

We thank the **Anonymous Referee #1** for his comments and suggestions. We are grateful for interesting suggestions allowing for manuscript improvement.

Anonymous Referee #1

The manuscript describes an application of RUSLE model in order to evaluate the impact of wildfire and mitigation strategies on soil losses.

The topic is particularly interesting and manuscript is well organized and pleasant to read.

Following the interesting Cerdà's comment I would invite the author to give more emphasis on the model application and parameter calibration respect to the results discussion. Indeed general conclusion, as already underlined by the authors, are not possible due to the limited available observations.

Authors:

The authors acknowledged the Professor Cerdà comments and suggestions.

In the introduction a paragraph has been added discussing the post fire natural recovery in the Mediterranean areas.

1. Introduction

Forest fires in Mediterranean area are natural processes due to the mutual interactions between climate and vegetation, forging the biodiversity typical of this ecosystem (e.g. Ursino and Rulli, 2011; Pausas and Paula, 2012). During the last decades the number, extent and severity of forest fires in the Mediterranean countries increased as a result of abandonment of agricultural lands, inadequate forest management, long seasonal droughts, environmental disturbances, human activities (e.g. Soulis et al., 2010; Rulli et al., 2006; Shakesby, 2011) leading to the alteration of natural fire regime. Consequently, areas usually experiencing frequent low severity fires are now hit by less frequent high severity fires, and other areas, adapted to high severity fire, are now subjected to an increase in fire frequency (Fulé et al., 2008). As a result, the mediterranean ecosystem is reducing its resilience to fire. Appropriate mitigation strategies can reduce the negative consequences of fire through a deep comprehension of fire effects and sustainable coexistence with forest fires, in terms of both human security and ecological processes (Pausas and Verdù, 2008).

Fire effects consist on direct damage of vegetation and alteration of physical and chemical soil properties, which in turn affect the hydrological response and sediment erosion and transport (e.g. Moody et al., 2008; Andreu et al., 2001). In particular, both runoff and even more erosion in the first year after fire occurrence often increases by several times compared to natural conditions (Rulli and Rosso, 2005). Measurements taken in the Sila Massif in Calabria (Italy) showed an 87% increase in runoff on areas recently burned compared to non burned areas (Terranova et al., 2009), and rainfall simulations in Liguria (Italy) showed post-fire overland flow and sediment yield respectively one and two orders of magnitude higher in a recently burnt site than in a long unburned site (Rulli et al., 2006).

Although the association among wildfire, flooding, increase in erosion and sedimentation has been observed all over the world (e.g. Benavides-Solorio and Mac Donald, 2005; Cerdà, 1998; Emmerich and Cox, 1994; Shakesby, 2011; Terranova et al. 2009), post wildfire research, especially regarding fire induced erosion enhancement, has a relatively brief history in the Mediterranean, starting from about the early 1980s (corresponding to the dramatic increase in fire activity) (Shakesby, 2011).

Burn severity has been identified as one of the most important variables affecting post fire changes in runoff response and soil losses (e.g. Fox et al., 2008). From low to high burn severity, the effect on erosion may vary from more than two orders of magnitude to only sevenfold, or no difference (Shakesby, 2011). Besides burn severity, many other factors concur in controlling post-fire runoff and erosion. Among these are loss of organic matter (e.g. Soto and Diaz-Ferros, 1998), increase of

bulk density (Neary et al., 2005), reduction of soil porosity and infiltration capacity (Robichaud et al., 2010), increase of soil water repellency (e.g. De Bano, 2000; Doerr et al., 2009). Other important factors are rainfall intensity, slope and aspect, antecedent soil moisture (Wischmeyer and Smith, 1978), soil aggregate stability (Fox et al., 2008), grade of soil water repellency (Keizer et al., 2008), and the time interval between the fire episode and the occurrence of rainfall (Rulli et al., 2006). Univariate analysis conducted on sediment yields in Colorado Front Range burned hillslopes showed that about 77% of the variability in post fire erosion rates is explained by five main factors: fire severity, bare soil percent cover, rainfall erosivity, soil water repellency and texture. Among these, bare soil percentage and rainfall erosivity alone explained 66% of variability in soil loss measurements (Benavides-Solorio and Mac Donald, 2005).

