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Impact of secondary vegetation succession on soil quality in a humid Mediterranean landscape

R.L. van Hall^{a,*}, L.H. Cammeraat^a, S.D. Keesstra^b, M. Zorn^c

^a Institute for Biodiversity and Ecosystem Dynamics, Earth Surface Science, University of Amsterdam, Science Park 904, 1098XH Amsterdam, The Netherlands

^b Soil Physics and Land Management Group, Wageningen University, P.O. Box 47, 6700AA Wageningen, The Netherlands

^c Anton Melik Geographical Institute, Research Centre of the Slovenian Academy of Sciences and Arts, Gosposka Ulica 13, Ljubljana, Slovenia

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ABSTRACT

Former agricultural fields are increasingly abandoned in several regions in Southern Europe. In many cases this leads to vegetation succession which may have a direct impact on soil quality, biodiversity and hydrological connectivity. The aim of this study is to provide insights on the role of vegetation succession in response to land abandonment on soil quality changes, while keeping aspect into consideration. Information on soil quality change is incomplete and highly scattered especially in the Mediterranean and deserves more attention.

Four different stages of land use change and vegetation succession (i.e. agricultural field, abandoned field, young forest, semi-mature forest) were selected and sampled on both north-, and south-facing slopes. For each of the eight conditions six representative sites were sampled. During vegetation succession soil organic carbon (SOC) content and total nitrogen (TN) content, and aggregate stability significantly increased. With increasing SOC, TN and aggregate stability the bulk density and pH decreased. In addition, the parameters SOC, TN and water retention are impacted by aspect. SOC contents increased slower over time on north exposed slopes, but were higher after 50 years. Carbon stocks showed a similar trend but were not different after 50 years for both studied expositions, due to aspect related changes in dry bulk density over time. Soil water availability was 24% higher for north-facing slopes. Soil water availability however did not change over time. Largest increase in soil quality was observed in the first 30 years after abandonment.

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1. Introduction

Since the Second World War, in several regions in southern Europe a trend of decreasing agricultural activity can be observed as a result of socio-economic changes (García-Ruiz and Lana-Renault, 2011; MacDonald et al., 2000; Keesstra, 2006). Former agricultural fields are abandoned which may lead to land degradation and desertification, and in many cases secondary vegetation succession occurs which may alter the resilience and response of the ecosystem (Cerdà, 1997; Geeson et al., 2002; Cammeraat et al., 2005; García-Ruiz et al., 2005). The restoration of soil quality after soil degradation due to unsustainable land use is of crucial importance to maintain or improve ecosystem services for future generations (Montanarella, 2015; Keesstra et al., 2016), as soil forms an essential part of the water-food-soil nexus (de Paul Obade and Lal, 2016). Therefore it is essential to understand the rate at which soil quality indicators change due to degradation, and under which conditions these changes can be reverted when the conditions in terms of land use improve. Soil quality is closely linked to soil carbon which has great importance to the global carbon cycle (Quinton et al.,

2010). Although much effort has been put in studying soil organic carbon (SOC) stocks, the information on SOC stocks change under secondary succession in the various global ecosystems is highly variable and needs further extension, especially in the Mediterranean (Novara et al., 2014; Trigalet et al., 2016). Soil quality also regulates soil water dynamics and infiltration and as such play an important role in the availability of fresh water resources. Current developments in land use change also predict a further increasing land abandonment and rewilding of Europe (Navarro and Pereira, 2015). In this study we looked in detail into soil quality changes as a result of natural reforestation during secondary succession in different stages of development, in areas that have been abandoned since the Second World War in the SW of Slovenia.

The impact of clearing and cultivation of natural forest on soils has been studied by various authors (e.g. Islam and Weil, 2000; An et al., 2008). The effects of reverse land cover change, i.e. secondary vegetation succession, leading to a forest cover, has recently also received more scientific attention, however, the information is highly scattered and ecosystem dependent. Also information on the role of slope exposition on soil quality change after abandonment is scarce, which is strange as vegetation development and soil moisture dynamics are very important, especially in the Mediterranean. Secondary vegetation succession

* Corresponding author.

