Soil erosion control on sloping olive fields in northwest Syria

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Abstract

Land degradation caused by soil erosion has been an environmental problem for many regions around the world for the past millennia. Dryland ecosystems are specifically prone to land degradation. The dryland areas are found in all continents, including the Mediterranean region, and are inhabited by almost 40% of the world's population. One of the countries were the process of land degradation in olive orchards is highly relevant is Syria, since it is already affected for large areas by soil degradation. One of the most important crops for income in Syria are olives. In the last decade, the number of olive trees in Syria has increased by 50%, now reaching 554.000 hectares. The problem with the recent expansion of olive trees in Syria, is that it expands into marginal and degraded lands.

This study therefore focuses on the quantification of the amount of hill slope erosion for an olive orchard with soil conservation structures in northwest Syria. The selected village already had been experimenting SWC techniques before and the selected fields contained semi-circular terraces around trees. Three olive orchards in northwest Syria, with a mean area of 0.42 ha, were used for Assessment of Current Erosion Damage (ACED) measurements. In one selected field, three 2m Gerlach troughs and 8 small collectors were used for the measurement of surface runoff and sediment concentration. The annual runoff and erosion values were modeled using the a spatially adjusted revised Morgan-Morgan-Finney (RMMF) model in PCRaster.

Based on the results of the different measurement techniques compared with the literature results, it has been concluded that the small collectors gave a better indication of the surface runoff and soil erosion values than the much lower Gerlach troughs measurements, due to the influence of a scale effect and the spatial heterogenity of the plots. The results from small collector measurements led to an annual expected runoff of approximately 879 m^3/ha. The corresponding runoff coefficients were approximately 15.3 %. The soil loss rates led to an annual expected soil loss of 5.9 ton/ha, based on small collector measurements versus an expected 9 ton/ha for the results based on the ACED measurements. Regarding the soil conservation structures, the ACED measurements indicate a strong decrease of soil erosion due to rill forming in fields with semi-circular terraces. However, the specific extent of the erosion control by the SWC remains under discussion.

Correlations among rainfall, runoff and sediment data further showed that the rainfall intensity is the driving factor influencing the runoff and sediment load, indicating a common process of surface runoff and soil loss generation. Unexpected runoff results were sometimes explained by the Antecedent Soil Moisture (AMC).

The model outcomes showed that the RMMF model is very well suited for annual surface runoff and soil erosion prediction on the field scale, predicting annual values of 826 m^3/ha for surface runoff and 8 ton/ha for soil loss, which are close to the measured values. Inner-field erosion pattern prediction was more difficult, leading to a slight to fair map overlap between the ACED erosion maps and the model outcomes based on the weighted kappa coefficient. This difference is expected to be the result of the dependence of the model on factors such as the DEM resolution, together with high spatial variability of field characteristics.

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1 Introduction

1.1 Introduction

Land degradation caused by soil erosion has been an environmental problem for many regions around the world for the past millennia. Dryland ecosystems are specifically prone to land degradation. The dryland areas are found in all continents, including the Mediterranean region, and are inhabited by almost 40% of the world's population. At this moment, high soil erodibilty is one of the main environmental problems in Mediterranean countries, were a high potential soil erosion risk exists for Italy, Spain, Greece and Portugal for respectively 27, 41, 43, and 68% of the total land area (CEC, 1992). In the Mediterranean region, soil erosion is strongly contributing to desertification, the process of land degradation in arid, semi-arid and dry sub-humid regions. Desertification is also a serious problem in highly affected Eastern Mediterranean countries, where for instance 10% of all land area in Syria is affected by desertification (UNEP, 2000).

Soil erosion can be described as the process whereby soil particles become loose and get displaced by erosive agents such as water and wind. In a broader sense soil erosion also includes gravity induced mass movements such as creep and landslides (Morgan et al., 2005). The high erosion susceptibility of the Mediterranean region is the result of the dry summer climate with low amounts of yearly rainfall (<800 mm) in combination with high rainfall intensities during winter. These winter rains cause for instance gullying, mass movements and flooding. But also the biologically marginality, relatively low organic matter content of the soil and the steep slopes of mountainous areas make the soil more erodible. Land use further affects erosion processes in several ways, e.g. by soil displacement by tillage practices, overgrazing, controlled burning and land abandonment (Poesen & Hooke, 1997).

In the Mediterranean region, olive trees have always been one of the most important sources of income and rural development. Olive fields and plantations are a typical land use for the Mediterranean region, since the species is suitable for relatively dry (<200 mm per year) and harsh environments, high temperatures and nutrient-poor soils. These characteristics gave it the reputations of "the rich tree for the poor environments" (France) and "the tree of lazy people" (Near East) (Pansit & Rebour, 1961; Tubeileh et al., 2004). However, olive production on slopes has been both accredited and criticized for their impact on soil erosion (Fleskens & Stroosnijder, 2007).