Strategies for watershed post fire rehabilitation are mainly aimed to restore soil cover and infiltration capacity and to reduce sediment detachment and downslope sediment transport (e.g. Fernández et al., 2010; Myronidis et al., 2010; Neary et al., 2005; Robichaud et al. 2010; Wohlgemuth et al., 2009) therefore acting mostly on soil characteristics like soil vegetation cover, erodibility, permeability or infiltration capacity.

There are many different mitigation strategies, which are suitable for diverse situations, and whose results depend on when, how and where they are applied (Wohlgemuth et al., 2009). Most of ecosystems are adapted to the fires and the recovery is done by nature. Cerdà and Doerr (2005) show how the recovery of the Mediterranean lands can be done without any human interference, observing during their 11 years field campaigns a time of 2-4 years for the recovery. Moreover, on the immediately post-fire the presence of ash, especially when covered with needles, can control and mitigate the soil losses protecting the soil from rainfall erosivity (Cerdà and Doerr (2008). Nevertheless, the rainfall regime characterized by heavy intensity rainfall occurring right after the fires season in some of the Mediterranean areas (e.g. Liguria, Tuscany, Sicily, etc.), the high spatial and temporal variability of rainfall and its associate hydrogeomorphological response and the occurrence of the fires at the rural-urban interface can require prompt post fire erosion reduction treatments.

Post fire treatments may be applied to hillslopes, channels and roadways.

Treatments used on hillslopes can be divided in three main types: mulch treatments, erosion barriers and chemical treatments (Neary et al., 2005; Robichaud and Elliot, 2006). Hillslope treatments are designed to avoid sediment delivery to downstream water bodies and they are considered to be the most useful (Robichaud 2010). Wagenbrenner et al. (2006) observed ground cover greatly influencing sediment production, meaning that the better performing treatments will be those immediately increasing the amount of ground cover and facilitating vegetative regrowth. Among these, mulch treatment is considered as one of the most effective watershed rehabilitation treatment, consisting in spreading mulch on burned slopes, to provide soil surface cover prior of vegetation regrowth. It produces soil protection from rain splash detachment and soil stabilization (Robichaud, 2007b; Wohlgemuth et al., 2009). For this purpose, several materials can be used: dry straw or wood-based mulches, wet mulches (hydromulch) mixed with water to form a slurry (Neary et al., 2005). Post-fire mulching needs to provide 60-80% ground cover to reduce hillslope erosion (Robichaud et al., 2010). Some problems can arise by using this technique consisting in mulches slopes slipping down, aerially spread mulches residual vegetation interception, so reducing the actual ground cover and potential effectiveness (Neary et al., 2005; Robichaud et al., 2010).

Erosion barriers are commonly placed in a way to capture sediments and interrupt long flow paths, so decreasing downslope shear stress soil erosion and sediment transport on hillslopes and into streams. Erosion barriers can be contour-felled logs, straw wattles, contour trenches, straw bales (Neary et al., 2005). A barrier treatment performance can be defined as the ratio of dry weight of sediment stored by the barrier and dry weight of collected sediment below the barrier. Erosion barriers present some weakness reducing runoff and soil loss for low intensity rain events, but do not achieve significant results for high intensity events. In addition, the capacity of barriers can be

overtopped soon after the first rain events, so determining the uselessness of not cleaned off barriers (Robichaud et al., 2010).

Rehabilitation treatments like ploughing or tilling on croplands burned areas are usually used to decrease soil aggregation and to break up the fire-induced water repellent soil layer to restore drainage capacity (Keizer et al., 2008).

Channel rehabilitation after fire is primarily done by cleaning channel beds and preventing obstruction of streams. The main treatments for these purposes are check dams or debris basins, debris clearing and streambank armoring (Neary et al., 2005).

Even if fire does not directly affect the road drainage system, the increased overland flow can overwhelm its capacity. Mitigation measures as waterbars and bypasses, culvert improvements, ditch cleaning and armoring can enhance road drainage system functionality.

Despite the observation of large post fire increase in soil losses in the Mediterranean area (e.g. Shakesby, 2011 and the references herein) analysis of the efficiency of post-fire erosion mitigation strategies are very scarce. Field studies assessing the effectiveness of mulching and barriers were carried out in Spain (e.g. Badia and Martí, 2000; Bautista et al., 2009; Fernández et al., 2011) and in Portugal (Ferreira et al., 2009), but a systematic analysis at basin scale for the Mediterranean area is still lacking.

