have tried to calculate this by using of the "classic" wind erosion equation implemented into a modern tool as the ArcGIS program is. It is only a calculation of the potential loss of soil, but it can become a reality under certain suitable conditions.

Wind erosion is a phenomenon in which the wind causes the soil abrasion, moving and transporting of soil particles and depositing them elsewhere. Wind erosion occurs mainly on light soils, in areas with low and variable rainfall, variable and high wind speed, in areas with frequent occurrence of drought (Borelli *et al*. 2015). These are conditions that at present, in times of increasing occurrence of drought, lead to an enlargement of wind erosion even into the areas where it has not previously existed.

MATERIALS AND METHODS

C.a. of Přísnotice is located in the southeast of the Czech Republic (Fig. 1), 25 km south from Brno. The total area of c.a is 770.08 hectares and is intensively agricultural used. An area of 594.59 hectares is managed by UAE.

The selected area belongs to the warmest localities in the Czech Republic with an average annual temperature of 10°C (data from meteorological station of UAE Žabčice). However, the potential productivity of the area from the point of view of agricultural production is somewhat limited by the relative lack of precipitation, which, in combination with the relatively high temperature and frequent drying winds, illustrates the typical character of the locality. C.a. of Přísnotice is one of the locations with a very low average annual precipitation which, in the period of 1991–2010, was only 496 mm (Žalud *et al.* 2013).

According to the map of the potential vulnerability of arable land by wind erosion (mapy.vumop.cz), more than 80 % of the land area of the c.a. of Přísnotice belongs into the category of most vulnerable soils by wind erosion.

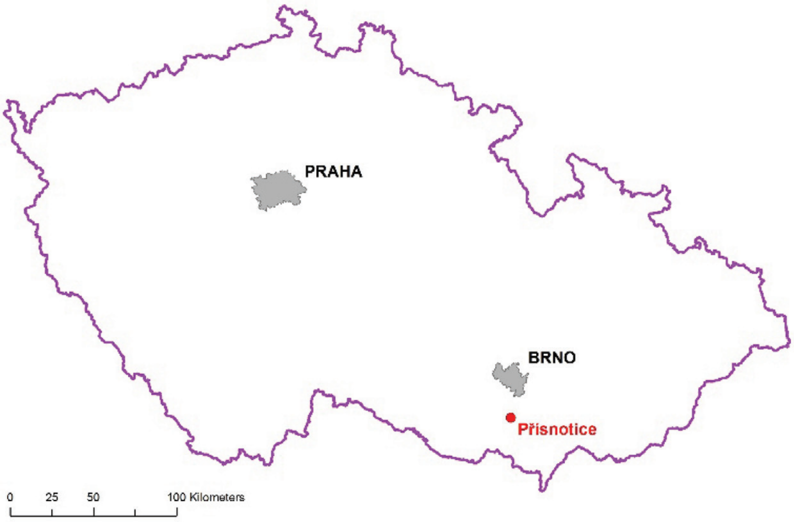


Figure 1. Location of the cadastral area of Přísnotice, Czech Republic (www.cuzk.cz)

Soil samples for the soil analyses, necessary for the potential wind erosion intensity assessment, were taken from eight different evaluated soil ecological units (BPEJ), which are located in the c.a. of Přísnotice (Tab. 1). For the most represented BPEJ with the code of 00501, seven soil samples were taken. For the other (smaller) BPEJ, fewer samples were taken (comparatively to the size of the area of its occurrence).