E-mail address: R.L.vanhall@gmail.com (R.L. van Hall).

and subsequent soil quality improvement generally proceed slowly (Ruiz-Sinoga and Martínez-Murillo, 2009). The impact of change is important with respect to ecosystems response and soil carbon storage and should be studied over the full time span from abandonment to full grown forests, to be able to evaluate their impact, also to anticipate on climate change and the predicted continuation trend of land abandonment.

When abandoned agricultural land changes back into forest under secondary succession, also soil properties will change (Lesschen et al., 2008; Nadal-Romero et al., 2016) and will affect nutrient cycling mechanisms, soil organic matter accumulation and the hydrological response (García-Ruiz et al., 2005; Keesstra, 2006; Novara et al., 2014; Gabarrón-Galeote et al., 2015). It is well known that standard agricultural practices generally, like tillage, have a negative impact on SOC (Cerdà et al., 2009). Grasslands under comparable conditions tend to have a higher amount of SOC at the surface than cultivated fields (Post and Kwon, 2000; Deng et al., 2016), due to high (root) biomass organic matter input, slow decomposition of plant debris and the lower removal of biomass during harvest. Tillage management increases microbial decay of plant residues, leading to higher mineralisation and lower SOC levels (Guzman and Al-Kaisi, 2011). In forested areas the above ground input of litter as well as roots represents a large percentage of the soil's total organic input (Kalbitz et al., 2007; Huang and Spohn, 2015), and organic-rich surface layers are likely to develop during secondary succession and the climax vegetation. Furthermore these organic-rich surface layers may contain nutrients which have been extracted from deeper soil layers and enter the soil layer through biological incorporation of litter into the top mineral horizons (Sauer et al., 2012). In general, secondary regrowth, leading to a forest cover, causes a progressive recovery of SOC (Post and Kwon, 2000), which is studied most widely and seen as the most important soil quality indicator (Nunes et al., 2012). In addition, vegetation cover, water retention capacity, and aggregate stability increase progressively after abandonment and successive vegetation development (Lesschen et al., 2008).

With increasing litter input, as a result of the vegetation succession, Total Nitrogen (TN) and SOC content are expected to increase. For semi-arid environments Lesschen et al. (2008) found that soil properties are able to recover to their level from before cultivation, but the recovery is slow. Even after 40 years SOC content was still lower compared to semi natural sites. Nadal-Romero et al. (2016) found that for a sub-humid Mediterranean area after 60 years even reforested areas did not reach the same level of SOC and soil quality of natural forests. Knops and Tilman (2000) predicted that recovery to 95% of the pre-agricultural levels of SOC would take 230 years for SOC. Foote and Grogan (2010) found that time for recovery of SOC after abandonment was a more important factor than soil type for a temperate ecosystem.

Another crucial indicator for soil quality is bulk density, which influences plant root penetration, water- and air-filled pore space, biological availability of nutrients and infiltration (Karlen et al., 1997). Aggregate stability, structure, vegetation (i.e. plant type and cover, SOC content), and topographic and climatic influences all play a role in controlling infiltration rate and capacity of a soil (Yimer et al., 2008). With bulk density changes over time after abandonment, also the pore size distribution of the soil changes, affecting the water holding capacity of soils.

Slope aspect is an important factor influencing local micro-climates, mainly due to the difference in solar radiation. This generally causes north-facing slopes to be cooler and moister compared to south-facing slopes. Lower soil temperature and less moisture evaporation cause less decomposition of soil organic matter (e.g. Rezaei and Gilkes, 2005; Gong et al., 2007; Begum et al., 2010). Therefore soil organic matter and the status of many soil nutrients (e.g. N, P), and with this the fertility of the soil, is generally better at north-facing slopes, compared to south-facing slopes (Gong et al., 2007).