Erosion features in Mediterranean olive orchards can, in general, be ascribed to two different processes: water erosion and tillage erosion (Francia Martinez et al., 2006). Tillage erosion is the effect of the movement of a tillage tool on the soil redistribution. The extent of the soil movement depends on factors such as soil type, micro topography, tillage type and tillage direction (Barneveld et al., 2009). Tillage is important for erosion, since it induces roughness and therefore has an impact on runoff and erosion patterns (Poesen & Hooke, 1997). One other reason for soil erosion under olive orchards is the vulnerability caused by a low tree density combined with poor vegetation cover (Francia Martinez et al., 2006). Several model studies predicted high erosion rates of approximately 80 ton/ha/yr for olive orchards and steep slopes, e.g. Schoorl & Veldkamp (2001), although several field measurements showed much lower erosion rates between 0-3 ton/ha/yr (Poesen & Hooke, 1997; Kosmas et al., 1997). In a review article on soil erosion in olive groves, Fleskens and Stroosnijder (2007) argue that the reported range of erosion on hill slopes in both model and experimental studies is sometimes as large as 40-100 ton/ha/yr. They note the underrepresentation of the importance of a rock fragment cover for slope stability and the local differences in infiltration capacity in erosion studies and models. Two other factors influencing the representativeness of erosion measurements are the infrequent high intensity rain events and the up scaling of experimental results (Fleskens & Stroosnijder, 2007).

Modifications of soil management in olive orchards may highly affect surface runoff and soil losses. The limited number of studies on the influence of different soil management techniques still give strong evidence that soil management has an influence on runoff generation and related water erosion (Gomez et al., 2002). Management techniques such as cover strips, specific ploughing techniques or the introduction of a dense vegetation cover show a clear reduction in runoff coefficients (Francia et al., 2000; Raglione et al., 1999; Gomez et al., 2002). Work by Gomez et al. (2002) showed that, to a lesser degree than soil management practices, tree canopy size also affects erosion rates. Larger tree canopies gave larger areas with relatively high infiltration rates under the trees (Gomez et al., 2002).

An interesting case study were the process of Mediterranean land degradation in olive orchards is highly relevant is Syria. Large areas of Syria are already affected by soil degradation, with estimates that this costs the country about 2.5 % per cent of total GNP (MSEA, Syria, 1997). However, in the last decade, the number of olive trees in Syria has increased by 50%, now reaching 554.000 hectares with 85.000.000 trees planted (Tubeileh & Bruggeman, 2007; Issa, 2006). The main olive regions are shown in Figure 1-1. The shift towards olive production is mainly socio-economic; diversifying income generation and increasing water-use efficiency with suitable crops (Tubeileh et al., 2004). Besides the economic importance, the olive cultivation also has a cultural function, since it has been planted for thousands of years and is mentioned in archaeological artefacts dating back to 2400 BC (Issa, 2006).

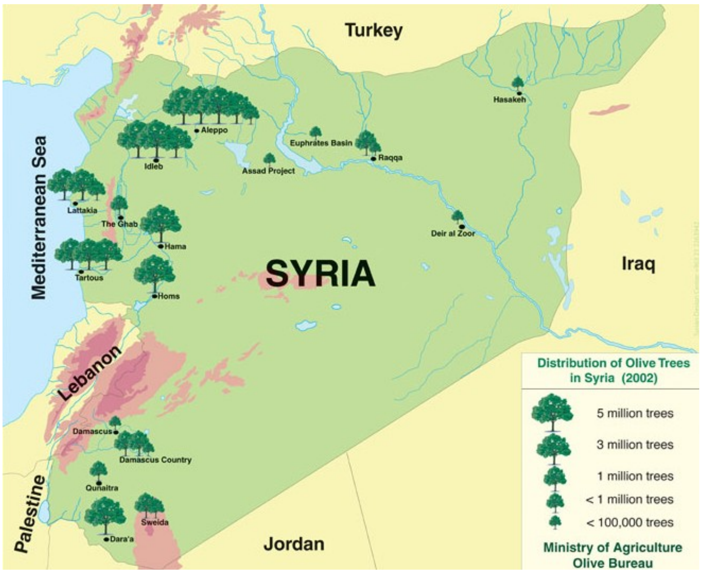


Figure 1-1 Distribution of olive trees in Syria. Source: MA Olive bureau, 2002

However, the problem with the recent expansion of olive trees in Syria, is that it expands into marginal and degraded lands. Although olive cultivation is a useful resource for marginal lands, previous research in the Khanassar Valley in Northern Syria showed the result of this expansion; drought problems and related extensive groundwater pumping. And since olive trees are often grown on steep slopes, land degradation by uncontrolled grazing, erosion and soil loss are important issues in this area (Tubeileh & Bruggeman, 2007).

