Land Use Policy 90 (2020) 104306

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Effectiveness and feasibility of different management practices to reduce soil erosion in an agricultural watershed

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ARTICLE INFO

Keywords:
Best Management Practices (BMPs)
SWAT
Common Agricultural Policy
Rural Development Program
Economic feasibility

ABSTRACT

Erosion is the most widespread form of soil degradation in Europe. EU Member States are called to identify areas prone to high risk of soil erosion and to adopt Best Management Practices (BMPs) to decrease land degradation. This study is aimed at identifying effective BMPs and their economic feasibility for controlling soil erosion in south-central Italy where lands are largely cultivated with winter wheat. The Soil and Water Assessment Tool (SWAT) was applied to simulate the baseline hydrologic and soil erosion processes of the Carapelle basin in the Puglia region, Italy. Calibrated sediment loads were reasonably accurate when statistically evaluated against measured data (R^2 = 0.5, NSE = 0.5, PBIAS = −2.8 %). The model performed equally well for simulating stream flow rates (R^2 = 0.6, NSE = 0.6, PBIAS = 5.3 %). The model maintained reliable performance during the validation period as well. Average annual specific sediment load was estimated 5.95 t ha^{-1} yr^{-1} mostly contributed by cultivated croplands. Based on regional agricultural policies, four management scenarios were implemented using the calibrated SWAT model: contour farming (BMP1), no tillage (BMP2); reforestation (BMP3) and contour farming and reforestation (BMP4). A threshold of sediment yield greater than 10 t $ha^{-1}yr^{-1}$ was selected to discretize target treatment areas where these BMPs were applied. Result show that combining contour farming and reforestation (BMP4) was the most effective (38 % reduction; from 5.95 to 3.70 t ha^{-1}) for erosion control, followed by BMP2 (29 %; from 5.95 to 4.20 t ha^{-1}), BMP1 (22 %; from 5.95 to 4.61 t ha^{-1}) and BMP3 (15 %; from 5.95 to 5.04 t ha^{-1}). An analysis of the farmer return-production cost ratio (FR/PC) indicated that the baseline (conventional tillage) and BMP1 were both economically sustainable in areas with slope < 20 % (FR/PC = 1.12 and 1.11, respectively). BMP2 received the highest FR/PC rating of 1.67 in areas with slope < 20 %. The baseline scenario had no economic advantage (FR/PC = 0.93) in steep slope areas. BMP3 was ranked at the top (FR/PC = 1.49) followed by BMP2 (FR/PC = 1.41) in areas with slope > 20 %. The results show that a program of measures can be effective for controlling soil erosion but it must be implemented over long time frames and it requires relevant investments from the public and private sectors.

1. Introduction

Protecting soils from eroding is a key element of the European Management Policies (European Commission (EC, 2006) due to the multi-functionality of soils (Wiggering et al., 2006). Lands degraded by soil erosion are sensitive to the loss of nutrients and organic matter in the topsoil which leads to lower crop production, higher pollution of water bodies and destruction of wildlife habitats (Prager et al., 2011). Pimentel and Burgess (2013) evidenced that inappropriate agricultural practices combined with heavy precipitation, steep topography, low vegetation cover, deforestation, and overgrazing are some of the main causes of soil erosion. In a study conducted by the European Soil Data Centre (ESDAC) (Panagos et al., 2012), over 20 % of European soils are estimated to be eroded by water and wind and about 275 ha of soil per day is lost to permanent soil sealing (Jones et al., 2012).

Mediterranean areas are characterized by a higher amount of sediment yield than other areas in Europe due to the presence of active badlands, rills, gullies and eroded torrential headwaters (Vanmaercke et al., 2011). The greater susceptibility in soil erosion in the Mediterranean areas is also contributed by the unique pattern of rainfall that is concentrated in winter and intense cultivation on steep slopes (García-Ruiz et al., 2013). Italy, as part of the Mediterranean areas, is subject to soil erosion especially in croplands (Panagos et al., 2015a; Abdelwahab et al., 2014). Best management practices (BMPs) such as

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https://doi.org/10.1016/j.landusepol.2019.104306
Received 21 November 2018; Received in revised form 30 September 2019; Accepted 12 October 2019

contour farming, hill ponds, and grassed waterways, no till farming systems, reforestation, and strip cropping have been widely used in croplands (Arabi et al., 2008; Mtibaa et al., 2018). Hence, one of the objectives of the Soil Thematic Strategy (European Commission (EC, 2006) led by Soil European Commission is to identify high risk areas of soil erosion for every Member State, in order to limit soil erosion impacts and to control non point sources (NPS) pollution using specific conservation measures (Asres et al., 2010; Abdelwahab et al., 2016; Vigiak et al., 2016).

The Common Agricultural Policy (CAP) has been instrumental in supporting agricultural production from the economic stand-point. After the Second World War, however, the financial measures tended to accelerate soil erosion. As a result, the focus has shifted and governmental incentives to landowners in the last several decades were centered on the implementation of BMPs to reduce soil losses (Coderoni and Esposti, 2018). In addition, funding provided by the European Union (EU) to counteract soil erosion is subordinated to the maintenance of a series of mandatory measures: the Good Agricultural Environmental Conditions (GAEC) (Panagos et al., 2016). It was estimated that the application of the GAEC has reduced soil loss from arable lands by 20 % in the past decade (Panagos et al., 2015a).

In Italy, agronomic measures have become mandatory by two regulations: the D.M.16809/2008 of the Ministry of Agricultural, Food and Forestry Policies (MiPAAF, 2008) about the Cross-Compliance Standard Temporary Measures for runoff water control on sloping land; the Decree n. 30125 of 2009 (MiPAAF, 2009) about the minimum land management that meets specific local conditions (Standard 1.1 Creation of temporary ditches for the prevention of soil erosion) (Bazzoffi et al., 2011). The Rural Development Programme (literally in Italian: Programma di Sviluppo Rurale; PSR) is the regional instrument for planning and financing the agricultural system. This seven-year period program is financed by the European Agricultural Fund for Rural Development (EAFRD) and provides 1.6 billion of Euro in the Puglia region. In particular, the aims of the target item number 8 and 10 are to expand forests and increase sustainable management in agricultural lands. These planned interventions are related with reducing soil erosion in agricultural lands. Thus, critical source areas need to be identified, and agricultural BMPs be evaluated for their functional effectiveness and economic feasibility (Mtibaa et al., 2018).

A large number of hydrological models have been developed to face these challenges with various levels of complexity (Kauffeldt et al., 2016). For example, the Agricultural Policy Environmental eXtender (APEX) (Williams and Izaurralde, 2005), the Water Erosion Prediction Project (Flanagan et al., 2012), the Soil Water Assessment Tool (SWAT) (Arnold et al., 1998), the Annualized Agricultural Non point Source (AnnAGNPS) (Bingner and Theurer, 2005), and the Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 2001) are commonly accepted by the global modeling community. In particular, SWAT is one of the most used models for watershed assessment because of its complete database enabling the simulation of various management practices as well as its complete algorithms to simulate hydrology, sediment transport, and NPS pollutant transport (Arabi et al., 2008; Parajuli et al., 2008; Yang et al., 2010; Tuppad et al., 2010; Betrie et al., 2011; Ramos et al., 2015). However, like other hydrological models, SWAT needs long-term experimental data for calibration and validation (De Girolamo et al., 2017).

In this study, a five-year data for water discharge and suspended sediment concentration collected at a stream gauge in the Carapelle watershed, a medium-size watershed located in Southern Italy, is used to evaluate the effectiveness of agricultural BMPs for controlling soil erosion. In particular, this paper aims to (i) quantify soil erosion in the Carapelle watershed to identify critical source areas under current managements; (ii) identify specific BMPs for controlling soil erosion based on regional policies and evaluate their effectiveness; and (iii) provide a procedural guideline to choose effective BMPs based on their performance and economic feasibility for both public and private sectors.

2. Materials and methods

2.1. Study area

The study area is the Carapelle, a watershed (506 km^2) located in the Puglia and the Campania regions (Southern Italy) (Fig. 1). The main channel flows for 52.16 km on 8.2 % slope between 120 and 1089 m a.s.l. of elevation. Climate is typical Mediterranean, characterized by warm and dry summers and wet winters. Indeed, August is the driest month while March and November are the wettest period (Abdelwahab et al., 2018). Similar to other Mediterranean streams, the Carapelle River is characterized by semi-arid climate regime with seasonal intermittent flows exhibiting extremely low flows in the summer months and high flow in winter and early spring (Romano et al., 2018). Precipitation ranges between 450 and 800 mm $year^{-1}$ and flash floods events are common from June to October. Rainfall is characterized by high spatial variability. These peculiarities of the rainfall regime influences watershed hydrology and sediment transport processes making monitoring activities a challenge, especially at daily time scale (Ricci et al., 2018).

