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Modelling soil erosion reduction by *Mahonia aquifolium* on hillslopes in Hungary: The impact of soil stabilization by roots

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ABSTRACT

Agricultural activities on hillslopes often cause soil erosion and degradation. Permanent vegetation strips on cultivated slopes could be an effective soil conservation technique to reduce erosion. Previous studies showed that cultivated *Mahonia aquifolium* can be an effective plant for water erosion control. However, no detailed studies have been carried out to evaluate the efficiency of *M. aquifolium* as a permanent vegetation strip. The objective of the present study is to evaluate the effectiveness of *M. aquifolium* strips on soil erosion control under various bio-physical conditions with the use of the Revised Morgan–Morgan–Finney model (RMMF). The RMMF model was first calibrated by using measured quantities of surface runoff and validated against soil loss data from *M. aquifolium* plots. After calibration the model showed erosion to be transport limited process for all *M. aquifolium* plots and a detachment limited for the bare soil control plot. The model was then used to predict surface runoff and soil loss for various soil types, slope angles and cultivations with and without *M. aquifolium* strips. The study indicated that the presence of *M. aquifolium* strips substantially reduced the soil loss rate on all studied crop fields. For steeper slopes with *M. aquifolium* strips the model predicted a lower soil loss rate than for gentle slopes without strips.

1. Introduction

In Hungary there is a total of 5.5 million ha of agricultural land and 47% of this is classified as private farm lands with a typical farm size of 3 ha (KSH, 2011). About 80% of the country's horticultural plant production is linked to these private farm holdings (Szabo, 2007). Soil erosion affects about 30 to 40% of the land in Hungary (Centeri et al., 2001). The majority of soil loss is linked to the hilly regions of the country affecting 1.3 million ha of land (Kertesz and Loczy, 1996). Conventional agricultural activities are often the main cause of soil degradation on hillsides (Heuser, 2010).

Due to soil erosion, the fertility of soil decreases and leads to the need for additional fertilization of cultivated lands which in turn creates an additional cost to farm inputs (Centeri et al., 2009). Small scale farm owners can rarely factor the costs of soil conservation into their farming budget due to a lack of profit (Centeri et al., 2009). When soil erosion occurs on small-scale farms the resulting reduction in cultivatable soil often leads to land abandonment. Appropriate plant selection with suitable cultivation and soil conservation techniques on hillslopes can result in a decrease in soil loss and an increase in available water in the soil, thereby allowing and encouraging continued agricultural activity (Myers and Wagger, 1996).

Mahonia aquifolium (Push) Nutt has been cultivated in Hungary for decades primarily for its cut green foliage (Hudek and Rey, 2009). The harvest of the foliage takes place during autumn and winter, and involves the removal of the entire canopy. The dense foliage plays a significant role in raindrop energy reduction, but after harvest its root system provides the only protective function against soil loss (Hudek et al., 2010). Roots increase the resistance of the soil by improving its mechanical and hydrological properties (e.g. Gray and Sotir, 1996; Styczen and Morgan, 1995). Plant roots improve soil structure and increase the soil's organic matter content (Angers and Caron, 1998). Roots can increase surface roughness and increase infiltration capacity thus reducing the volume and velocity of surface runoff (Reubens et al., 2007). The tensile strength of roots as well as their adhesive properties help to reinforce the soil and reduce soil erosion (Greenway, 1987; Stokes et al., 2008; Van Beek et al., 2008). The most effective root system for soil erosion control is a dense root network with a large number of fine roots close to the soil surface (Bischetti et al., 2005; Gyssels et al., 2005; Reubens et al., 2007; Wu, 1976).

In a previous field study (Hudek et al., 2010) the root system of cultivated *M. aquifolium* was found to be well suited for shallow soil stabilization from an early age. In Hudek et al. (2010) the *M. aquifolium* root study showed that a cultivated plant (ploughing, fertilization, weed and disease control are applied) has in general a well developed, dense, lateral and sinker root system, and the densest root area ratio (0.04%) in the top 0.05 m soil layer where the soil is generally weakest. The study (Hudek et al., 2010) also showed that the mean number of

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roots and the root area ratio (RAR) were significantly higher for cultivated *M. aquifolium* plants compared to non-cultivated (ploughing, fertilization, irrigation, weed and disease control are neglected) ones. A gradual decrease in the mean number of roots and RAR by depth was also observed. However, there was no significant difference found between the root tensile strength (T_R) of cultivated and non-cultivated *M. aquifolium*. In addition to the root data, surface runoff and soil loss data were collected from the experimental plots with cultivated *M. aquifolium* (Hudek and Rey, 2009). A detailed description of the plots can be found in Section 2.1 together with their results in Section 3.2 and Table 3. Those data were collected with the intention of testing the impact of *M. aquifolium* on slope stabilization. The field study confirmed the effectiveness of cultivated *M. aquifolium* on water erosion control (Hudek and Rey, 2009).