Given the complexity of fire-related issues, and the importance of fire effects on watershed response and erosion dynamics, accurate predictions of post-fire runoff and sediment yields are needed to guide management decisions, mitigate post-fire soil loss and land degradation and for post-fire rehabilitation planning (Fernández et al., 2010). Land use changes impact on soil losses prediction has been carried out by using different kind of modeling depending on study area extent, data availability and output degree of accuracy required. The Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995) and the disturbed-WEPP (Elliot et al., 2001) are process-based erosion prediction models evaluating mean erosion rate in natural and disturbed condition. ERMiT (Robichaud *et al.*, 2007a) is a probability-based erosion prediction model using multiple runs of WEPP model and developed to predict surface erosion from postfire hillslopes, and to evaluate the potential effectiveness of various erosion mitigation practices. Empirical models based on the Revised Universal Soil Loss Equation (RUSLE) were used by several authors (e.g. Terranova et al. 2009, Fernández et al. 2010 and Ranzi et al., 2012) to account for forest fire and land use changes effect on erosion in large scale basins. A fully distributed hydro-geomorphological model was developed by Rulli and Rosso (2005; 2007) for analyzing both the hydrological and erosion and deposition process dynamics for both natural and disturbed basin condition, focusing in particular on post fire erosion process in Mediterranean ecosystem.

This paper investigates first year post fire erosion mitigation strategies effectiveness through a distributed model based on the Revised Universal Soil Loss Equation properly parameterized and validated, by using field measurements and literature data, for a Mediterranean basin located in Sardinia, Italy. Soil losses corresponding to six different scenarios are analyzed through appropriate RUSLE parameters changes so describing the particular soil treatment to which the study area is subjected. In detail, the amount and spatial distribution of soil losses under natural condition, burned, after tilling/ploughing treatment, after mulching treatment, with barriers and after a combination of the all treatments are examined.

Anonymous Referee #1

In the following specific comments are listed.

Abstracts

lines 17-19. This sentence can be clearer.

Section 1 - Introduction

page 10880 line 15. *In the text I found many discrepancies in the references. I will list what I found but I invite the authors to carefully double check it. Myronidis et al. 2009 - in the reference list is 2010.*

page 10880 line 24. *Robichaud, 2009 is not present in the reference list*

page 10880 line 25. *Wagenbrenner et al. 2007 - in the reference list is 2006*

page 10882 lines 1-5. *These lines could be included before, at the end of page 10879.*

page 10882 line 14. *Elliot et al. 2001. - in the reference list is 2009.*

page 10882 line 21. *Ranzi et al., 2011 - in the reference list is 2012.*

Authors:

The references have been checked.

Referee #1

Section 2 - Study Area

I would suggest to the authors to include in this Section the text about the available observations described at the beginning of the Discussion section.

Authors:

A section (named 2.2 Soil loss measurements in the study area) devoted to the description of the available data for the study area has been added in the manuscript and it is reported below:

2.2. Soil loss measurements in the study area

Measured mean erosion in Mediterranean Europe amounts to 1.3 t/ha*year (Cerdan et al., 2010). In Italy forty reservoirs sediment deposition dataset, acquired by direct sonar sub-bottom profiler measurements or derived from estimates and measures carried by Italian Electricity Power Company during reservoirs dredging (Van Rompaey et al., 2005), reports mean erosion of about 2.3 t/ha*year. Concerning the Sardinian region, these measurements show mean erosion of about 4.0 t/ha*year. Measurements in Mulargia and Flumendosa basins, located south of island, show a mean erosion of 5.56 t/ha*year (respectively 10.3 t/ha*year and 0.9 t/ha*year) (Van Rompaey et al., 2003). Lower values are also recorded in Bonassai (SS), south-west of the studied area, where mean erosion rates lie around 0.025 t/ha*year (Acutis et al., 1996), and a field study carried out in Pattada (SS) reports a mean soil loss of 0.034 t/ha*year (0.049 t/ha*year on ploughed land, 0.048 t/ha*year on grassland, 0.033 t/ha*year on natural pasture, 0.014 t/ha*year on burned pasture, 0.025 t/ha*year on slashed bushland) (Rivoira et al., 1989); the authors themselves, though, note that these values have to be considered quite low for Sardinian conditions. Two field campaigns were carried out in Ottava (SS), a field site in the northern part of the Rio Mannu basin (Porqueddu and Roggero, 1994; Porqueddu et al., 2001). During first experiment, lasted from 1989 to 1991, soil loss on several soil uses (permanent pasture, annual forage crop, and continuously ploughed soil) were measured. The second experiment took place from 1994 to 1997, assessing soil loss data for four common crops of the Sardinian hilly areas which are natural pasture, improved pasture, annual forage crop and winter cereal. During the two experimental campaigns mean soil loss of respectively 2.55 and 0.86 t/ha*year were measured. Table 3 reports soil losses for each soil use and for each experiment.