Streamflow and suspended sediment concentration (SSC) have been monitored at the outlet of the watershed (41° 17′ 50.347″ N; 15° 36′ 2.583″ E; Ordona Village) for five years between 2007 and 2011. The monitoring report and instrument details can be found in Gentile et al. (2008) and Gentile et al. (2010). In this area, the main economic activity is agriculture with an extensive cultivation of winter wheat on more than 75 % of the watershed area. In this area, winter wheat is planted in November and then harvested in July. Traditionally, a 4-year crop rotation is adopted with mineral fertilizer applications in December (fertilizer grade: 25-15-00) and February (urea). Forest and pasture are prevalent in the mountainous areas (Aquilino et al., 2014). Urban lands are limited to a few small villages. Due to these aspects of land uses, the main erosion processes are sheet and rill erosion which are strongly related to tillage operations. Indeed, farmers usually practice the conventional tillage over the area (Baseline), which consist of plowing up and down slopes (25-40 cm depth) (Fig. 1). Moreover, past studies carried out in this area found that morphology has a significant influence on soil erosion (Ricci et al., 2018). Therefore, the soil erosion control policies must be focused on land management as well as topographic effects in source areas.

2.2. BMPs type and applications

Based on policy guideline found in the National regulation, DM 2490/2017 (MiPAAF, 2017), and Rural Development Program (PSR 2014-2020) of the Puglia region (PSR, 2014), the most applied BMPs in the rural areas are: contour farming, no tillage, and reforestation. The Natural Resources Conservation Service (NRCS) conservation practice standard (USDA-NRCS, 2017) was used to describe and analyze the effects of the BMPs studied.

Contour farming is a practice that aims at increasing the infiltration and reducing the surface erosion processes (e.g. rills) tilling the land along the contour lines. As a direct effect, there is a reduction of the fertilizer loss and an increase of the crop yields. Liu et al. (2013) pointed out that the major effect is obtained in the slope ranges between 3 % and 8 % since in steep slope areas there could be a high risk of tractor overturning (Abubakar et al., 2010). In Italy, contour farming is one of the standard land management practices in hilly areas (Bazzoffi et al., 2011) with the local name of “Girapoggio”. This technique has been used since the beginning of the 1900 in the Apennine and Sub-Apennine areas especially in the regions of Central Italy.

No tillage or Sod seeding consists of avoiding deep tillage (e.g.

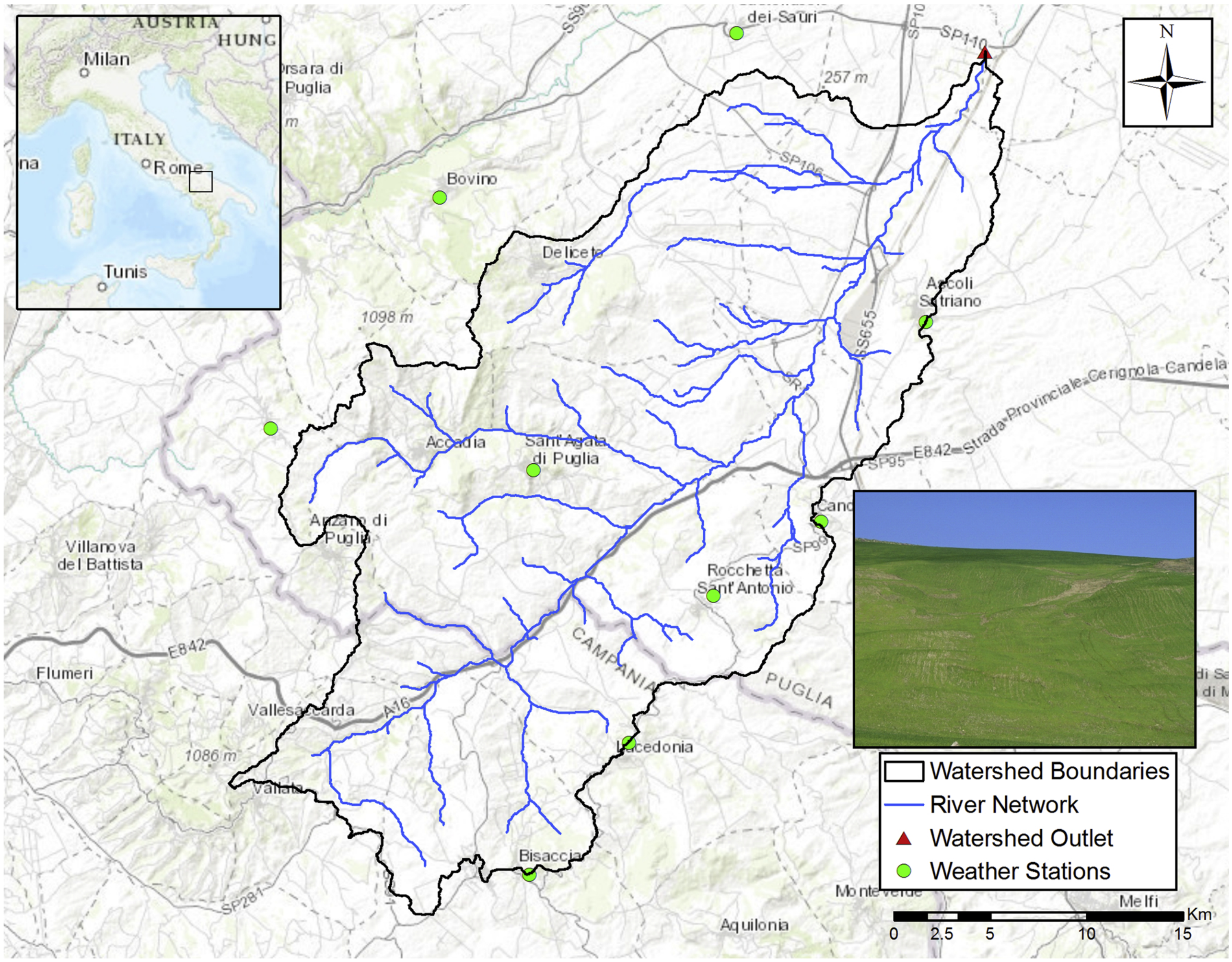

Fig. 1. Study area: the Carapelle watershed (Puglia, SE Italy).

plowing), leaving the residue on the soil and carrying out only in-row operations, such as drilling during the transplanting or furrowing and closing the soil during the seeding by means of a seed row/furrow closing device. This practice can lead to reduce surface runoff, increase soil infiltration and, consequently, improve soil properties and reduce soil erosion (Ullrich and Volk, 2009). No tillage is a management system still in development, and it is most used in some areas in Central and Northern Italy (Pianura Padana) (Cavalchini et al., 2013). No tillage can potentially be adopted in Southern Italy as well due to its positive effects on crop yields and quality (De Vita et al., 2007; Vastola et al., 2017).

Reforestation is a management practice that falls into the category of land use change (LUC), as it is a change to a land use type that is less prone to soil erosion (Bakker et al., 2008), and guarantees many positive effects, including improving water quality, new wildlife habitat and wood production. In Italy, reforestation increased after the second world war, based on the national environmental policies. Indeed, the National Forest and Carbon Inventory (INFC) estimated that the surface area of forests increased by 20 % in the past 20 years (National Forest and Carbon Inventory (INFC, 2015).

2.3. Modeling hydrology and sediment yield

The semi-distributed, continuous hydrological model SWAT (Arnold et al., 1998, 1993) was developed by the United States Department of Agriculture (USDA) to assess the hydrological, sediment and nutrient regime in a watershed and to examine the impact of the application of soil management practices at different timescales (Arnold et al., 2012a). The SWAT2015 version Rev. 637 (Winchell et al., 2013) was run at daily timescale for an eight-year period (2004-2011) with the first three years (2004-2006) used to warm up the model. The first step for modeling the hydrological and sediment processes is the watershed delineation based on the outlet point defined by the user. In this study, we chose the location of streamflow gauge as the outlet for the purpose of model calibration. The model divides the watershed into sub-watersheds and further divides the sub-watersheds in homogenous areas by slope, land use, soil characteristics and management defined as Hydrological response units (HRUs).

In the study watershed, sloping cultivated areas are known to be the main source of sediment yield (Abdelwahab et al., 2018; Ricci et al., 2018). Considering that the aim of the present study was to estimate the efficiency of the BMPs, a smaller spatial scale (i.e., higher resolution with greater details) was set for the sub-watersheds definition. The number of sub-watersheds and HRUs was increased in comparison with previous studies (Abdelwahab et al., 2018; Ricci et al., 2018) in order to better determine the reduction of the annual sediment yield due to the application of BMPs in upland areas. Hence, it was choosen a threshold of 200 ha, instead of 2000 ha, as in the previous studies, resulting in 115 sub-watersheds. In order to keep the proportion of the main soil type, slope and land uses in every sub-watershed percentage threshold of 5 %, 25 %, and 25 % for soil type, slope and land uses, respectively, were chosen to create 451 HRUs. Subsequently, the model was recalibrated. The SWAT model estimates surface runoff volume and sediment yield for each HRU then routes through the channel network to obtain

Table 1
SWAT model input data, source and resolution.