Table 1. Area of occurrence of BPEJ in the cadastral area of Přísnotice, soil type and average content of non-erodible fraction (NEF) in the soil

BPEJ	Area (hectares)	Soil type	NEF (%)
00300	9.07	haplic chernozem	180.6
00501	397.64	haplic chernozem	150.5
02112	90.60	haplic arenosol	144.8
02113	3.98	haplic arenosol	226.4
05600	13.13	eutric fluvisoil	82.4
05800	52.68	eutric fluvisoil	46.5
05900	28.78	gleyic eutric fluvisoil	37.5
06000	34.16	mollic fluvisol	110.5

The original Wind Erosion Equation (WEQ) (Woodruff and Siddoway 1965) is still used method for potential soil loss by wind. The result of the equation provides a general view of the amount of wind erosion intensity from the area of interest. However, it does not deal with local problems occurring on certain parts of the territory, it does not include the influence and radius of wind barriers (e.g. windbreaks) located in the territory, it identifies the individual factors only as the average values for the whole area. The WEQ is used in the form (1):

$$E = f(I \times K \times C \times L \times V), \tag{1}$$

where E = the average annual potential loss by wind in $t \cdot ha^{-1} \cdot year^{-1}$,
I = soil erodibility index ($t \cdot ha^{-1} \cdot year^{-1}$),
K = soil roughness factor (–),
C = climatic factor (–),
L = unsheltered length factor (–),
V = vegetative cover factor (–).

Using the equation together with GIS, it becomes an advanced tool for solving wind erosion issues on a spatial scale. It is possible to create maps of all the input factors of the equation by using the WEQ in ArcGIS and build them into interactions with GIS analytical tools. Schwab et al. (1993) have derived, based on statistical analyses of the WEQ, following relationships (2) and (3):
if the product of I, K, C, and L is less than 5.5×10^6, then

$$E = 0.0015 \times 2.718^{\left(-\frac{V}{4500}\right)} \times \left(I^{1.87} \times K^2 \times \left(\frac{C}{100}\right)^{1.3}\right) \times L^{0.3}\ , \tag{2}$$

if the product of I, K, C, and L is equal to or greater than 5.5×10^6, then

$$E = 2.718^{\left(-\frac{V}{4500}\right)} \times \left(I \times K \times \frac{C}{100}\right). \tag{3}$$

Soil erodibility index I

Soil erodibility index is expressed as potential annual soil loss in $t.ha^{-1}$ from a wide, unsheltered isolated field, with bare, smooth, level, loose and non-crusted surface. The soil erodibility factor is related to the percentage of non-erodible surface soil particles larger than 0.84 mm in diameter which can be determined by dry sieving method (Chepil 1942). The content of non-erodible particles in the soil was determined by aggregate analysis (López *et al.* 2007) from soil samples taken on particular BPEJ occurring in the area of interest. Factor I can be deduced from the table (Woodruff and Siddoway 1965) or more exactly calculated from equation (4):

$$I = 525 \times 2.718^{-0.04NEF}, \tag{4}$$

where *NEF* = content of dry soil fraction greater than 0.84 mm (%).

Soil roughness factor K

The roughness factor of the soil surface expresses the effect of the roughness formed by knolls, ridges, and microrelief waves on soil erosion. Factor K depends on the value of the equivalent roughness K’, which represents the height of terrain roughness in cm (Vrána 1978). It is practically impossible to determine the average annual value of the surface roughness of the soil surface, which is regularly cultivated and used by farmers. The roughness of the soil surface changes not only due to various agrotechnical operations, but also due to rain, surface runoff or soil thawing. Because, the potential wind erosion is determined in our case, it is advisable to assume a flat soil surface in our investigated territory and consider the value of factor *K*=1.

Climatic factor C

The climatic factor is an index of climatic erosivity, which includes the wind speed and the soil surface moisture. Factor *C* can be calculated from equations (5) and (6) (Woodruff and Siddoway 1965):

$$C = 386 \times \frac{u^3}{(PE)^2} \tag{5}$$

$$PE = 3.16 \times \sum_{i=1}^{12} \left(\frac{P_i}{1.8T_i + 22}\right)^{\frac{10}{9}} \tag{6}$$

where u = average annual wind velocity (m.s^{-1}),
PE = Thornthwaite index,
P_i = monthly precipitation (mm),
T_i = average monthly air temperature (°C).