In many agricultural areas with poor (small scale) farmers, like Syria, inexpensive indigenous soil and water conservation (ISWC) techniques are used to reduce water erosion. However, there is limited information on ISWC techniques in the Mediterranean and West Asian region and a general lack of quantification of ISWC effects on soil erosion rates. One exception is the use of vegetative strips for reduction of surface runoff and soil erosion. Previous studies showed the effectiveness of this technique, even leading to reduction of the event mean sediment concentration by a factor of four (Le Bissonnais et al., 2004; Raya Martinez et al., 2004; Francia Martinez et al., 2006). Previous research in Kenya and the West Bank showed the potential of trash and stone lines, a technique used across arid and semi-arid regions, for reduction of runoff (Wakindiki and Ben-Hur, 2002; Al-Seekh & Mohammad, 2009).

In Syria, several techniques for soil conservation within olive orchards can be found. In Western Syria there is an ancient tradition of stone wall bench terraces. Also examples of small stone walls or vegetation strips on contour lines can be found. In North Western Syria, previous research on conservation techniques has focused on (indigenous) water harvesting techniques, since the area has severe water scarcity problems. One of the used techniques, an annually constructed V-shaped micro catchment around trees is also influencing runoff and erosion. However, none of those techniques have been quantified for this region.

Besides experimental data, modelling is often an useful method to determine the effect of erosion processes for different time and spatial scales. Numerous erosion models have been developed, varying in spatial and temporal scale. A major paradigm shift has occurred since the 1980's from statistical and empirical models to process-based models. The physically based process models use the equations of mass conservation and momentum conservation to calculate sediment flow (Aksoy & Kavvas, 2005). In the last decade several soil erosion models for the Mediterranean region have been built, which vary in the spatial scale of application. The empirical USLE and RUSLE models and the process-based EUROSEM model have been applied to the plot and field scale, while for instance the Mediterranean focussed MEDALUS and MEDRUSH models are targeted towards hill slope and catchment scale, respectively. One of the main complications with erosion modelling for the Mediterranean region is the sporadic but intense nature of runoff events (Poesen & Hooke, 1997). There is a limited number of studies undertaken to model slopes with olive orchards and existing studies vary widely in approach and focus. Gomez et al. (2002) developed a physically based model for single events, which they calibrated and validated with field experiments and previous research results. An approach focusing on multi-scale landscape processing, with the main purpose being prediction of long term soil distribution for different scenarios, was developed by Schoorl & Veldkamp (2001).

There is only a very limited amount of modelling studies done, which incorporate the effect of ISWC techniques on hill slopes. The exception are studies focussing on the practice of vegetative filter strips (VFS), which are areas of vegetation designed to remove sediment and pollution from surface water runoff. None of the model studies which incorporate the effect of ISWC techniques focus on olive orchards (Van der Zanden, 2009).

1.2 Research objectives

The main objective of this study was to quantify the amount of soil erosion on a hill slope scale for an olive orchard with soil conservation structures in northwest Syria.

This main objective was divided into the following sub-objectives:

1. To quantify the amount of hill slope erosion on a field scale
2. To assess the suitability of the soil conservation structures, which were applied during the field observation period
3. To model the measured amounts of hill slope erosion in olive orchards using the revised Morgan, Morgan and Finney (RMMF) erosion model.

2 Material and Methods

2.1 Area description

The olive orchards selected for this study are located in the village of Maghara in the northwest of the Syrian Arab Republic, which is part of the Afrin district (36°32’24”N 36°39’21” E). The location is approximately 5 km from the Turkish border and about 130 km northwest of Aleppo (Figure 2-1). The typical landscape of the area consists of steep hillsides and deeply incised valleys. The valley bottoms are gentler, because of the accumulation of slopewash and deposits (De Pauw et al., 2004).