Description	Source and data resolution
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM); resolution of 20 × 20 m Data source: http://www.sinanet.isprambiente.it
Land use data	Land Use Map (UDS) of Puglia and Land Agricultural Use Map (CUAS) of Campania; resolution of 100 m Data source: http://sit.puglia.it; http://sit.regione.campania.it
Soil database data	Agro-ecological Characterization of the Puglia Region ACLA2; resolution 250 × 250 m; 9 soil profiles Data source: Regione Puglia, 2001
Weather data	8 Gauging station Daily data: precipitation, solar radiation, wind speed, relative humidity, min. and max temperature Data source: http://www.protezionecivile.puglia.it
Measured Data for calibration and validation	Four years of measured daily streamflow and sediment load (2007-2011).

the streamflow and sediment load (Neitsch et al., 2011). The surface runoff is calculated by the modified Soil Conservation Service-Curve Number method (SCS-CN) (United States Department of Agriculture, 1972), while the stream velocity and discharge relationship is determined by Manning's equation. The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), derived from the Universal Soil Loss Equation (USLE), is used to estimate the sediment yield. Subsequently, the processes of channel degradation or sediment deposition in the channel are simulated with a simplified Bagnold's stream power relationship (Bagnold, 1977), where the maximum transport is estimated based on the peak channel velocity. Among the equations provided by the model for the potential evapotranspiration, the Hargreaves method (Hargreaves, 1975) was selected, which needs temperature and solar radiation as input data. A detailed description of the SWAT model can be found in Abdelwahab, (2018).

To set up the model, several types of data are required (Table 1). For watershed delineation, a digital elevation model (DEM) (20 × 20 m) was used. Soil profiles and characteristics such as texture, field capacity, wilting point, and hydraulic conductivity were obtained from the Agro-ecological Characterization of the Puglia Region project or ACLA2 (250 m). The main soil types were silty clay loam, sand clay loam, and loamy soils. A land use map was developed by merging the Land Agricultural Use Map (CUAS) of Campania (100 m) and the Land Use Map (UDS) of Puglia (100 m) for greater accuracy. Finally, a SWAT code was assigned to each land use type for database assimilation. As reported above, the main crop is winter wheat, which covers more than 75 % of the watershed. Other land uses are forests, olive groves, pasture, and urban areas. Through field surveys and interviews with the farmers, management information for winter wheat and olive groves were included in the management file (.mgt). For winter wheat, a 4-year crop rotation (wheat, wheat, wheat, clover) was considered with ploughing, which is perpendicular to the slope lines (25-40 cm depth), in August, harrowing in October, planting in November and harvesting in July. Fertilizer applications were carried out in December (fertilizer grade: 25-15-00) and February (urea). For olives trees, three shallow tillage operations (ploughing and harrowing) were applied every two months starting in April, and two fertilizer applications were carried out in December (manure) and in spring (fertilizer grade: 26-00-00), while the plants are harvested in November (Abdelwahab et al., 2016). Climate data for the studied period (daily maximum and minimum temperatures, daily precipitation, and solar radiation) were acquired from eight weather stations located inside the watershed or in the surrounding areas. Climate data were provided by the Civil Protection Agency and by the Agrometeorological Service of Puglia Region.

2.4. Model calibration and validation

The entire evaluation period (2007-2011) was split into two periods (Arnold et al., 2012a) to calibrate and validate the model. The first period, from January 2007 to April 2009 was used for calibration, whilst the second period, from January 2010 to December 2011, was used for validation. The period from April to December 2009 was discarded because of a lack of recorded data due to malfunctioning of the power supply system. A preliminary calibration was carried out by adjusting Ground Water flow (GW) parameters (eg. Alpha_BF and GW_delay) using the Baseflow Filter Program (Arnold and Allen, 1999) in order to have a good concordance between measured and simulated values of base flow/surface runoff (Brouziyne et al., 2017). A sensitivity analysis, which involved model parameters that influence runoff and sediment prediction (Malagó et al., 2017; Arnold et al., 2015), was performed with the SWAT-CUP automated tool applying the Sequential Uncertainty Fitting version 2 (SUFI2) (Abbaspour et al., 2015). A detailed description of the sensitivity analysis can be found in Ricci et al. (2018). In addition, the Manning "n" roughness coefficient for the main channel (CH_N2) was considered in the sediment load calibration (Abdelwahab et al., 2018). The USLE P-factor (erosion management practice factor varying 0-1) was set to 1.0 because in no conservation practice was applied in the watershed. Since the hydrology can be considered the driving factor for all other watershed processes (Arnold et al., 2012b, 2015; Malagó et al., 2015; Brouziyne et al., 2017), the calibration and the validation were performed first for the hydrology and then subsequently for sediment load. SWAT-CUP allows to conduct either manual or automatic calibration, so firstly selected parameters

Table 2
SWAT model parameters used for the calibration and their final values.

Parameters	Description	Calibrated value
Runoff		
CN2.mgt	Curve Number	60-88
GWQMN.gw	Threshold depth of water in shallow aquifer	1281.62
GW_DELAY.gw	Groundwater delay time	92.76
ALPHA_BF.gw	Baseflow alpha factor	0.59
GW_REVAP.gw	Groundwater "revap" coefficient	0.028
REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur	172.61
RCHRG_DP.gw	Deep aquifer percolation fraction	0.38
SURLAG.bsn	Surface runoff lag time [days]	4.00
SOL_AWC.sol	Available water capacity of the soil layer	0.08-0.26
SOL_K.sol	Saturated hydraulic conductivity	1.95-13.15
CH_N1.sub	Manning's "n" value for the tributary channels	0.08
CH_K1.sub	Effective hydraulic conductivity in tributary channel	1.00
CH_K2.rte	Effective hyd. Cond. In the main channel	56.68
OV_N.hru	Manning's "n" value for overland flow	2.99
Sediment		
CH_N2.rte	Manning's "n" value for main channel	0.05-0.14
ADJ_PKR.bsn	Peak rate adjustment factor for sediment routing in the subbasin (tributary channels)	3.00
PRF_BSN.bsn	Peak rate adjustment factor for sediment routing in the main channel	2.9
SPEXP.bsn	Exponent parameter for calculating sediment reentrained in channel sediment routing	2.00
SPCON.bsn	Maximum amount of sediment reentrained during channel sediment routing	0.001

Table 3
SWAT parameters modified in BMPs simulations.

BMP code	BMP name	Selected Criteria	Number of Selected HRUs	Modified parameters in BMP simulations
BMP1	Contour farming	10 t ha^{-1} Slope < 20 % (tractor overturning risk)	44	CNII table provided by Arnold et al. (2012b) Contoured w/residue for every hydrologic group USLE_P table provided by Arnold et al. (2012b) values for slope classes
BMP2	No tillage	Erosion > 10 t ha^{-1}	59	Removing tillage operation in target HRUs BIOMIX set to 0.4 OV_N set to 0.320 CNII decreased by 2
BMP3	Reforestation	Erosion > 10 t ha^{-1} Slope > 20 %	15	Change of the land use in the target HRUs CNII values for crops Contoured w/residue for every hydrologic group provided in the table provided by Arnold et al. (2012b)
BMP4	BMP1 + BMP3	Same criteria used in BMP1 and BMP3	44 + 15	Same criteria used in BMP1 and BMP3

(Table 2) were changed manually one at a time to reach a close correspondence between the simulated and the observed curves (Jeong et al., 2010). In the next step, an automatic procedure was used to find the best parameters based on the objective function selected, that was the Nash and Sutcliffe (1970) Efficiency (NSE). In Table 2 the parameters used for the calibration and their final values are reported.

The model efficiency at daily time scale was evaluated using the coefficient of determination (R^2), NSE, and Percent Bias (PBIAS %) (Van Liew et al., 2003; Moriasi et al., 2007). Acceptable model performance values are considered based on NSE and $R^2 > 0.5$, PBIAS $\leq \pm 25$ % for streamflow and ± 55 % for sediment load (negative PBIAS indicates overestimations). These values, suggested by Moriasi et al. (2007) are also adopted in other studies (Furl et al., 2015; Nerantzaki et al., 2015; Briak et al., 2016; Zettam et al., 2017; Melaku et al., 2018).

2.5. BMPs scenarios evaluation and modeling

Four scenarios of BMPs were designed and tested based on the aforementioned National and Regional policy guideline: contour farming (BMP1), no tillage (BMP2), reforestation (BMP3), and a combination between contour farming and reforestation (BMP4) (Table 3). The effect of the implemented scenarios was evaluated by taking into account the reduction of both specific sediment load (t ha^{-1}) at the outlet and of landscape sediment yield (t ha^{-1}) at subwatersheds and HRUs level. Target areas (HRUs) were selected based on the actual sediment yield and an average annual threshold value of 10 t ha^{-1} at which level soil erosion risk is known to be high (Kuhlman et al., 2010; Mtibaa et al., 2018). Therefore, a total of 59 HRUs, all classified as winter wheat fields, were identified. For BMP1, since contour farming cannot be carried out in steep slope areas (> 20 %), a second criteria of discretization, based on the slope (< 20 %), was applied to narrow the applicable areas down to 44 HRUs. The no tillage operation was applied to all the 59 HRUs in the BMP2 scenario. The BMP3 scenario was considered taking into account that in steep slope areas (slope > 20 %) it is difficult to till the land with traditional techniques, and so it could be better to convert the land use to forest or to grassland (Zhang et al., 2014). Hence, the reforestation was applied to 15 HRUs on steep slopes (> 20 %). Finally, the BMP4 scenario is a combination between the contour farming and the reforestation that was applied to all the 59 HRUs. The comparison of the effectiveness of the implemented BMPs scenarios was carried out considering as Baseline the current situation in which the HRUs are under the conventional tillage.