However, the value of factor *C* determined for a longer period is questionable, because gusty wind speed is important for wind erosion processes, especially in spring and autumn when the soil is not covered by vegetation. For this reason, it is more accurate to use dynamic wind velocity (Hagen 1991, Grešová and Streďanský 2011, Liu *et al.* 2015) in the eq. (5).

Unsheltered length factor L

The unsheltered length of eroding field is expressed as the length of unprotected field or erosion surface in meters in the prevailing wind direction. In the original concept (Woodruff and Siddoway 1965), the unsheltered length means the length from a sheltered edge of a field, parallel to the direction of the prevailing wind, to the end of the unsheltered field (distance in meters from barrier to barrier).

According to USDA methodology (2002), the protected part of the field is an area 10 times the height of the barrier located beyond barrier in the prevailing wind direction and thus affects the calculation of the unsheltered distance of field.

However, the protective effect of the wind barrier is even greater according to the research carried out in the Czech Republic (e.g. Riedl 1973, Pivcová 2000, Podhrázská *et al.* 2008, Khel *et al.* 2017). The protected part of the field is, according Czech researchers, an area 10 times the height of the barrier located ahead of the wind barrier (windward side) and 20 times the height of the barrier located beyond the barrier (leeward side) in the prevailing wind direction.

For this reason, the intensity of wind erosion has been determined in two variants – for a) situation where the protective effect of wind barriers is not considered and for b) situation with protective effect of wind barrier on the wind – and leeward side.

Vegetative cover factor V

Vegetative cover factor reflects the influence of the amount, type, and orientation of vegetation cover on the soil surface. Williams et al. (1984) proposed an equation for the *V*-factor based on the small grain equivalent SGe (in kg·ha^{-1}) (7):

$$V = 0.2533 \times SGe^{1.363}. \tag{7}$$

The SGe can be assessed by (8) (Armbrust and Lyles 1985):

$$SGe = a \times X^{b}, \tag{8}$$

where X = the amount of biomass which is converter to small-grain equivalent (kg·ha^{-1}),

a, b = coefficients typical for certain crops (Lyles and Allison 1981).

Since wind erosion occurs in our climatic conditions mainly in the spring and partly in the autumn, when the soil is mostly not protected by vegetation, it is reasonable to assume for wind erosion assessment, that the land is not covered by vegetation and the factor $V = 1$.

RESULTS AND DISCUSSION

The complex calculation for wind erosion was performed using ArcGIS 10.6. Raster layers were created for factor *I* (Fig. 2) and *L* (Fig. 3), the other factors were constants (*K* and $V = 1$, factor *C* was calculated as 22,6). Potential soil loss by wind was calculated according eq. (2) using the Raster Calculator. Subsequently, map outputs showing the potential vulnerability of soil to wind erosion were made (Fig. 5 and 6).

Unsheltered length factor was created with Flow Length command in ArcGIS (Fig. 3). The protective effect of barriers depends on their height thus all barriers were divided into four groups according to their average height that was measured using the digital altimeter directly in the terrain. The groups are then: trees (with average height of 20 m), built up area (10 m), vineyards (1.7 m) and orchards (5 m). Regarding to barriers located outside the c.a. in the prevailing wind direction (that is northwest), it was necessary to include them into the calculations so that the unsheltered length factor, and total soil loss respectively, were not counted from the cadastral borders. This situation concerns mainly the soil blocks marked as 9, 11, and 12 (Fig. 4).