The aim of this study is to provide insight on how of vegetation succession affects soil quality in response to land abandonment. This will be

evaluated by looking at the temporal changes in SOC, SOC stocks, TN, bulk density, aggregate stability, pH, water retention and soil texture as key parameters for soil quality for three stages of land abandonment (10 years, 25 and 50 years after abandonment) and on contrasting northern and southern exposed slopes.

2. Study area

The study area is situated in the southwestern part of Slovenia and part of the 91 km² Dragonja catchment (Fig. 1). The 30 km long Dragonja river flows from east to west into the Gulf of Trieste in the northern most part of the Adriatic Sea. Therefore most hill slopes are north-, or south-facing. Elevations of the catchment range from 484 m to sea level. The upper part of the catchment, which is the actual study area, consists of the Rokava sub-catchment (20 km²) to the north, and the Upper-Dragonja sub-catchment (32 km²) to the south (Keesstra, 2006).

The climate of the study area is characterized as sub-Mediterranean (Köppen-type Cfa; Ogrin, 1996), with average January temperatures between 0 and 4 °C, average July temperatures between 19 and 22 °C, and average annual temperature just above 10 °C. In the study area average yearly precipitations is between 1100 and 1200 mm, with app. 40% of precipitation in fall and with app. 20% of precipitation in other seasons (Zorn, 2012).

The substrate in the catchment consists mainly of sub-horizontal impermeable Eocene flysch beds (Zorn, 2009), which consist of highly erodible and calcareous clay- and siltstones, with intermittent sandstone layers with a maximum thickness of 1.5 m.

The catchment consists of long flat ridges (up to 400 m above sea level) above deep and narrow river valleys, where most settlements have developed (Zorn and Petan, 2008). In the Upper Dragonja sub-catchment valleys are narrow and the aspect of the slope does not affect its steepness. In the Rokava sub-catchment however, north-facing slopes are much steeper than south-facing slopes and the valley is wider (Keesstra, 2006). The soils in the valley are calcareous.

The catchment has been cultivated for a long period, probably since Roman time (Keesstra, 2007). Due to socioeconomic changes since the Second World War depopulation and abandonment of farming has occurred in the catchment and with this a breakdown of the cultural landscape. This was followed by natural reforestation (Urbanc, 2008; Keesstra et al., 2009a, 2009b). The cover by forest increased in the upper part of the catchment where the study area was from around 30% in the mid-1950s to >60% the Rokava sub-catchment and >70% in the Upper Dragonja sub-catchment about a decade ago (Keesstra, 2007).

3. Methods

3.1. Sample design and collection

Fields with different phases of secondary succession ranging from agricultural fields to mature forests, with two opposing aspects were studied. We applied space for time substitution (Paine, 1985; Cammeraat and Imeson, 1998) as the fields selected were comparable with regard to lithology, slope angle, soil type and former land use (vineyards). This approach is often adopted in soil quality research and especially in SOC studies as soil quality indicators only slowly change over time (e.g. Martínez-Fernández et al., 1995; West and Post, 2002; Ruiz-Sinoga and Martínez-Murillo, 2009; Novara et al., 2014; Trigalet et al., 2016). In the summer of 2013 topsoil samples have been taken in the study area (upper 10 cm). The samples were collected in vineyards, abandoned fields, young forests and semi-mature forests, representing the four stages (age group 0–3) of vegetation succession. Age group 0 reflects current agricultural use; age group 1 reflects 5–10 year abandonment and age group 3 and 4 cover 25 and 50 years of abandonment respectively. As an additional condition,

Fig. 1. Upper part of the Dragonja catchment, southwest Slovenia (48° 28'N, 13° 35'E).