SWAT parameters were modified to implement selected BMPs at specific fields so that the model implementation reflects real world practices (Betrie et al., 2011). To reflect the impact of BMP1 many authors suggest that parameters including CN and the USLE P factor have to be modified (Arabi et al., 2008; Gevaert et al., 2008; Tuppad et al., 2010; Wang et al., 2018). In this study, values for these parameters were edited following the recommendation by Arnold et al. (2012b). The CN parameter was fixed to the values referred to the contoured farming with residue because in the study area crop residues are usually left in the field after harvesting grains. The effect of BMP2 was simulated in SWAT by removing tillage operations in the target HRUs, as recommended by Ullrich and Volk (2009), while CN was decreased by a two-point value as suggested by Mtibaa et al. (2018). Biological soil mixing efficiency (BIOMIX) and Manning's roughness coefficient for overland flow (OV_N) were also modified and increased to 0.4 and 0.320, respectively (Neitsch et al., 2011). BMP3 was implemented in SWAT by changing the land use of the 15 selected target HRUs (Betrie et al., 2011) as well as the relative CN value which was switched from wheat to forest (Arnold et al., 2012b). In the BMP4 scenario, a combination of BMP1 and BMP3 was simulated in order to take advantage of the effectiveness of joining the two BMPs (Mtibaa et al., 2018).

2.6. Economic feasibility of BMPs

Two aspects should be taken into consideration to evaluate the BMPs feasibility: the suitability at the field level (farmers) as well as at the watershed scale. Due to price fluctuation of durum wheat and the variability of crop yields from one year to another, it is difficult to forecast income of farmers precisely. For this reason, the economic analysis conducted in this work refers to a historical period - the year 2018 (Table 4). To make the evaluation more consistent, economical values derived from PSR that do not refer to 2018 were discounted with an interest rate of 1.02 %. This value was derived from the harmonized European index suggested by the ISTAT (https://www.istat.it/it/archivio/17484) that takes into account the revaluation of the capital and the variation of the interests introduced by the European Central Bank.

The economic feasibility of the four BMPs scenarios for the private sector was evaluated by considering the subsidy policy available for every single farmer in the study area. The PSR data were compared with the four scenarios after the first year of implementation in terms of farm returns (FR) and Production Cost (PC; Euro ha^{-1}) ratio (FR/PC). For each BMP, the specific farm return (Euro ha^{-1}) was calculated by multiplying the crop yield to the crop selling unit price and by including an increased or decreased rate of crop yield, based on the slope and the BMP considered (Liu et al., 2014; Mtibaa et al., 2018). Any subsidy provided by the CAP or PSR was also added. The specific production costs (Euro ha^{-1}), reported in the PSR (PSR, 2014) was increased or decreased on the basis of slope and on the BMP considered (Liu et al., 2014).

The winter wheat production in 2018, under the conventional tillage and on slopes less than 20 %, increased by 5 % in the scenario BMP1. In BMP2 the crop yield increased by 10 %, because of the reduced loss of fertile soil as a result of no tillage practice which was

Table 4
Principal income and costs considered in the economic analysis.

Description	Unit	Value	Data Source
Income			
Winter wheat selling unit price	Euro t^{-1}	222	https://www.obiettivocereali.com
Wood selling unit price	Euro t^{-1}	25.7	PSR, 2014 (measure 8.1)
Subsidy conventional tillage	Euro $ha^{-1}y^{-1}$	100	https://terraevita.edagricole.it
Subsidy contour farming	Euro $ha^{-1}y^{-1}$	100	https://terraevita.edagricole.it
Subsidy No Tillage	Euro $ha^{-1}y^{-1}$	322	PSR, 2014 (measure 10.1.3)
Subsidy Reforestation[a]	Euro $ha^{-1}y^{-1}$	6000	PSR, 2014 (measure 8.1)
Subsidy Reforestation implant[b]	Euro $ha^{-1}y^{-1}$	2500	PSR, 2014 (measure 8.1)
Subsidy reforestation lost incomes[b]	Euro $ha^{-1}y^{-1}$	100	PSR, 2014 (measure 8.1)
Costs			
Winter wheat conventional tillage	Euro $ha^{-1}y^{-1}$	684	https://terraevita.edagricole.it
Transaction cost for No Tillage	Euro ha^{-1}	63 (10 % of the tillage cost)	PSR, 2014 (measure 10.1.3)
Investment for upgrade agricultural machines (No Tillage)	Euro	6000	Farmers survey
Forest medium-cycle investment cost[a]	Euro $ha^{-1}y^{-1}$	6051	PSR, 2014 (measure 8.1)
Forest maintainace operation[b]	Euro $ha^{-1}y^{-1}$	2518	PSR, 2014 (measure 8.1)

[a] for the first 12 years.
[b] for 12 years.

evidenced by De Vita et al. (2007) and reported by local farmers. Lastly, a reduction of 10 % in crop yield was applied to fields on slopes higher than 20 %, based on the higher susceptibility of soil erosion.

Table 4 summarizes the income and costs data considered in the economic analysis. The wheat crop selling unit price was set according to commercial reports, the subsidies for baseline and BMPs are based on the CAP policy, and the PSR. The contour farming is not prescribed in the PSR; therefore the conventional value was used (100 Euro ha^{-1}). The unit cost for the conventional tillage (Table 4) was increased to 752 Euro ha^{-1} for slopes higher than 20 % to account for the greater use of agricultural machines. The contour farming included additional farming and harvesting costs as it is more time consuming, therefore a unit cost of 717 Euro ha^{-1} was considered. For the no tillage scenario, the unit cost was 694 Euro ha^{-1} (which included also the project and transaction costs defined as the 10 % of the unit cost) since the outgoings derived from the plowing and the harrowing were excluded. In this scenario, an additional investment is required (Table 4), which is the investment that the farmers must support to upgrade the agricultural machines (e.g. sod seeder), based on the ten-year period of depreciation.

In the BMP3 scenario, the costs to implant a medium-cycle forest (12 years) and to the maintenance were considered as reported in the PSR documents (measure 8.1). In addition, a further subsidy was guaranteed, for the first 12 years, taking into account the lost incomes caused by the conversion from wheat field to forest. Considering the economic analysis reported in the PSR documents after 12 years the forest could be subjected to a first cut that can produce a yield of about 87.50 t ha^{-1} of firewood. Therefore, for the evaluation of the farm returns a selling price of 25 Euro t^{-1} and a cut operation price of 732 Euro ha^{-1}, both discounted at 2018, were considered.

The suitability of the BMPs scenarios at the watershed scale was evaluated including the implementation cost of the BMPs by the public sector (subsidies), the costs related to the crop productivity loss (CPL), and the soil loss value. The total practice cost (TPC) for the public sector at the watershed scale was obtained summing the subsidies for each HRU. The evaluation was carried out in the first year, in the second year and after 12 years to take into account the changes in the subsidies for the BMP3 and BMP4. The economic value of CPL was calculated multiplying the Land Productivity loss (LPL, %) by the Crop Area (CA, ha) and Crop Productivity (CP, t ha^{-1}) and, finally, by the unit price (Euro t^{-1}) (Panagos et al., 2018). LPL (%) is the ratio between the area of severe erosion (> 10 t ha^{-1}) (SEA, ha) and the total agricultural areas of the watershed (TAA, ha). This ratio is then multiplied by 0.08 that is the value of crop productivity loss in intensively cultivated agricultural fields (Panagos et al., 2018). The economic value of the soil loss was calculated multiplying the sediment load (t yr^{-1}) by the commercial price of soil estimated in 20$ (Panagos et al., 2015b), converted and discounted at the time of this study (19.46 Euro).

3. Results

3.1. Streamflow and sediment load

The model showed a satisfactory performance in the estimation of the streamflow and sediment load at daily time scale, in both calibration and validation periods. Statistical performance indicators are summarized in Figs. 2 and 3. In particular, SWAT underestimated the streamflow observations in the calibration period (PBIAS + 5.3 %) and overestimated them in the validation period (PBIAS −17.2 %); it overestimated the observed sediment load in the calibration period (PBIAS −2.8 %) and underestimated them in the validation period (PBIAS + 5.1 %). Fig. 2 demonstrates the performance of the model being able to reproduce the temporal variability in observed streamflow. While the model performed well to simulate the streamflow, several peaks were underestimated especially during the calibration. In 2011, which was a dry year, the model overestimated streamflow in general during low flow periods. Peak flows were relatively well simulated. For example, the model estimated the highest peak only by 6 % lower (observed 94 $m^3 s^{-1}$; simulated 79 $m^3 s^{-1}$) in the wettest month during the simulation period (November 2010). The average yearly rainfall over the study period was 662 mm with the difference of 346 mm between the driest year (542 mm in 2007) and the wettest year (888 mm in 2010). Overall, 71 % of the rainfall is lost as evapotranspiration (470 mm) that is a value similar to those obtained by Romanazzi et al. (2015) in the region. Average yearly surface runoff was estimated 86 mm, corresponding to 17 % of the rainfall, and the average yearly total water yield was 180 mm, which was equivalent to 27 % of the rainfall.

The analysis of Fig. 3 confirms that the simulated loads are in line with the observed data, although some peaks are underestimated. The highest sediment peak load (November 11, 2010) was underestimated by 49.5 % (observed 3.07 t ha^{-1}; simulated 1.52 t ha^{-1}). A dominant erosion pattern is observed in the winter months (December to April) caused by the high frequency of rainfall events. The average annual specific sediment load was 5.95 t ha^{-1} yr^{-1}, while the specific sediment loads simulated for the driest (2007) and the wettest (2010) years were 1.46 t ha^{-1} and 8.41 t ha^{-1}, respectively.