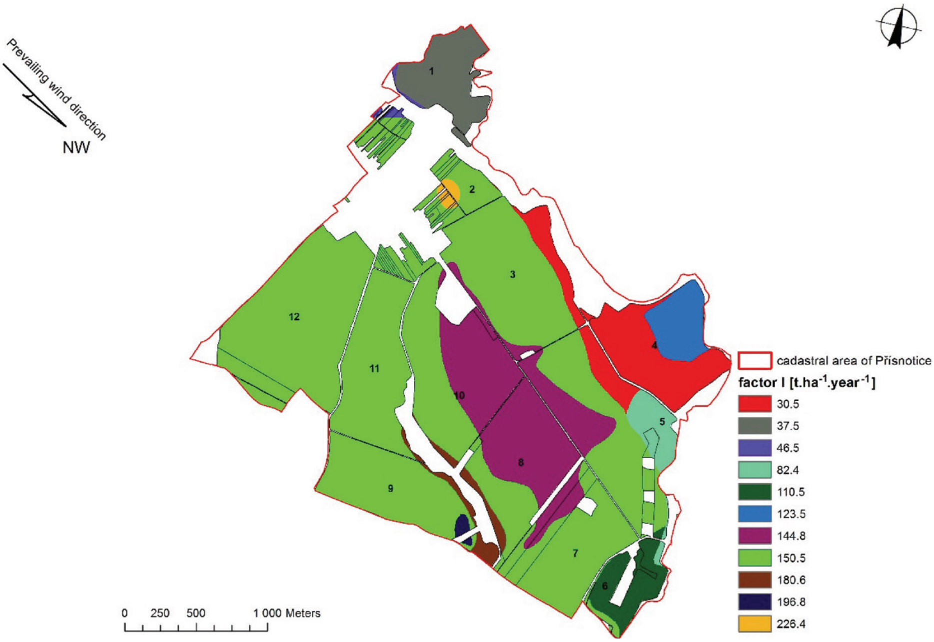
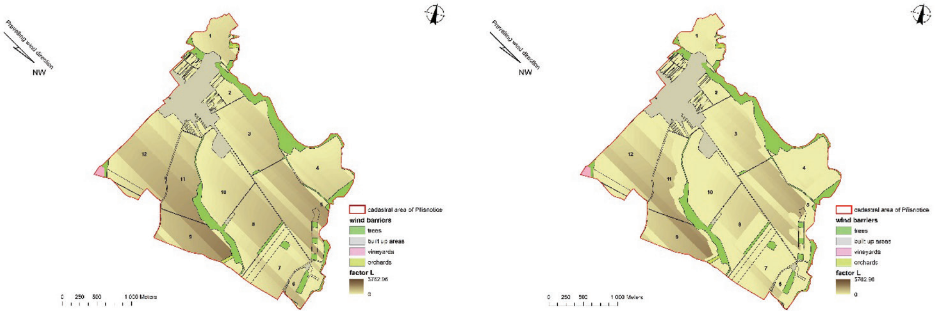


Figure 2. Soil erodibility index/factor

The increasing soil erosion along the increasing erosion surface length is shown in the Fig. 5 and 6. In the buffer zone of barriers the soil loss is zero, the growth starts from the border of the buffer zone in the prevailing wind direction up to the barrier, where the soil transport stops. Behind the barrier increasing soil erosion begins again.

In the a) variant, where the protective effect of the barriers was not taken into account (Fig. 5), the wind erosion intensity reaches 47.6 t·ha^{-1}·year^{-1}. The soil blocks 9 and 11 are the most vulnerable.



a) without protective effect of barriers

b) with protective effect of barriers (10x the barrier height on the windward side and 20x the barrier height on the leeward side)