north- (N) and south- (S) facing slopes have been compared resulting in eight different conditions. Per condition six representative sites were selected on similar slope position with a maximum slope angle of 10%. Some general vegetation characteristics of the 48 sites averaged per age group and per aspect can be found in Table 1. On the sample locations (Fig. 1) within a plot of 10 by 10 m three topsoil samples were collected which were air-dried and then packed. Additionally, three samples were taken using cylindrical cores with a volume of 100 cm³ which were stored air-tight on a dark location. For each condition an infiltration experiment was carried out using a small mobile rain simulator covering a circular surface with a diameter of 30 cm (706.5 cm²). The rain simulator was a dripping plate type simulator, as described by Bowyer-Bower and Burt (1989) and Lascelles et al. (2000) but with a smaller dripping plate. Falling height of the raindrops was only 40 cm. The rained area was bounded by a circular metal ring with a tapping point at the lowest side to collect overland flow. The ring was carefully inserted into the topsoil for about 1 cm. The rainfall intensity was set to about 140 mm.h⁻¹, and the experiment was carried out for a maximum of 1 h.

The samples were air-dried before being transported to the soil laboratory of the University of Amsterdam where analysis was carried out.

3.2. Soil sample analysis

For all the analyses the samples were sieved and only the fraction <2 mm was used, except for aggregate stability where the fraction 4–4.8 mm was used. Total carbon (TC) and TN were determined by dry combustion using an elemental analyzer (Elementar Vario El Cube).

SOC was determined by wet combustion using K₂Cr₂O₇ and sulphuric acid (H₂SO₄), based on the method described by Allison (1935). In addition pH_{H2O} was measured in soil extracts of a 1:2.5 weight ratio.

Table 1

Average vegetation characteristics on different slope expositions.

		Aspect			
		N		S	
		Species (average nr)	Cover (%)	Species (average nr)	Cover (%)
Age group 0	Trees	0	0.0	0	0.0
	Shrubs	1	30.8	1	34.2
	Herbs	5	12.5	5	16.2
	Grasses	2	17.5	3	31.2
	Juveniles	0	0.0	0	0.3
Age group 1	Trees	2	6.7	2	4.3
	Shrubs	3	14.7	3	25.3
	Herbs	9	17.5	7	12.2
	Grasses	4	61.7	3	49.2
	Juveniles	1	0.7	1	1.0
Age group 2	Trees	3	35.8	2	39.2
	Shrubs	3	27.5	2	15.0
	Herbs	6	5.8	4	5.0
	Grasses	3	40.8	2	35.8
	Juveniles	1	4.2	1	3.2
Age group 3	Trees	4	13.0	3	18.7
	Shrubs	3	4.0	3	17.0
	Herbs	5	6.2	4	5.3
	Grasses	2	40.8	2	35.3
	Juveniles	3	12.0	2	9.2

The total SOC stock ($\text{t} \cdot \text{ha}^{-1}$) of the soil was calculated from the SOC content (%) and bulk density (BD; $\text{g} \cdot \text{cm}^{-3}$) for a soil depth (d ; cm) of 10 cm (Eq. (1)):

$$\text{SOC stock} = \text{SOC} \cdot \text{BD} \cdot d \quad (1)$$

Standard grain size analysis was applied using a set of mesh sieves analysis for the fraction $>125 \mu\text{m}$. After this, the grain size distribution of the fraction $<125 \mu\text{m}$ was determined using a sedigraph (Sedigraph 5100). GRADISTAD, a package that runs within Microsoft Excel, was used to analyse the results (Blott and Pye, 2001).

Ultrasonic dispersion following Imeson and Vis (1984) and North (1976) was used to determine aggregate stability of the fraction 4–4.8 mm. Per condition, 15 pre-wetted aggregates (pF 1) were immersed in 40 ml of distilled and subjected to the ultrasonic probe output for 10 s with the tip placed 11 mm under the water surface. Four different energy outputs were used ranging from 60 W to 75 W. The procedure was repeated 3 times per condition and the stable fraction was averaged per sample.

Bulk density (BD) was measured using the undisturbed core method, using 100 cm^3 rings (Blake and Hartge, 1986).