After the validation process, the watershed HRUs were classified according to sediment yields for further analysis (Fig. 4A). Among HRUs, winter wheat fields were found to be the highest contributor of

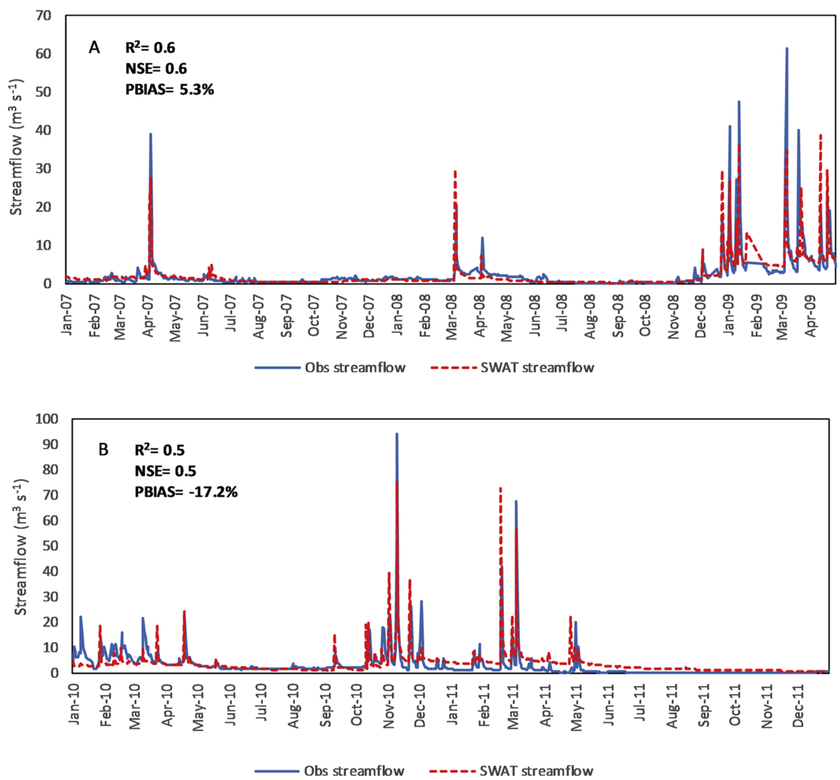

Fig. 2. SWAT streamflow calibration (A) and validation (B) at daily time scale and statistical indices: the coefficient of determination (R^2), the Nash and Sutcliffe Efficiency (NSE), and the Percent Bias (PBIAS %).

sediment yield while forests and rangelands contributed the lowest. The yearly sediment yield rate ranged between 0.00 and 63.80 t ha^{-1} yr^{-1}. Slope class was used as another factor influencing the sediment production. As depicted in Fig. 4A and in B, the flat areas near the watershed outlet are characterized by the lowest sediment yield values, while the sloping cultivated lands are the sediment source areas. In order to maximize the effects of BMPs application in the watershed, the sub-watershed representation (Fig. 4B) was used in the following Section 3.2 “Modeling BMPs”.

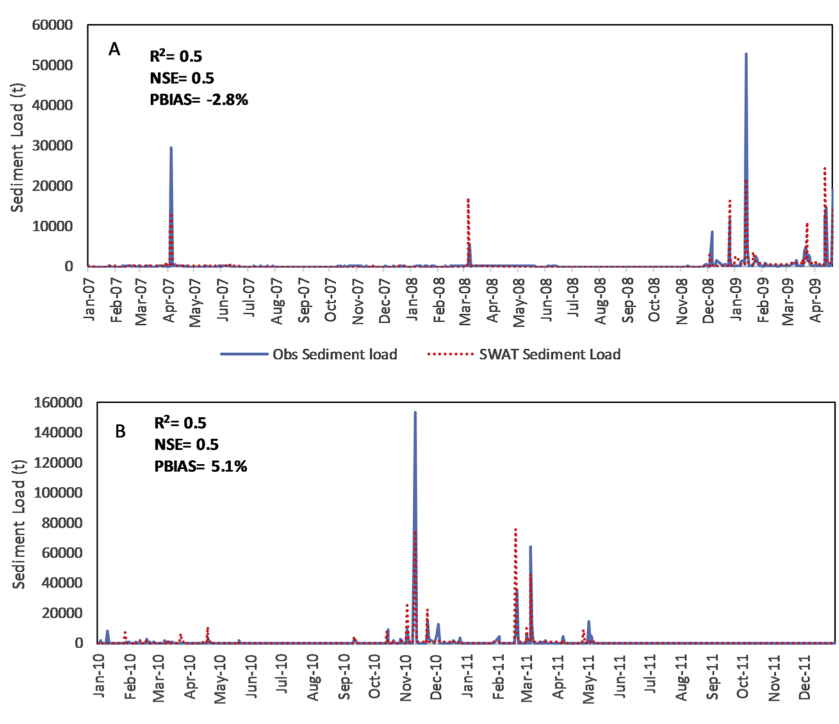

Fig. 3. SWAT sediment load calibration (A) and validation (B) at daily time scale and statistical indices: the coefficient of determination (R^2), the Nash and Sutcliffe Efficiency (NSE), and the Percent Bias (PBIAS %).

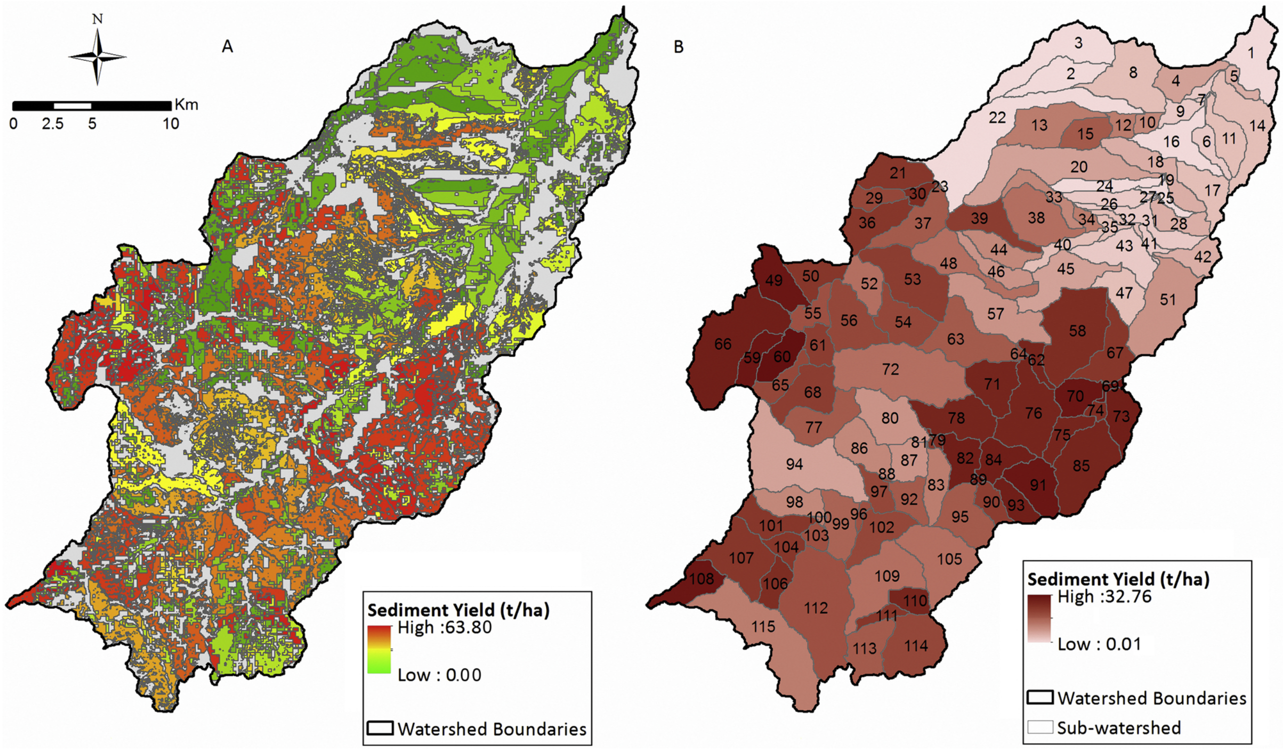

Fig. 4. Annual spatial distribution of the simulated sediment yield (t ha^{-1}), within the HRUs (A) and the sub-watershed (B): Baseline. Numbers in (B) refers to the SWAT sub-watersheds.

Table 5
Simulated monthly and annual average specific sediment load at the watershed outlet (for the study period2007-2011).