Figure 3. Unsheltered length factor

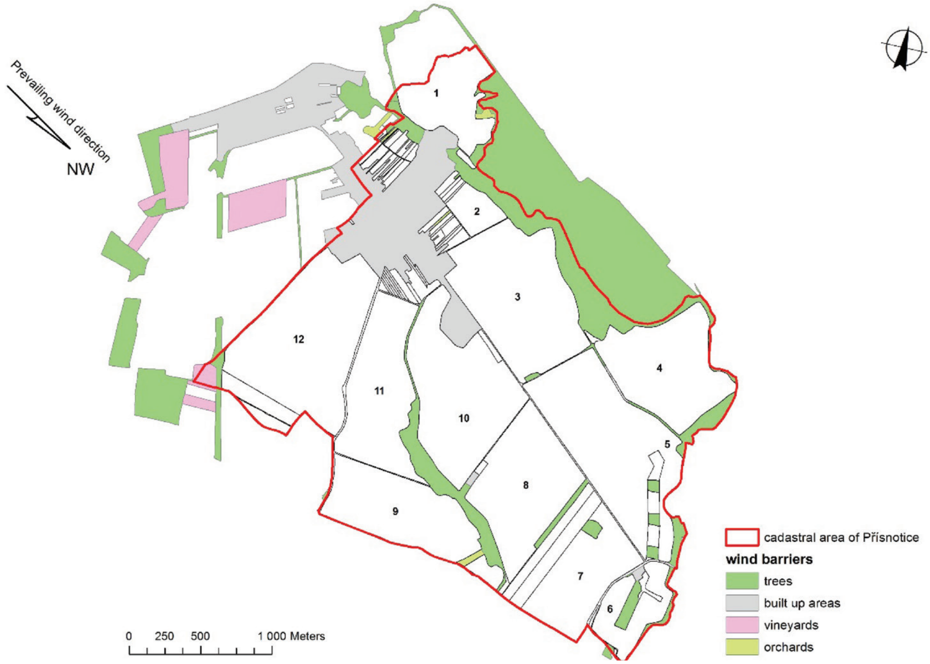


Figure 4. Wind barriers inside and outside (but in the prevailing wind direction) of cadastral area of Přísnotice

In the b) variant, where the protective effect of the barrier is assumed (Fig. 6), the loss of soil is lower obviously, the maximum value is 4.7 t.ha^{-1}.year^{-1}. Again, the soil blocks 9 and 11 are the most vulnerable. The protective effect of barriers outside the c.a. is, of course, disputable over such a large distance, mainly because it is not a „classic" windbreak for which the protective effect is defined, but only linear vegetation or built-up area, eventually.

The risk of wind erosion can be mitigated by erosion control measures, such as windbreaks. Medium to deep soils occur in the c.a., for which the soil loss limit is 4 t.ha^{-1}.year^{-1} (Janeček *et al.* 2012). The soil loss limit was therefore exceeded, even in a situation where a relatively high protective barrier effect has been proposed.

The advantage of determining of wind erosion vulnerability using ArcGIS is that it is possible to identify particular parts of soil blocks from the map outputs, which are the most vulnerable. Similarly, you can design a windbreak network and simulate its protective effect using ArcGIS.

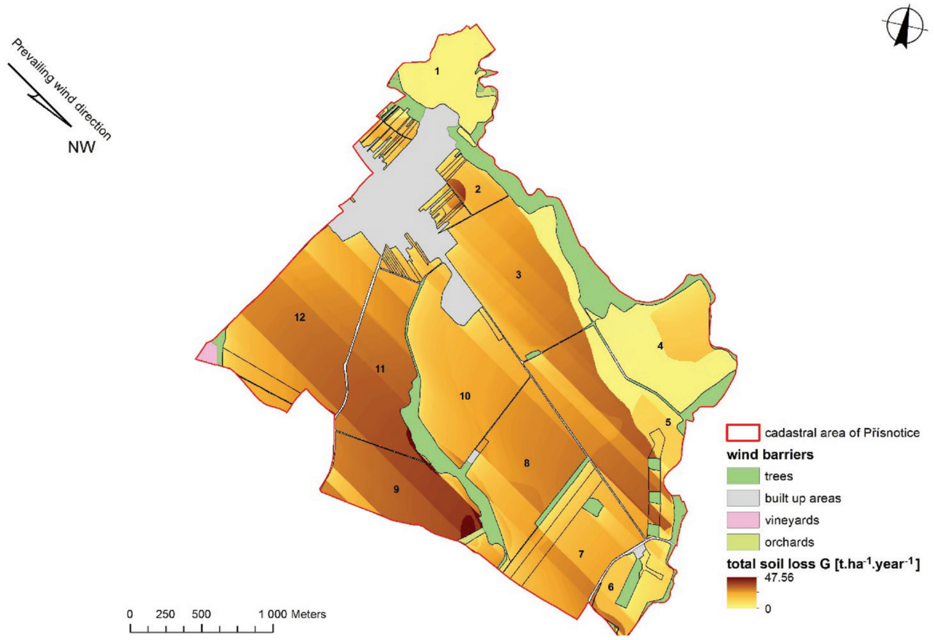


Figure 5. Wind erosion intensity in the cadastral area of Přísnotice in various distances from barriers (without their protective effect)