Referee #1

page 10883 line 19. *Regione Autonoma della Sardegna 2000 - in the reference list is 2006 or 2009*

page 10884 line 2. *Regione Sardegna 2010 as before.*

Section 3 - Materials and methods

page 10884 line 6. *Renard et al., 1997 - this reference is missing in the final list.*

page 10884 line 12. *Solorio and Mac Donald, 2005 - this reference is missing in the final list*

page 10884 line 13. *Mac Donald, 2007 - this reference is missing in the final list*

Authors:

The references have been checked

Referee #1

page 10884 line 15. Here Authors could emphasize that it could be important to appropriately preprocess DEM since the LS factor depends on the contributing area and cell slope. This is probably why the authors chose to use the PEM4PIT approach for flat area issue.

Authors:

We add this sentence to explain better how we use the PEM4PIT approach:

The Digital Elevation Model (DEM) of the basin, at 25m resolution, is accurately pre-processed since the RUSLE model is sensitive to the geomorphologic attributes. Pits and artificial flat areas are corrected applying the PEM4PIT method (Grimaldi et al. 2004; Grimaldi et al. 2007; Petroselli and Alvarez ,2012) that allows to enforce a slope on the erroneous flat cells using a simplified physically-based landscape evolution model. Soil loss is then evaluated for each cell through RUSLE equation.

Referee #1

page 10884 line 16. the sentence “to subdivide the study area in square cells of 25 by 25 m” can be removed.

Authors:

The authors removed the sentence

Referee #1

page 10885 line 7. APAT, 2009 is not present in the reference list.

page 10885 line 13. Renard et al., 1997 is not present in the reference list.

Authors:

The authors checked the references

Referee #1

page 10886 lines 3-13 I would invert the order following the same order of the RUSLE equation. So I would described LS factor before C factor.

page 10886 line 11. Probably more details on the Moore and Burch (1986) equation (that is missed in the reference list) could help the reader to understand the role of the topography in the RUSLE equation.

Authors:

The authors added in the manuscript the Moore and Burch (1986) equation and they described the LS factor before the C factor.

Referee #1

Section 4 - Study scenarios

In my opinion this is the most important section and authors should be careful to well justify the parameter choice).

Authors:

The section “study scenarios” has been improved paying attention to better explain the parameters choice. The subchapter “study scenarios” is reported below

Study scenarios

The influence of soil condition (natural and burned) and three rehabilitation practices and their combination on soil losses have been analyzed referring to six scenarios which are described in the following.

The first scenario assesses soil loss at basin scale in natural (unburned) conditions. In this scenario the conservation practices factor P was set equal to 1 all over the basin, except for paved roads, railways and bare surface where P factor is set to 0. Due to the lack of information on particular conservation practices for the study basin, the other RUSLE parameters have been evaluated as described in soil loss modeling section.

The second scenario analyzes fire effect on soil losses. During the summer 2009 a forest fire burned about 47 km² of the study area, as Figure 1 reports .

In burned area fire effects on soil characteristics have been mimed by changing the C factor, soil drainage capacity, and soil organic matter content. Fire, in fact, induces both a increase in soil aggregation leading to an increase in bulk density and soil compaction and a decrease of soil cohesiveness (Andreu et al., 2001). Moreover, the combustion of the organic matter can lead to the formation of a soil hydrophobic layer affecting soil hydrologic properties (De Bano, 2000). Changing of conservation factor C in burned areas has been suggested by several authors. Terranova et al., (2009) assumed C equal to 0.2, 0.05, 0.01 corresponding to high, medium or low burn severity for burned area in Calabria region (Italy) having Mediterranean characteristics like the Rio Mannu basin. Another usually adopted hypothesis is to set C equal to 1 for areas with a percentage cover lower than 15%. In Slovakia, a study on soil erosion assessment set C factor ranging 0.35-0.55 to areas classified as “burnt areas” in Corine Land Cover map (Cebecauer et al., 2004). Larsen et al. (2007) assigned to C factor on burned areas having maximum of 0.33 and mean of 0.2.