The water retention curve (pF) was determined using a combination of a low range suction system using a burette and membrane system (0–200 kPa) and a high range suction system using a pressure chamber technique (1000 kPa and higher) (Klute, 1986). In this study we used the volumetric soil moisture content at field capacity (pF 2.2) and wilting point (pF 4.2) to calculate plant available soil water (AW; $\text{cm}^3 \cdot \text{cm}^{-3}$) by subtracting the volumetric water contents at pF 4.2 from those at pF 2.2.

Statistical analyses were performed using R. The results of SOC and TN contents were normally distributed and a linear model fitted the data best. Afterwards analysis of variance (ANOVA) was used to determine if either age group, aspect, or both had a significant influence on the outcome of the response variable. If significant, a post-hoc Tukey test was performed to see if there was a significant difference in value for N and S facing slopes per age group. Aggregate stability and bulk density were not normal distributed and a Kruskal-Wallis test, followed by Dunn's test, was used to determine significant differences between the conditions.

4. Results

4.1. Soil organic carbon

SOC contents ranged from 1.6 to 5.6% and differed significantly ($P < 0.01$) between N and S facing slopes and among age groups

(Fig. 2). For most age groups, SOC contents are higher on S facing slopes compared to N facing slopes. Averaged for all age groups, SOC contents are 29% higher for the S facing slopes. For both aspects the lowest contents are found for age group 0 and significantly higher contents for age group 1, 2 and 3 with the exception of age group 2 of the N exposed slopes. Age group 3 also showed significant higher SOC contents than age group 2 for the N exposed slope. From age group 0 to age group 1 SOC contents almost tripled for the N exposed slopes, whereas it only doubled for the S exposed slopes. SOC stocks (Fig. 3) for the upper 10 cm ranged between 20 and $60 \text{ t} \cdot \text{ha}^{-1}$ and showed a similar pattern as the SOC contents, but less explicit. In age group 2, the stocks are significantly ($P < 0.05$) lower for N exposed slopes compared to S exposed slopes and both S and N exposed slopes increased significantly ($P < 0.05$) for age group 3 in comparison to age group 0. S facing slopes had a significantly ($P < 0.05$) higher SOC stock in age group 1 compared to age group 0. N facing slopes had a more gradual increase in SOC stock and had a significant ($P < 0.05$) difference between age group 0 and 3. SOC stocks approximately doubled over the time range of the 4 age groups.

4.2. Total nitrogen

TN contents ranged between 0.10 and 0.65% and were significantly ($P < 0.05$) different for N, and S facing slopes. On average TN contents are 28% higher on S facing slopes. For both aspects the lowest contents were found for age group 0, which were, with the exception of N facing slopes of age group 2, significantly ($P < 0.05$) lower than those of the other age groups (Fig. 4).

4.3. Dry bulk density and aggregate stability

Dry bulk density ranged from 0.83 to $1.62 \text{ g} \cdot \text{cm}^{-3}$ and was generally lower on N facing slopes with the exception of age group 2 (Fig. 5). The highest bulk density was found on N facing slopes of age group 0. The bulk density of the S facing slopes decreases afterwards with significant ($P < 0.05$) differences between age group 0 and 2. This was not found for N facing slopes where the bulk density of age groups 0 and 2 is similar. The bulk density of age group 3 of the N facing slopes, however, was significantly ($P < 0.05$) lower than that of age groups 0 and 2.

Aggregate stability varied considerably between samples of the same condition (Fig. 6). For N facing slopes aggregates of age group 3 are significantly ($P < 0.05$) more stable than those of age group 0. For S facing slopes the difference between age group 0 and 2 is significant ($P < 0.05$). On average aggregates of age group 0 were the least stable and aggregates of age group 3 the most stable.

Fig. 2. OC contents ($n = 6$ except for age group 0 where $n = 12$). Capital letters indicate significant differences between age groups for each aspect separately.

Fig. 3. OC stock for the upper 10 cm of the soil ($n = 6$ except for age group 0 where $n = 12$). Capital letters indicate significant differences between age groups for each aspect separately.