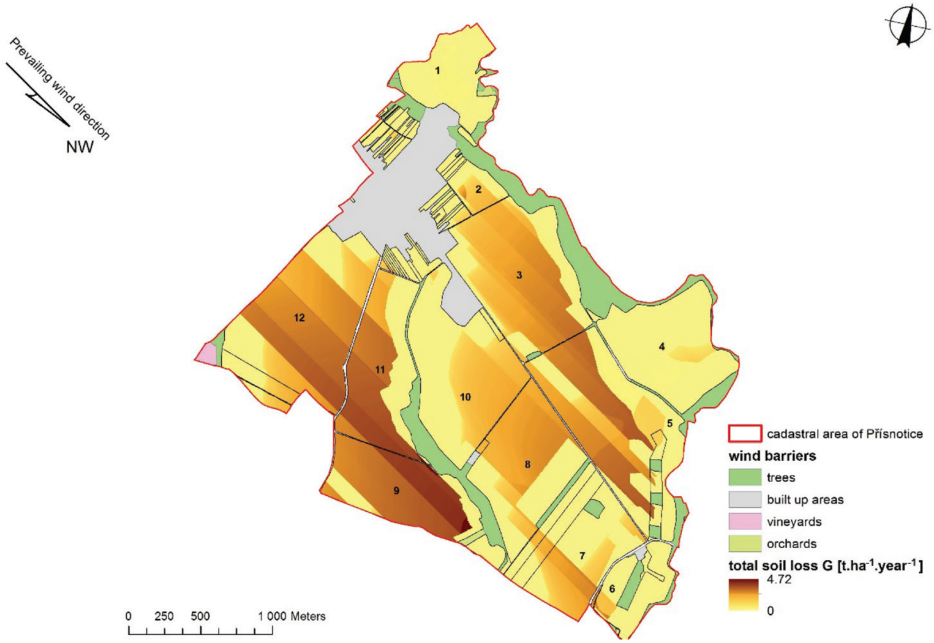


Figure 6. Wind erosion intensity in the cadastral area of Přísnotice in various distances from barriers and protective effect of barriers on their wind – and leeward side

CONCLUSION

Wind erosion in the cadastral area of Přísnotice threatens especially long unprotected lands. In the first variant, where the protective effect of the barriers was not taken into account, the wind erosion intensity reached 47.6 t.ha^{-1}.year^{-1}. In the second variant, where the protective effect of the barrier was assumed, the loss of soil was lower, the maximum value was 4.7 t.ha^{-1}.year^{-1}. The soil loss limit was exceeded, even in a situation where a relatively high protective barrier effect has been proposed.

As mentioned at the beginning, no land consolidation has been done so far in the c.a. of Přísnotice, but just this could solve the problem with wind erosion. Land consolidation represents, apart from the arrangement of soil blocks (which is its main objective), certain „protective" tool that can reduce soil erosion just by windbreak network design.

Proposal of land consolidation in the c.a. of Přísnotice could become a task (under the guidance of a skilled designer) for the students of the study program of Land consolidation and soil protection, which can be studied at MENDELU.

This would interface theory and practice, and future designers would participate in creating a concrete project of a complex land consolidation already during their study, thus giving them the opportunity to participate in the arrangement of the agriculture landscape managed by their alma mater. In this way, the UAE could be an exemplar by its approach for other farmers, which obstruct land consolidation especially due to the lack of information on the benefits resulting from their realization.

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Received: 25 of September 2018
Accepted: 22 of February 2019