By considering the ecosystem of the Rio Mannu basin and the fire severity, the C factor for the burned area was set equal to 0.2.

Post fire organic matter decrease has been simulated by considering burned areas having fertility class one level lower than in natural condition and soil water repellency layer formation has been accounted by reducing soil drainage capacity which was set to drainage class “very slow”.

The third scenario analyses the effects of rehabilitation treatments like ploughing or tilling on crop burned areas. It mimics the breaking up of the hydrophobic layer by acting on the soil's drainage capacity. The partial restoration of soils drainage capacity due to ploughing or tilling has been reproduced by assigning to under treatment burned area a one level lower drainage class then natural condition drainage class.

The fourth scenario studies the mulching rehabilitation practice. Straw mulch is considered one of the more cost-effective stabilization treatments in reducing post-fire erosion. Besides, wood mulches provide greater resistance to wind erosion than straw mulch and also they are more decay resistant than hydromulch (Robichaud et al., 2010).

In this study, both straw and wood mulching on burned forested areas have been considered. In particular gentle slopes (slope < 30°) have been treated with straw mulching and steeper slopes (30 – 50%) with wood chip mulching. The treatment has been applied on about 45% of the burned slopes. Mulching effect on soil has been mimed by changing RUSLE parameters P and C. According to Fernández et al. (2010), P = 0.343 has been used for straw mulching on slopes < 30% and P = 0.943 for wood chip mulch on slopes up to 50% (Figure 3a) . In addition, the effect of seeding and regrowth of vegetation on soil erosion have been described through C factor. It was set equal to 0.13 corresponding to the mean value of C on the burned area prior the fire occurrence (Figure 3b).

The fifth scenario analyses the effectiveness in capturing soil losses by erosion barriers or trenches on arable land. Barriers at the distance of 50 meters along the contour lines were placed on crop land. This treatment is applied to a share of 35% of the burned area. Barriers application

as rehabilitation treatments is usually modeled by modifying RUSLE P factor. Wischmeier and Smith (1978) and later Terranova et al., (2009) propose a P factor of 0.2 for reverse bench barriers. Myronidis et al., (2010) distinguished P factor for treatments and slope. They set $P=0.85$ for branch piles and woodboards on gentle slopes ($< 30\%$), $P= 0.75$ for branch piles and woodboards or log barriers on steeper slopes (30% to 50%), and $P=1$ for slopes greater than 50% .

In this study, for taking in account the slope influence in the capturing effect of the erosion barriers, the P factor values introduced by Myronidis et al., (2010) were used (Figure 3c).

The sixth scenario considers the combination of all rehabilitation practices described in the previous scenarios 3, 4 and 5. In particular the effectiveness of the treatments combination is tested by assuming the following pattern: tilling all over the burned area, mulching on woodland and erosion barriers or trenches on arable land. The P factor has been set accordingly as showed in figure 3d, and the C factor is the same as in scenario 4 (Figure 2f).

Referee #1

page 10888 line 27. Myronidis et al. 2009 - in the reference list is 2010.

page 10889 line 3 – same

Authors:

The references have been checked

Referee #1

Section 5 - Results

In general, if authors decide to move the “observation” in “Case Study” Section, they could also merge Results and Discussion. Reading these Sections it seems that some information are repeated several times.

Authors:

The authors moved “observation” in the “ case study” naming the paragraph *“Soil loss measurements in the study area”*.

The authors merged the paragraphs “results” and “discussion” .

Referee #1

Section 6 - Discussion

page 10891 line 21. Van Rompaey et al., 2003 - it is 2005 in the reference list.

page 10893 line 15. Vacca et al., 2001 it is 2000 in the reference list.

page 10894 line 10. Vafeidis et al., 2006 - it is 2007 in the reference list.

Figures

FIGURE 1. I would use a picture of Italy without geographical names and instead of “Precipitation measurements” I would use “raingauges”

Authors:

The references have been checked and “Precipitation measurements” has been changed in “raingauges”

The authors thank very much **Anonymous Referee #1** for his review allowing for manuscript improvement.