	Specific sediment load (t ha^{-1})				
Months	Baseline	BMP1	BMP2	BMP3	BMP4
1	1.64	1.26	1.06	1.37	0.99
2	0.92	0.72	0.68	0.81	0.61
3	1.22	0.97	0.96	1.05	0.80
4	0.23	0.18	0.19	0.20	0.14
5	0.02	0.01	0.01	0.01	0.01
6	0.04	0.03	0.03	0.03	0.03
7	0.06	0.05	0.05	0.04	0.03
8	0.01	0.00	0.00	0.01	0.00
9	0.09	0.06	0.07	0.08	0.05
10	0.24	0.17	0.17	0.21	0.14
11	0.76	0.61	0.60	0.64	0.49
12	0.72	0.54	0.41	0.59	0.41
Total	5.95	4.60	4.23	5.04	3.70

3.2. BMPs scenarios modeling

Four BMPs scenarios were simulated and their effectiveness was examined at a monthly and a yearly time scale at the watershed outlet from 2007 to 2011 (Table 5). BMP4 was the most effective to reduce specific sediment loads by 38 % (from 5.95 t ha^{-1} to 3.70 t ha^{-1}), followed by BMP2 with 29 % (from 5.95 t ha^{-1} to 4.20 t ha^{-1}) and by BMP1 with 22 % (from 5.95 t ha^{-1} to 4.61 t ha^{-1}). BMP3 exhibited only a marginal reduction of 15 % (from 5.95 t ha^{-1} to 5.04 t ha^{-1}). BMP4 and BMP2 were good alternative scenarios particularly in winter months, when the frequency of rainfall was high, with a reduction of 37 % and 30 %, respectively. Indeed, from December to April the biomass in the field leads to increase surface roughness and protects soils from eroding during intense rainfall events (Mtibaa et al., 2018). During the same period, BMP1 showed a reduction of 22 % and BMP3 a reduction of 15 %.

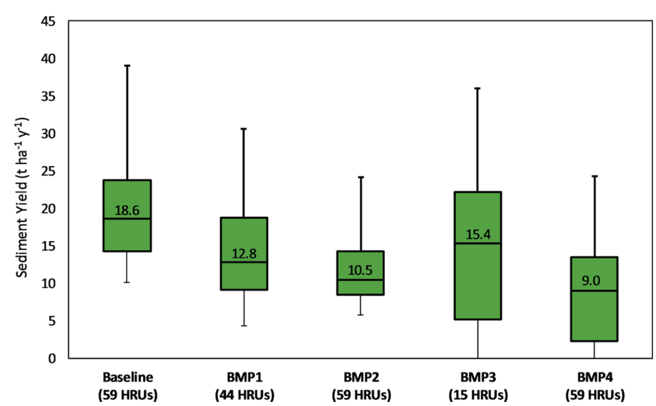

Fig. 5. Box plot of sediment yield including only the 59 target HRUs. The horizontal line within the box and the numbers indicates the median values, boundaries indicate the 25th and the 75th, whiskers indicate the 5th and the 95th percentile. The HRUs number within the brackets indicate the target HRUs for each BMP.

Annual sediment yield (t ha^{-1}) from the targeted HRUs was compared between the Baseline scenario and scenarios for the four BMPs (Fig. 5). The Baseline scenario again showed the highest sediment yield, both in terms of maximum and median value, while the implementation of BMP1 resulted in a decrease of the median sediment yield in the target HRUs of 5.8 t ha^{-1}. As expected, BMP2 is the practice with the greater impact on managing sediment yield. BMP3 yielded a median value similar to the Baseline though the values of the 25th percentile and the minimum were lower in this scenario. This is due to the fact that only 15 HRUs were considered for reforestation in the area of 1988 ha (18.6 % of total area of 59 target HRUs). An additional treatment to BMP1 by adding BMP3 (as prescribed to BMP4) was appreciable, as demonstrated by the sum of the positive impact of the two BMPs resulting in a decrease of the median and 25th percentile values (Fig. 5).

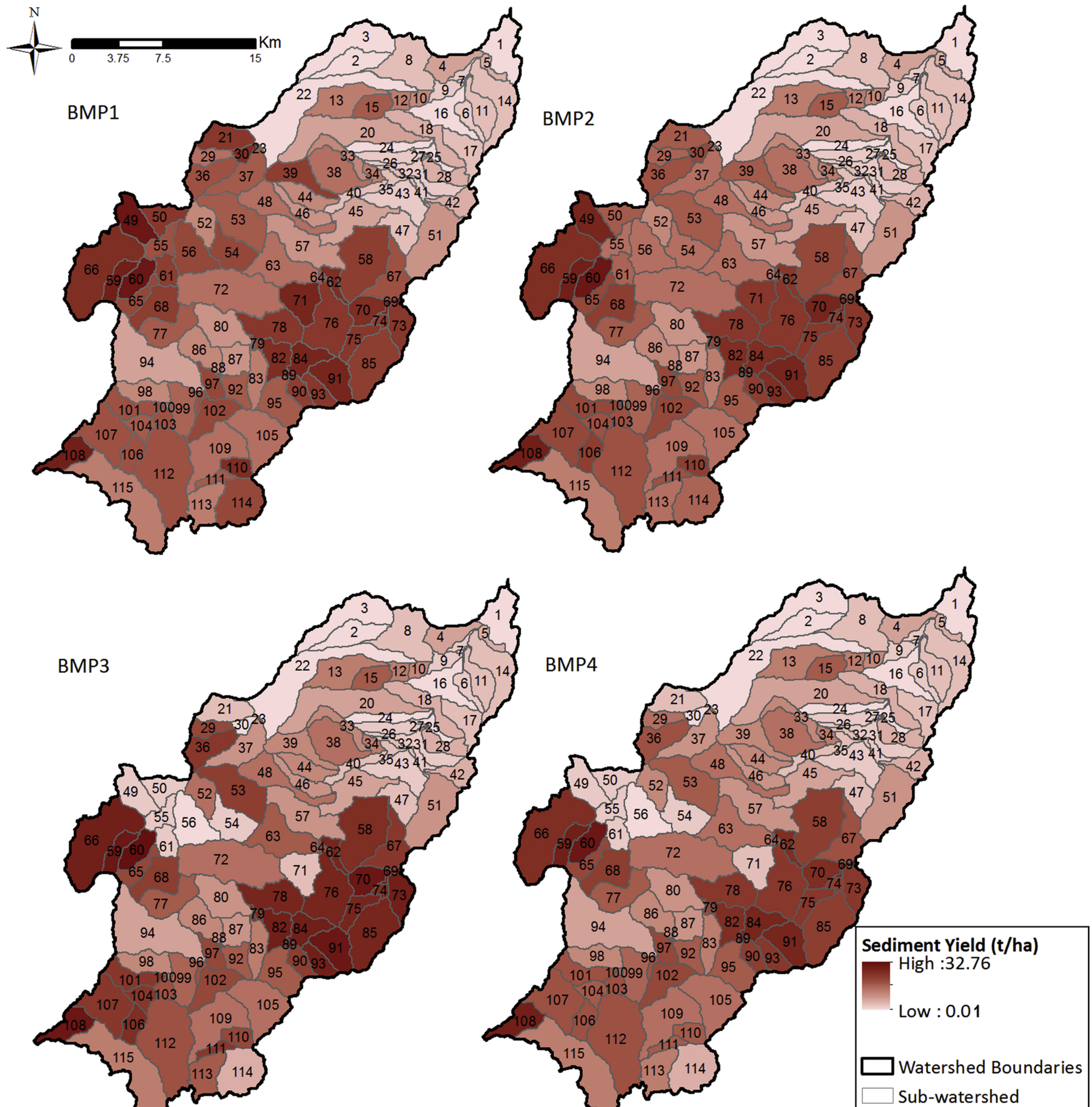

Fig. 6. Annual spatial distribution of the sediment yield (t ha^{-1}) for the different BMPs scenarios. Numbers refers to the SWAT sub-watersheds.

A visual comparison was carried out to analyze the spatial distribution of soil erosion areas at the sub-watershed scale between different BMPs scenarios. The baseline scenario (Fig. 4B) showed lower and upper values of sediment yield varying from 0.01 to 32.76 t ha^{-1}, respectively. Based on these values, in order to obtain a good visual result, the sediment yield maps were reconstructed with 20 classes. Fig. 6 depicts the four maps for the implemented BMPs scenarios showing the distribution of the sediment yield among the sub-watersheds. If only the target 59 HRUs and their sub-watersheds were considered, the scenarios BMP1 and BMP2 produced a reduction of the sediment yield by 36 % and 37 %, respectively, compared with the Baseline. BMP4 resulted in a high reduction of sediment yield by 52 %. BMP3 showed a higher reduction of sediment yield in particular sub-watersheds. For instance, sub-watershed 21 has about 85 % of the area occupied by winter wheat from which the average sediment yield was 8.74 t ha^{-1} in the Baseline. After implementing BMP3, the sediment yield drastically reduced to 0.17 t ha^{-1} in the same sub-catchment (Figs. 4B and 6).

3.3. Economic feasibility of BMPs

For economic analysis, the total farmer returns and the costs are referred to the year 2018, for which an average value of 3 t ha^{-1} was assumed for the winter wheat yield when managed with the conventional tillage (PSR, 2014 Agricultural census 2010). On the other hand, the SWAT model simulation showed a variability in crop yields among HRUs and between years, which was confirmed by local farmers. Hence, the value of 3 t ha^{-1} was adjusted for slope higher than 20 % to lower values but was increased for the scenarios of BMP1, BMP2, and BMP4. Table 6 shows the results derived from the economic feasibility

Table 6

Economic analysis comparing the Baseline and the four implemented BMPs scenarios. Baseline is for winter wheat production with conventional tillage; BMP1 is for contour farming; BMP2 is for No tillage; BMP3 is for reforestation and BMP4 is for the combination between BMP1 and BMP4. Where applicable the target HRUs were split into two slope classes (> or < 20 %).