Fig. 4. TN contents ($n = 6$ except for age group 0 where $n = 12$). Capital letters indicate significant differences between age groups for each aspect separately.

4.4. Grain size distribution and pH

No significant differences were found for the medium value of the grain size distribution which had an average D_{50} of $94.0 \mu\text{m}$ and the texture was well sorted (Table 2). The lowest values were found for the samples of age group 0. The values increase for the samples of age group 1 and decrease again for the samples of age group 2. N facing slopes show increasing values for age group 3 compared to age group 2.

All samples had a pH ranging from 6.14 to 7.65 with the exception of N facing slopes of age group 0 where significantly lower values, ranging between 4.54 and 6.78 were measured.

4.5. Hydrology

The field capacity ranged from 0.28 to $0.49 \text{ cm}^3 \cdot \text{cm}^{-3}$ and was significantly ($P < 0.05$) higher on N facing slopes compared to S facing slopes but does not differ significantly between age groups. Although not significant, the available soil water seems to increase slightly with time since abandonment (Fig. 7).

All tested sites showed no overland flow after 1 h of the rain simulation experiment indicating a high infiltration capacity of $>140 \text{ mm} \cdot \text{hr}^{-1}$.

Fig. 5. Bulk density ($n = 6$ except for age group 0 where $n = 12$). Capital letters indicate significant differences between conditions.

Fig. 6. Aggregate stability ($n = 6$ except for age group 0 where $n = 12$). Capital letters indicate significant differences between conditions.

5. Discussion

5.1. Soil quality change in response to land abandonment

We evaluated the temporal changes in SOC, TN, bulk density, aggregate stability, pH, water retention and soil texture as key parameters for soil quality for three stages of land abandonment (5–10 years, 25 and 40 years after abandonment).

The results show that vegetation succession significantly influenced most of the measured soil parameters, and consequently soil quality. When vegetation had a longer succession period the SOC contents and stock increased significantly ($P < 0.05$) between age group 0 and age group 3. The lowest SOC contents were found for age group 0, which is probably due to the negative effects of agriculture on SOC contents, which is a general observation in literature (Post and Kwon, 2000; Deng et al., 2016). Significantly ($P < 0.05$) higher SOC contents were found for the samples of age group 1, confirming results found by Jiao et al. (2011) where conversion from farmland to natural grassland caused an increase of 18% soil organic matter. Liu et al. (2002) found a linear relation for the increase in soil's SOC and TN with years since reforestation or natural succession as well as Foote and Grogan (2010) and Novak et al. (2014). Other literature indicated only a linear increase during the first decades (Knops and Tilman, 2000; McLauchlan, 2006) or the establishment of perennial vegetation (Post and Kwon, 2000) or even a decay after 2 decades (Jia et al., 2005). However, the SOC stocks were relatively high and ranged between 40 and $80 \text{ t} \cdot \text{ha}^{-1}$ (based on individual plots), considering that only the upper 10 cm was studied here. On average the SOC stock increased from $26 \text{ t} \cdot \text{ha}^{-1}$ to $58 \text{ t} \cdot \text{ha}^{-1}$ for the upper 10 cm of the soil, which is much higher than reported elsewhere. The data suggests that the SOC stock can be doubled within a few decades after abandonment. The period covered by the different age classes is however too short to estimate the relative saturation for carbon, which should need observations of at least 2 centuries (Knops and Tilman, 2000). Boix-Fayos et al. (2009) reported changes under semiarid conditions up to 71% in SOC and the difference with our results could possibly be explained by the more humid climate in Slovenia. However, Del Galdo et al. (2003) reported even lower increases for a humid area in N Italy.

TN was also significantly ($P < 0.05$) influenced by vegetation succession. Similar to the results found for SOC the lowest contents were found for age group 0, which is caused by agricultural practices (García-Orenes et al., 2009). Significantly ($P < 0.05$) higher contents are found for age group 1, 2 and 3, which is in line with the results of Dunjó et al. (2003); Liu et al. (2002) and Foote and Grogan (2010).