In addition to its suitability for soil protection, *M. aquifolium* can provide income to small-scale private farm owners, improving the long-term economic strength of these hillslope farms and consequently help prevent or reduce ongoing land abandonment. The crop value per ha in Hungary varies widely, e.g., almond is approximately 9000 EUR per ha, sour cherry is 3700 EUR per ha (Apáti, 2009) and cereal is about 2000 EUR per ha (Avar, 2013). The value for *M. aquifolium* as a cut green foliage per ha starts from 5700 EUR. Data on plant value for herbal or medicinal purposes was not accessible. However the demand for herbal plants is growing worldwide at an estimated rate of 10–15% per year (IFAD, 2008). Non-traditional horticultural crops generally involve a higher level of risk than traditional crops that already are well known in the market. But they have a higher economic return per unit area compared to traditional crops (IFAD, 2008). Small-scale farms are generally at a disadvantage when compared to larger farms in the wholesale market. Most successful small-scale farms choose to market their product directly to consumers and farmers may have to develop their own customer base. Small-scale farms are more sensitive to extreme price swings however; in the case of *M. aquifolium* this risk is lower as the plant can be marketed for numerous purposes e.g. ornamental, herbal medicine, natural colorant, alimentation. As *M. aquifolium* can provide a more stable source of income for farmers thus can reduce the risk of land abandonment which consequently would decrease the risk of soil degradation of hillsides.

The use of permanent vegetation strips between crops on cultivated slopes is an effective way to trap runoff and sediment and reduce the risk of soil as well as agro-chemicals escaping from farmlands and polluting the off-site environment (Biamah et al., 1993; Mickovski et al., 2005). In this study it is hypothesized that contour strips of *M. aquifolium* on sloping agricultural fields are an effective method to control surface runoff and to reduce soil loss. Building on the empirical evidence gathered at the erosion plots, a modelling approach was applied to evaluate the efficiency of *M. aquifolium* under various bio-physical conditions on reducing soil erosion. In light of the overall scarcity of data, the application of a soil erosion model to predict soil loss and surface runoff from small-scale farms provides an efficient means to explore, for both farmers and soil conservationists alike, the suitability of erosion control measures and to develop strategies. It makes more sense from a logistics point of you as field experiments are expensive and time consuming.The model can help simulate soil loss and runoff results of the farm under different cultivation techniques and can help the farmer choose the optimal cultivation technique from an environmental and economical point of view. Model simulations provide immediate information on the combination of different plant selection and cultivation techniques which allow farmers to strike a balance between environmental, farm sustainability and economical viability (e.g. before establishment of vegetative filter strips we can see a potential costs vs. benefit so as to make an informed decision on future farming practice). Data availability and prediction accuracy of models are among the most important factors for model selection (Moehansyah et al., 2004). Robustness and a strong physical basis are also important if a model is to be applied to different conditions.

Various erosion models (e.g. USLE, EUROSEM, WEPP) have been successfully applied in Hungary to predict soil loss and surface runoff from cultivated hill-slopes (Centeri et al., 2009). However, despite previous field studies on *M. aquifolium* cultivation (Hudek and Rey, 2009; Hudek et al., 2010) a limited amount of input data for model applications is available and a parsimonious model was sought which could estimate the annual soil loss from a field-size hillslope with limited available field data. Hence, the Revised Morgan–Morgan–Finney model (RMMF) was selected for this study. The RMMF is an empirical model with a relatively strong physical basis. It requires little input data, is easy to understand and apply, and has already been effectively used in different environments (e.g. Lopez-Vicente et al., 2008; Morgan, 2001; Shrestha et al., 2004; Vigiak et al., 2005).

A limitation of the RMMF model is that it does not include the impact of plant roots on soil erodibility. Yet, numerous studies have shown that plant roots notably increase the soil's resistance to erosion (e.g. De Baets and Poesen, 2010; De Baets et al., 2007; Gyssels et al., 2005). In those model studies, in which the effect of roots (grass mixture and carrot) was quantified (e.g. De Baets and Poesen, 2010; De Baets et al., 2008), the model equations were based on extensive laboratory datasets. But even in the absence of such detailed datasets, there is a need for the inclusion of a simple, yet effective parameterization of root effects in erosion models. The RMMF model incorporates the effects of vegetation both on the water and the sediment phase of erosion processes exclusively in terms of the above ground biomass. Infiltration is implicitly

Table 1
Soil texture, organic carbon (OC), total N (TN), soil C:N ratio and soil organic matter (SOM) and calcium carbonate ($CaCO_3$) results from the experimental plots at Tyúkosdűlő in Szentendre, Hungary.

Soil properties	Units	M4	M12	M20	M25	CBS
Physical						
<2μ	g kg−1	303	239	387	315	340
2–20μ	g kg−1	141	113	168	151	129
20–50μ	g kg−1	106	84	135	107	109
50–200μ	g kg−1	190	246	139	161	183
200–2000μ	g kg−1	258	317	169	266	236
Chemical						
OC	g kg−1	13.60	14.70	14.60	14.60	16.10
TN	g kg−1	1.22	1.30	1.32	1.35	1.48
C:N	ratio	11.13	11.37	11.07	11.10	10.83
SOM	g kg−1	23.53	25.56	25.36	25.37	27.90
$CaCO_3$	g kg−1	<1	<1	<1	<1	<1

4 year old cultivated *M. aquifolium* plot (M4), 12 year old cultivated *M. aquifolium* plot (M12), 20 year old cultivated *M. aquifolium* plot (M20), 25 year old cultivated *M. aquifolium* plot (M25) and control bare soil plot (CBS).