Practice	Num. of HRUs	Area ha	Specific Yield (SY) Euro t^{-1}	Unit Price (UP) Euro ha^{-1}y^{-1}	Subsidy (S) Euro ha^{-1}y^{-1}	Subsidy first year (SFY) Euro ha^{-1}y^{-1}	Farm returns (FR[a]) Euro ha^{-1}y^{-1}	Production Costs (PC) Euro ha^{-1}	Investments Cost (IC) Euro ha^{-1}	(FR + SFY)-C[a] Euro ha^{-1}	FR/PC
< 20 %											
Baseline	44	8708	3.00	222	100		766	684		82	1.12
BMP1	44	8708	3.15	222	100		799	717		81	1.11
BMP2	44	8708	3.30	222	322		1055	631	63[c]	361-A[d]	1.67
BMP3	–										
BMP4	44	8708	3.15	222	100		799	717		81	1.11
> 20 %											
Baseline	15	1988	2.70	222	100		699	752		−53	0.93
BMP1	–										
BMP2	15	1988	2.97	222	322		981	695	69[c]	217-A[d]	1.41
BMP3	15	1988	87.50	25.7	2500[b] + 100[b]	6000	4849	2518[b] + 732[e]	6051	1548	1.49
BMP4	15	1988	87.50	25.7	2500[b] + 100[b]	6000	4849	2518[b] + 732[e]	6051	1548	1.49

[a]FR = (SY × UP) + S, C = PC + IC; [b] for the first 12 years; [c] transaction cost for the implementation of no tillage; A[d] the cost of depreciation (6000 Euro) must be added for each farm; [e] cost for the forest cut after 12 years.

analysis, which are presented in terms of surface unit (Euro ha^{-1}). For simplicity, the target HRUs were partitioned into two slope classes (< 20 % or > 20 %) even for those scenarios where all the target HRUs were managed with the same practice (e.g. Baseline and BMP2). Considering the Baseline, the analysis showed that the profit for the farmers corresponds to 82 Euro ha^{-1} in areas where slopes are less than 20 % and to a negative value (−53 Euro ha^{-1}) for areas with slopes higher than 20 %. The BMP1, which was implemented only for 44 HRUs with slope less than 20 %, showed a value almost similar to the Baseline (81 Euro ha^{-1}). Values obtained for BMP2 were 361 Euro ha^{-1} in areas with a slope less than 20 %. The value reduced to 217 Euro ha^{-1} where slope was higher than 20 %. The BMP3, which was applied only in steep slope areas (> 20 %) resulted in a value of profit of 4849 Euro ha^{-1} by discounting the further incomes despite the lack of harvest in the first 12 years. As expected, the unit profit obtained for BMP4 in the two slope classes was identical to the results highlighted for BMP1 and BMP3.

The analysis of the benefit cost ratio (FR/PC) for the private sector confirmed the results obtained with the economic feasibility analysis. The Baseline was economically profitable in non-steep slope areas (FR/PC 1.12) while it was not economically advantageous in areas with slope higher than the 20 % (FR/C 0.93). The BMP3 was economically the most profitable option in steep slope areas (FR/C 1.49) followed by BMP1 (FR/C 1.41). For slopes lower than 20 %, the BMP2 was the most profitable (FR/PC 1.67) option followed by BMP1 (1.11).

Table 7 shows the economic suitability at the watershed scale performed considering the value of CPL and of soil loss and, for each BMPs scenario, the implementation costs for the first, the second and after 12 years. From the economic point of view, the highest values of CPL and soil loss were obtained for the baseline, while the lowest were estimated for the BMP4 followed by BMP2, BMP1, and BMP3. Regarding the costs for the implementation, at the first year BMP3 and BMP4 showed higher costs compared to all other practices, while they are economically advantageous after 12 years when the forest is subjected to the first cut. After 12 years, no subsidies are devoted to the reforestation, therefore the TPC at the watershed scale become lower than the baseline.

4. Discussion

4.1. Modeling streamflow and sediment load

Modeling streamflow and sediment load using a hydrological model in the Mediterranean climate areas is a challenge (De Girolamo et al., 2015a,b). Nonetheless, the statistical results obtained in the Carapelle watershed were satisfactory for both streamflow and sediment load, showing that the SWAT model is a useful tool for simulating hydrological processes in these environments (Abouabdillah et al., 2014; Mtibaa et al., 2018). In particular, during the validation period (2010-2011) the model showed slightly lower performances for the streamflow mainly due to the extraordinary flood event recorded on 10th November 2010 when a daily runoff of 15.89 mm was recorded, that corresponds to 94 % of average November monthly amount (period: 1987-2007). The simulation of this extreme event caused an error of the model in predicting low flow in the subsequent period due to an overestimation of the baseflow (Fig. 2B). In SWAT, the values of CN are adjusted to take into account the antecedent soil moisture conditions, which are in this case close to saturation, and consequently, the infiltration capacity decreases, resulting in a streamflow increase (Niraula et al., 2012; Qiu et al., 2012).

The model showed a tendency to underestimate sediment load during the validation period. Among the various possible causes of the underestimation, some processes typical of the Mediterranean streams, such as bank collapse (De Girolamo et al., 2018) might not have been correctly quantified in SWAT with its Modified USLE equation and the Bagnold's stream power function (Duvert et al., 2012).

Input data can influence the estimation of streamflow and sediment

Table 7
Economic suitability at watershed scale at the first year, second year and after 12 years for each BMP.

Practice	LPL	CPL	CPL*UP Euro	Specific sediment load (t ha^{-1})	Soil loss value Euro	TPC first year[a] Euro	TPC econd year[a] Euro	TPC after 12 year[a] Euro
Baseline	0.021	2510	557115	5.95	4692233	4018699	4018699	4018699
BMP1	0.012	1508	334698	4.61	3597378	4018699	4018699	4018699
BMP2	0.010	1273	282619	4.20	3284563	6393211	6393211	6393211
BMP3	0.017	2043	453554	5.04	3910194	20916699	8988699	3819899
BMP4	0.009	1041	231138	3.70	2893544	20916699	8988699	3819899

* LPL is for Land Production Loss, CPL is for Crop Production Loss, UP is for Unit Price.
[a] TPC is for Total Practice Cost = (BMP subsidy × BMP ha) + (subsidy conventional tillage × conventional tillage ha). Soil loss replacement cost: 19.46 Euro t^{-1}.

loads (Heathman et al., 2008) especially in areas with complex topography (Tuo et al., 2016; Zeiger and Hubbart, 2017). In order to improve the performance of the model, the number of the sub-watersheds and HRUs was increased taking into account the topography of the upland areas. Indeed, the sediment yield generated from the MUSLE is strongly related to the slope and land use (Han et al., 2013) which are greatly influenced by changing the thresholds to discretize the sub-watersheds and, consequently, the HRUs. Decreasing this threshold an increment of sub-basins and HRUs was obtained and consequently an increase of average slope and increase of land uses present in the sub-basins. This study pointed out the relevance of the watershed delineation for simulating the impact of BMPs (Arabi et al., 2006).

4.2. Is it possible to reduce soil erosion?

The main purpose of the modeling carried out with the SWAT model was to quantify the effect of conservation measures applied in areas prone to soil erosion for an integrated watershed management. It has been demonstrated that the implementation of BMPs has to be chosen specifically according to the characteristic of individual sites (Xie et al., 2015; Lal, 2015), thus requiring a complex approach that must consider not only the reduction of sediment production, but also local environmental policies and economic feasibility (Haas et al., 2017). Hence, the impact of three single and one combined BMPs scenarios were evaluated, considering the sediment budget at the watershed outlet as well as at HRUs and sub-watershed scale. The implemented scenarios were selected by taking into account the guidelines provided by CAP and PSR. Generally, the model showed similar trends in terms of sediment reduction at the outlet and the median sediment yield at the HRUs scale.

Overall, at the watershed scale (Table 5) every modeled scenario gave a positive impact on the sediment load both at annual and monthly time step. In particular, as expected, the monthly analysis showed that the biggest reduction of sediment load was achieved in the winter wet months. The BMP2 produced the lowest sediment load at the outlet. The same scenario also presented a low value for the median sediment yield at HRUs level. Indeed, the peak runoff and sediment yield reduced as surface roughness (OV_N) increased (Tripathi et al., 2005; Ullrich and Volk, 2009). The positive effect of no tillage to sediment yield found in this study is also reported by Parajuli et al. (2013); Maalim and Melesse (2013) and Liu et al. (2014). No tillage has the advantage of easy applicability but involves an initial investment for the replacement of the agricultural machineries (e.g. sod seeder). Despite this, no tillage practice is attractive to farmers because it reduces the production costs if switched from conventional tillage (Pittelkow et al., 2015). Other benefits of no tillage include improvement in soil fertility and humidity in semi-arid areas for yield growth (De Vita et al., 2007). In particular, this practice is financed by the PSR through the regional measure 10.1.3 as a part of the GAEC suggested by the CAP (De Vita et al., 2007); hence, the initial investment could be easily regained. The BMP2 was found to be the most economically feasible based on the C-FR analysis referred to the first year of implementation. However, a long-term economic assessment should follow the current study to take into account two main aspects: firstly, the subsidy provided by the PSR may not be renewed in the new programming; secondly, a reduction of the grain yield could occur in particular wet years (Pittelkow et al., 2015).