On average bulk density decreased from ca $1.3 \text{ g} \cdot \text{cm}^{-3}$ to $1.0 \text{ g} \cdot \text{cm}^{-3}$. Li and Shao (2006) also found a decrease in bulk density for a dryland soil on a time sequence from arable to forested soils on

Table 2pH and texture of the studied locations (mean $\pm$ standard deviation). Different letters indicate significant differences between age groups.

Soil property	Aspect	Age group 0	Age group 1	Age group 2	Age group 3
pH _{H2O}	N	5.57 $\pm$ 0.80 b	6.61 $\pm$ 0.36 a	6.63 $\pm$ 0.39 a	7.07 $\pm$ 0.35 a
	S	7.18 $\pm$ 0.20 a	7.26 $\pm$ 0.20 a	7.22 $\pm$ 0.27 a	7.36 $\pm$ 0.28 a
Mean grain size D ₅₀ (μ m)	N	87.14 $\pm$ 4.19 a	97.37 $\pm$ 7.04 a	90.58 $\pm$ 4.58 a	96.60 $\pm$ 7.83 a
	S	90.64 $\pm$ 5.18 a	99.96 $\pm$ 7.85 a	94.87 $\pm$ 4.27 a	94.55 $\pm$ 4.80 a

the Loess Plateau in China. The high bulk density found for age group 0 could be influenced by compaction of the soil as a result of the use of agricultural machinery (Zhang et al., 2010). Beside the influence of by vegetation succession on bulk density this could also be due to the changes in SOC, since decreases in SOC cause increases in bulk density (e.g. Rawls, 1983; Soane, 1990; Arvidsson, 1998; Li and Shao, 2006). A negative correlation ($r^2 = 0.48$; $P < 0.001$) was found between bulk density and SOC. It can be expected that biological activity increases in the soil as a response to increasing organic matter inputs, which enhances porosity and consequent soil bulk density. Total available water did not change over time, which was not expected, as bulk density also changed over time and some literature also reported an increase in water holding capacity over time after abandonment (e.g. Dunjó et al., 2003).

Aggregate stability showed a considerable variation within the different conditions, and this might explain that the difference was only found to be significant between S facing slopes of age group 0 and 3. A trend of increasing aggregate stability as succession proceeds can however be observed, confirming results found by others (e.g. Cammeraat and Imeson, 1998; Cerdà, 1998; Cheng et al., 2015; Qiu et al., 2015; Erktan et al., 2016). The positive correlation ($P < 0.001$) between SOC and aggregate stability could also explain the changes in aggregate stability since increasing SOC in soils induces soil aggregation (Cerdà, 1998; Hugar and Veena, 2014).

5.2. Impact of slope exposition on soil quality

The impact of slope aspects is clear for many of the studied soil quality indicators. Aspect had a significant ($P > 0.01$) effect on SOC contents. At the semi-mature stage of the forest (age group 3) SOC was significantly higher at the N exposed slopes. However higher SOC contents were found on S facing slopes for age group 1 and 2 than on N slopes, but did not increase after age group 2. This could be caused by the

type and stage of vegetation development, since natural shrublands have higher SOC contents than reforested land (Liu et al., 2002) and it might indicate that already a steady state had been reached. SOC contents of age group 3 on N slopes however, were significantly ($P < 0.05$) higher than of age group 2. Higher SOC levels are generally attributed to lower soil temperatures and higher soil moisture. Previous research in the Dragonja catchment found higher soil moisture on N facing slopes (van der Tol et al., 2008). However the relationship between slope exposition and SOC contents varies in literature, with reports of higher SOC contents at N slopes (Begum et al., 2010), no difference (Måren et al., 2015) or less SOC (Sidari et al., 2008) and indicates that processes are complicated needing further more detailed research. The change in SOC on S exposed slopes was faster during the first phases of succession, between age group 0, 1 and 2, whereas for the N slope SOC increased slower in these age groups which might be comparable to the trends as found by Novak et al. (2014) in Hungarian vineyards, where S exposed slopes had faster SOC increase, which would be related to the more dry conditions and associated reduced mineralization of organic matter.

