SOIL EROSION RISK AND AGROFORESTRY IMPLEMENTATION IN TUSCANY: LOCATING BEST PRACTICES FOR VULNERABILITY MANAGEMENT WITH A GIS-BASED SCENARIO APPROACH

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Abstract

In the Mediterranean basin, water soil erosion is increasing by extreme rainfall events. Agroforestry practices could reduce erosion risk by enhancing soil cover. The aims of this study are to (i) model the potential erosion risk of the cropland of Tuscany Region and (ii) classify silvoarable practices to be implemented for reducing the risk. A GIS-based assessment was carried out to classify agroforestry support practices needed to keep erosion risk under a sustainable threshold (11 Mg ha^{-1} yr^{-1}). In the most part of cropland (58.7%) P-factors ranged from 0.99 to 0.1, thus alley cropping and multi-storey practices could maintain erosion risk under the threshold. Agroforestry practices combined with contour farming are suggested where the erosion risk is higher ($P < 0.1$, 12.4% of cropland). Overall, the implementation of agroforestry practices on total cropland surface could prevent the loss of about 69.5 Mg ha^{-1} yr^{-1} of soil at regional scale.

Keywords: silvoarable; soil loss; perennial crops; RUSLE

Introduction

In the Mediterranean region the increased frequency of extreme precipitation events leads to the increase of soil erosion risk due to the higher rainfall erosivity (Panagos et al. 2015a).

In Tuscany, Central Italy, rainfall erosivity shows high values due to the precipitation pattern (Borrelli et al. 2016) and soil erosion risk is increased by the prevalence of annual crops on arable land (ISTAT 2010). In fact, only 18% of the arable land is covered by temporary grasslands and perennial crops such as alfalfa or other meadows, that are able to enhance soil protection by a better soil coverage and a reduced tillage requirement, compared to annual crops.

Agroforestry systems - "the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions" - can reduce soil erosion risk by enhancing cover-management factor (Palma et al. 2007). Based on this, the aims of this study are to: (i) model the potential erosion risk in Tuscany Region and (ii) classify silvoarable practices to reduce erosion risk under a recommended threshold.

Materials and methods

The study area included the arable land of Tuscany Region (593,464 ha), identified using the last version of a land-use map produced by the regional administration (Regione Toscana 2015). The map is composed by 121,959 polygons for irrigated and non-irrigated arable land (class 211 and class 212, respectively). Land-use data from the 2010 national census (ISTAT

2010) was used to assess the current partition of arable land into areas cultivated with different crops (Table 1). The coastal area of the region is characterized by the presence of winter cereals, industrial crops and maize-based cropping systems, whereas the inland hilly areas are covered by extensive grazing systems, mainly based on the presence of cool-season annual grasses and legumes.

For the aims of this study, a GIS-based assessment was implemented using the Revised Universal Soil Loss Equation (RUSLE, Renard et al. 1997) in which soil losses are calculated as in Eq.1:

Eq.1 – Revised Universal Soil Loss Equation:

$$A = R \ x \ K \ x \ LS \ x \ C \ x \ P$$

Where: *A* is the soil loss expressed as megagrams per hectare and year (Mg ha^{-1} y^{-1}); *R* is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} y^{-1}) extrapolated from the map proposed by the JRC-EU (Panagos et al. 2015a); *K* is the soil erodibility factor (Mg h MJ^{-1} mm^{-1}) calculated as reported by Vallebona et al. (2016), using the soil map of the Tuscany Region; *LS* is the slope length and steepness factor (dimensionless) derived using the algorithm proposed by Desmet and Govers (1996), computed using System for Automated Geoscientific Analyses (SAGA 2014) software and data from high-resolution (10 m) Digital Elevation Model (DEM) of the Tuscany Region; *C* is the cover management factor (dimensionless) calculated as weighted average of 11 different *C*-factors for all the crops or crop categories cultivated in Tuscany as reported in Table 1.

Table 1: C-factor for all the crops or crop categories cultivated in Tuscany used in the study.

Crop (or crop category)	**UAA* (ha)**	**% (on total arable land)**	**Crop C-factor**	
Wheat	122143	25.74%	0.20	Panagos et al. 2015b
Other cereals	29467	6.21%	0.20	Panagos et al. 2015b
Corn	13718	2.89%	0.38	Panagos et al. 2015b
Sunflower	18549	3.91%	0.32	Panagos et al. 2015b
Other industrial crops	11326	2.39%	0.30	Panagos et al. 2015b
Vegetable	10097	2.13%	0.34	Panagos et al. 2015b
Annual forage crop	69327	14.61%	0.30	Vallebona et al. 2016
Alfalfa	47412	9.99%	0.03	Vallebona et al. 2016
Other meadow	36505	7.69%	0.04	Vallebona et al. 2016
Pulses	17057	3.59%	0.32	Panagos et al. 2015b
Set-aside	98996	20.86%	0.22	Bazzoffi 2007

*UAA = Utilized Agricultural Area

In this study, erosion was estimated with *P*-factor = 1. Then, considering the maximum erosion limit (L) of 11 Mg $ha^{-1}yr^{-1}$ proposed by USDA Soil Conservation Service (1973), we estimated the *P*-factor values of the best agroforestry practices (*P*-bp) needed to keep the erosion risk under the proposed threshold.