The BMP1 is the second single-BMP scenario in terms of sediment load reduction followed by the BMP3. In the BMP1, the reduction of sediment load is caused by reduced surface runoff obtained by impounding water in small depressions (Gassman et al., 2006; Arabi et al., 2008). Like the no tillage practice, the BMP1 promoted higher yield by reducing the loss of fertile soil and by keeping more moisture in soils. For this reason, contour farming has been considered part of the structural practices useful to decrease sheet and rill erosion, together with strip cropping, contour buffer strips, terraces, grass terraces, and tile drain (Santhi et al., 2014; Ginzky et al., 2017). The BMP1 was selected because it falls within the GAEC required by the EU (Borrelli et al., 2016). In Italy, such practice is not so widespread because it is not included in the good agricultural conditions and so, usually, it is implemented only if an evidence of soil erosion is noticed. Farmers consider this practice as time consuming because of the creation of additional rows in corners and at the end of the field (USDA-NRCS, 2008). However, it does not require particular investments in agricultural machinery (e.g. tractor) while ensuring a reduction of sediment yield by 36 %. Currently, the required public investment for the BMP1 implementation is the same as the baseline, meanwhile, the benefits at the watershed scale are estimated in approximately 1.09×10^6 Euro y^{-1}, as a result of the minor productivity loss and of the minor soil loss value. Hence, this practice should be favored, making it mandatory by law, as many EU Countries have done (Spain, Romania, Belgium, Greece, Malta, and Cyprus) (Borrelli et al., 2016), or increasing the subsidies.

In areas with slope higher than 20 %, it was chosen to convert the land use to forest (BMP3). It was demonstrated that the production of sediment in the Carapelle watershed is strictly related to the slope increase and the type of land use (Ricci et al., 2018). Moreover, steep slope areas are the most sensitive to land use change, thus in order to maximize the effect on soil erosion, these areas have to be converted to grassland or forest (Zhang et al., 2014). The BMP3 showed a greater reduction of sediment yield referred to a single sub-watershed (Fig. 6) because of the change in land use from one that is prone to soil erosion to one that minimizes it. Forests reduce the production of sediment by decreasing the effect of the raindrop splashes and improving the soil protection from the detachment with surface litters (Xiao et al., 2015). Despite this, it is considered unrealistic to apply the reforestation to the entire watershed; indeed, implanting a forest in an arable land can cause a loss of profit for the farmers. The regional policy in Puglia finances this practice through the measure 8.1 of the PSR, allowing the use of fast-growing species that can give income in few years, and covers almost the 100 % of the cost of implant and maintenance. Furthermore, an additional subsidy is guaranteed for the first 12 years after the implant in order to replace the lack of income. In addition, the savings related to the fewer tillage to which forests are subject to with respect to winter wheat fields must be considered.

As resulted from the economic feasibility assessment, areas with slope < 20 % managed with the conventional tillage and contour farming showed similar levels of farm return, which means that this practice is, although not subsidized, a good alternative because it can reduce the sediment production and does not incur additional expenses. In areas with slope > 20 %, winter wheat production with conventional tillage was found to be unprofitable due to insufficient crop yield and higher expenses (e.g. fuel cost). The negative value is mainly caused by the production costs data used for the economic analysis that are at best average values for the Puglia region. A debate about the convenience in durum wheat production is not new. Pazienza and Zanni (2009) pointed out that if the crop production was low this production could be unprofitable when the market price goes down. It can be supposed that the production costs (i.e. agricultural workers salary) in marginal areas is lower than that guaranteed in economically developed regions.

The land use change from wheat to forest in the Puglia region can represent a good solution in steep slope areas where the conventional tillage is not sustainable (FR/PC 0.93). However, the lost income derived from the implementation of this BMP, at least for the first 12 years, could not find agreement among farmers. Hence, a broader economic evaluation should be considered taking into account the profit that can be earned from the first cut of the forest onwards (about 12 years after the implant). Considering the economic analysis reported in the PSR documents a further farm return of 4849 Euro ha^{-1} was obtained that generated the highest FR/C (1.49) for steep slope areas. Moreover, an increase of subsidies should be devoted to this BMP in consideration of the reduction of the use of fertilizers and, nutrient loads in surface and groundwater, which makes the environmental objectives of Water Framework Directive more easily achievable. Finally, as already evidenced by several studies (Strauch et al., 2013; Ramos et al., 2015; Mtibaa et al., 2018), the combination of two BMPs resulted to be more effective than a single BMP. The implementation of the BMP4 allowed obtaining a unit profit similar to the Baseline in areas with slope < 20 % while the benefit of the BMP4 implementation was greater in the steep slope areas (> 20 %). Indeed, the combination of BMPs suggested in the scenario BMP4 turned out highly effective in the region because of the significant reduction in sediment yield by almost 40 % on average as the practice focuses on managing steep slope areas while limiting farmers' capital investment.

4.3. Adoption of soil conservation practices: potential barriers

The results of this study demonstrate that watershed planning and management can be effective in responding to soil erosion. On the other hand, the results show that the programs of soil conservation must be implemented over long time frames and they require investments from the public and private sectors. These investments can constitute a limit in their applicability. The economic evaluation performed in this study highlights that, especially in areas where the crop production is low (< 3 t ha^{-1}), the public subsidies are necessary to sustain agriculture and to ensure environmental outcomes. Indeed, without subsidies, only the BMP1 could be a viable solution in areas with slope < 20 %. Therefore, a relevant public investment is necessary which can only be tackled on a European scale through the Common Agricultural Policy. This requires studies at European scale operating with a common methodology and standard datasets able to objectively identify areas where remedial measures are needed. However, local studies for monitoring human induced changes to the soil every 5-10 years are also needed to refine EU policies (Panagos et al., 2015a; Robinson, 2015).

Generally speaking, aside from income differences, several barriers limit the adoption of BMPs both in Italy and in many other countries. Social and political factors, as well as individual characteristics (i.e. farmer age and education) in addition to economic incentives, were found to influence farmer decisions to participate in environmental practices (Karali et al., 2014). A lack of awareness of the causes and effects of soil erosion, which induces most farmers to not relate BMPs to the indirect benefits, and the knowledge gaps in estimating the return of investments do not favor their adoption.

Despite the efforts and investments at EU, national and regional level to promote soil conservation measures and to support the agricultural system, the adoption of BMPs for soil erosion control has been not significant in the Apulia region. Here, some specific regional characteristics, such as the small size of farms, and institutional factors, such as the low availability of the regional consultancy services for gathering information and guidance, play a key role in influencing the BMPs adoption. Thus, conventional tillage is perceived as more profitable than contour farming. No tillage, which is the most widely applied conservation practice in the European countries due to its effectiveness in preventing erosion and flooding (Panagos et al., 2016), is not yet accepted by farmers in the Carapelle basin. This is probably due to the fact that it needs some time after changing from conventional to no tillage before reaching the benefits of improved soil structure.

The present study suggests that additional actions are needed to raise the awareness of the soil degradation problem and to remove the barriers that are limiting the adoption of BMPs. Some indirect interventions, such as information and technical assistance, should be upgraded to inform farmers and to support those producers who are willing but unable to change their agricultural systems to adopt BMPs. At the international level, platforms for raising awareness and proposing actions to address the global soil degradation problem should be sustained and supported as well as it is desirable the funding and research actions to promote resilience to soil degradation factors (Panagos et al., 2016).

5. Conclusions

The present study was aimed at developing a methodological approach to choose the most effective BMPs for sediment yield reduction and economic feasibility. To do this, sediment yield was estimated for an agricultural watershed in Italy under the conventional tillage management and for four other BMPs scenarios using the SWAT model. The specific farm returns including regional subsidies and costs were computed based on public data available in national and regional rural policies documents. The SWAT model was proved to be a useful tool for identifying source areas of sediment yield and for simulating various BMP scenarios.

At the watershed outlet, no tillage was found to be the single BMP scenario producing the highest sediment load reduction while reforestation the least effective. However, the analysis of the sediment yield revealed that reforestation was the best solution in steep slope areas because it guarantees a constant ground cover throughout the year preventing the soil particle detachment and, consequently, a lower loss of soil. Moreover, for steep slope areas, reforestation showed the highest farm returns considering the subsidies, which can be obtained from the rural development program (measure 8.1). Contour farming produced a fair reduction of sediment load, therefore, it could be considered a good alternative scenario for smooth slope areas. Despite this practice is not financed by regional programs, it could represent a viable solution even if there were not subsidies due to the low investment costs. Results obtained in this work highlights that there is no a "universal" BMP but the best solution must be identified studying the characteristics of each target areas.

This study shows that the programs of measures can be effective for responding to soil erosion, however, a relevant public investment is required to implement the measures. Moreover, additional actions are needed to raise the awareness of the soil degradation problem and to remove the barriers that are limiting the adoption of BMPs.

Acknowledgments

The authors would acknowledge Dr. Jeff Arnold for his precious suggestions concerning the modeling activities and the Grassland Soil and Water Research Laboratory USDA-ARS (Temple, TX) group for sharing constructive discussions. Thanks are also due to the reviewers for their useful comments and recommendations that helped us to improve the manuscript.

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