Looking at the SOC stocks, in which also changes in bulk density are incorporated, N facing slope SOC stocks increased 145%, thereby improving soil quality slightly more than on S facing slopes, where SOC increased 105%. However there was no difference in the SOC stock development over the whole period studied between both aspects (Fig. 3).

Aspect furthermore significantly ($P < 0.05$) influenced TN contents with higher contents on S facing slopes, as also found by Huang et al. (2015) who looked in more detail into the effect of exposition on the presence of different N-species and concluded that mineralization of N is most sensitive to slope aspect.

For S slopes bulk density decreased significantly ($P < 0.05$) between age group 0 and 2. For N slopes the bulk density was significantly ($P < 0.05$) lower for age group 3 compared to age group 0 and 2. On N facing slopes bulk density decreased 25%, having slightly more influence on soil quality than S facing slopes. This indicates a slower response as also was observed for SOC. This is also reflected in the increase field capacity (pF 2.2) at N slopes which is the result of the development of larger pores, which pattern is not present for the S slopes. Available soil water did not change significantly over time, but was significantly higher on N than on S exposed slopes. Martínez-Fernández et al. (1995) and Li and Shao (2006) found similar results showing that field capacity did change over time but not total plant available water. Geroy et al. (2011) found that N facing slopes had approximately 25% higher water retention capacity, which combined with reduced solar insolation caused higher soil moisture. Van der Tol et al. (2008) found that N facing slopes had higher available soil moisture in the same area. This was also reflected in their observation of the transpiration of the full grown forest where transpiration followed soil moisture availability, and which was clearly higher on the N exposed slopes, at least for most of the dry season, except for the very dry stage in the late dry season, when S exposed slopes had a slightly higher transpiration, but at very low levels. We expect that these micro-climatological differences also influence biomass production and hence can at least partly explain the differences found in soil quality indicators between our studied slope aspects. Soil aggregation did not differ between slope exposition, only over time. Apparently the SOC turnover and conversion during vegetation succession did not have a significant effect on binding

Fig. 7. Volumetric water content at pF 2.2, pF 4.2 and total available water.

processes, which was not expected as soil moisture status rules mineralization and microbial processes important for the formation of binding agents within soil aggregates such as glomalin (Rillig et al., 2003). It is also not confirming the results reported in Cammeraat and Imeson (1998) who reported a better aggregation on N and W exposed slopes for both bare soil and under grass tussocks in a semi-arid environment.

Infiltration rates were very high suggesting that overland flow only occurs under extremely high rainfall intensities and durations, and that most drainage occurs through the soil.

6. Conclusion

The aim of this study was to provide insights on the role of vegetation succession on change of soil quality in response to land abandonment.

How vegetation succession influences soil quality is dependent on which factors you assess. However, we could state that vegetation succession in response to land abandonment positively influenced soil quality since SOC and SOC stock, TN and aggregate stability increased whereas bulk density decreased.

- SOC, TN, bulk density, and aggregate stability were significantly ($P < 0.05$) influenced by the stage of vegetation succession. For SOC and TN, significantly ($P < 0.05$) higher contents are already found after the first 10 years and gradually leveled off over time.
- Water retention and soil texture did not change significantly between the different age groups over time.
- Water retention does, however differ between N and S facing slopes with a higher field capacity and bulk density on N facing slopes. SOC and TN were also significantly ($P < 0.05$) influenced by aspect, with respectively 27%, and 26% higher contents.
- S slopes responded faster in comparison to N slopes with regard to the improvement of soil. This means that the first phase of vegetation succession with herbs and grasses had a larger initial impact on soil quality change than during the later phase of forest development.
- We can conclude that set aside or abandonment is an effective land use change to improve and restore soil quality, to maintain or improve soil hydrological functioning and to sequester SOC.

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