Based on this, the estimated P-factor values were classified in three classes: (1) *P*-bp = 1, (2) 0.99 > *P*-bp > 0.1 and (3) *P*-bp < 0.1. The relative best agroforestry practices for the management of erosion vulnerability were associated to *P*-bp ranges according to Delgado and

Canters (2012): (1) border planting of trees or live-fencing (very low risk to low erosion risk); (2) alley cropping and multi-storey cropping (intermediate erosion risk) and (3) hedgerow contour planting (high to very high erosion risk). The soil loss mitigation rate was calculated as the difference between the average A and L value in each class.

Results and discussion

In the arable land of the study area, the R-factor ranged from 954 to 2,741 MJ mm h^{-1} ha^{-1} y^{-1}, similarly to what reported by Borrelli et al. (2016) in a national-scale study. The K-factor ranged from 0.015 to 0.044 (Mg h MJ^{-1} mm^{-1}), while the LS-factor showed the largest variation ranging from 0.001 to 103.64. The weighted average C-factor was equal to 0.21 due to the high presence of winter cereals in Tuscany, covering about 25% of the arable land (Table 1). The average soil loss rate ranged from 3.6 to 221.3 in class 1 and class 3, respectively (Table 2). Regarding support practices, the results of the study allowed to identify classes of agroforestry practices to keep the erosion risk under the threshold (11 Mg $ha^{-1}yr^{-1}$) as reported in the Table 2.

Table 2: Results of the estimation of erosion risk classes and P-factor values.

Class	Erosion risk	Average soil loss rate* (Mg ha-1 yr-1)	Soil loss range (Mg ha-1 yr-1)	Soil conservation requirement	Best agroforestry practices	P-bp factor range	Surface (ha)	Class frequency
1	very low to low	3.6	≤ 11	Conserve soil nutrients and fertility	Border planting of trees or Windbreaks	= 1	171,575	28.9%
2	Intermediate to high	38.6	11 - 110	Reduce erosion	Alley cropping and Multistorey cropping	0.99 - 0.1	348,311	58.7%
3	Very high	221.3	> 110	Stabilization of slopes and maintenance of ground cover to reduce soil erosion	Hedgerow contour planting of trees	< 0.1	73,577	12.4%

* Soil loss calculated using RUSLE Model and P-factor = 1

In particular, about one third of the cropland of the Tuscany Region was characterized by a low erosion risk with soil loss ratio under the recommended threshold (*P*-bp =1). These areas are mainly located in the coastal zone of the region and in the inland plain areas (Figure 1).

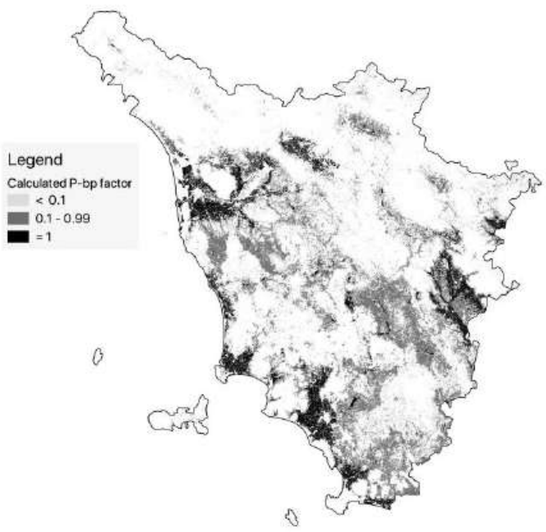

Figure 1: Map of the *P*-bp factor classes location in Tuscany Region.

In this case, agroforestry systems could contribute to conserve soil fertility and to reduce nutrient leaching by the implementation of silvoarable practices as windbreaks or border planting. However, the majority of the regional cropland (58.7%) showed *P*-bp ranging from 0.99 to 0.1, thus needing support practices to cope with an intermediate to high soil erosion risk. This class is mainly present in hilly inland areas due to their geomorphological characteristics that lead to higher vulnerability to water erosion. Thus, the introduction of alley cropping and multi-storey practices could be useful to maintain the soil loss risk under the recommended threshold in the hilly land of Tuscany Region. The area characterized by a very high risk (*P*-bp < 0.1) of erosion covers 12.4% of the investigated study area and it requires support practices to strongly reduce the soil loss, in order to stabilize and maintain slopes. In this case, agroforestry practices are more effective in increasing soil protection when combined with contour farming, as reported by other authors (Palma et al. 2007). The implementation of suggested agroforestry practices could prevent the loss of about 69.5 Mg Ha^{-1} Yr^{-1} of soil, calculated as the weighted average of potential mitigation rates of each proposed class.

Conclusion

In Tuscany, about 71% of the arable land suffers from intermediate to very high water erosion risk. Thus, the implementation of agroforestry practices, such as alley cropping and contour planting, should be encouraged in order to maintain the erosion risk under a tolerable soil erosion threshold. The potential soil loss could be reduced of about 69 Mg Ha^{-1} Yr^{-1} adopting appropriate agroforestry systems on about 422,000 ha of cropland, where the erosion risk is higher. To facilitate this process, regional policy-makers and advisors should be made aware of the potential ecosystem services provided by silvoarable systems through increased innovation transfer and networking activities.

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