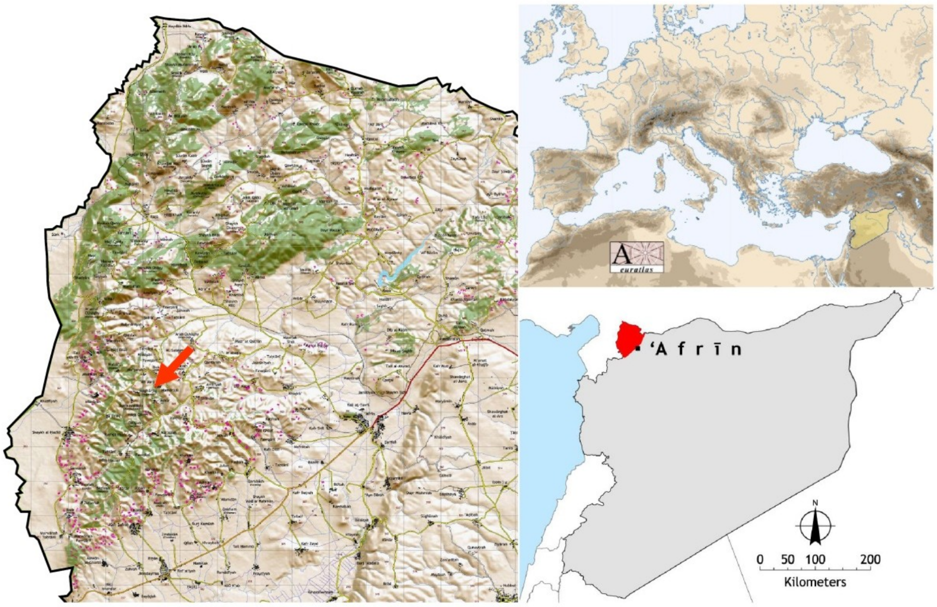


Figure 2-1 Location field work area in Afrin district, northwest Syria

The climate is Mediterranean, Cs by the Köppen climate system, therefore characterised by moderate temperatures and rains in the winter, and dry and hot summers. The mean annual temperature is 17 degrees. The annual rainfall is 400-650 mm, which is particularly concentrated in the period between October and May. This is typical for the North-western part of Syria, since about 60% of Syria has a desert or semi-desert climate with an annual rainfall below 200mm. The annual reference evaporation (ET_0) is about 1200-1600 mm, which is a typical value for the coastal and mountainous areas of Syria (Bruggeman et al., 2005).

The research area is characterised by carbonate-type rock, with calcisols and gypsisols (FAO classification) as the dominant soils in the area (Bruggeman et al., 2005). The soils are in general light to dark brown and moderately fine-textured. The high content of loam (>40%) makes the soils susceptible to erosion (Morgan, 2006). The soils contain limestone fragments, which occupy approximately 10 percent of the solum. In most places, the soil depths have been reduced to a depth of less than 25 cm, under which the limestone bedrock is found.

The vegetation cover in the area has changed strongly during the past 100 years. In the period of 1913-1920, the native forest in the area started to be cleared. Gradually in the ensuing period, farmers replaced the forest with olive groves, as well as almond, walnut and other forestry plantations (De Pauw, 2001). Today, almost all hill slopes are planted with olives. The orchards are mainly planted with the Zeiti variety, which is a Syrian olive variety which is popular because of the high yield and high oil content (30-32%) but has a relatively low drought tolerance. The farmers mix this with some trees of the Qaisi variety, which has a higher drought tolerance but a lower yield, used for table olives. Some farmers use intercropping with other plants or trees, especially grape (*Vitis vinifera L.)* (Tubeileh et al., 2004).

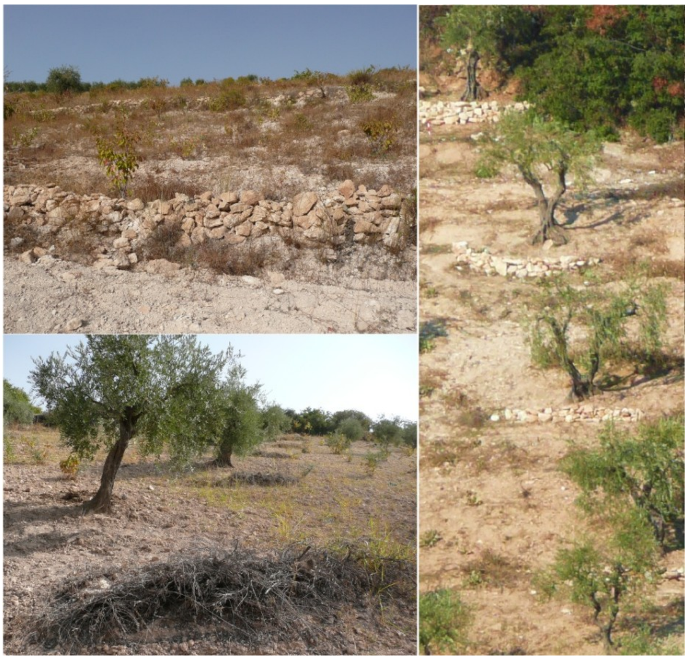


Figure 2-2 Examples of soil conservation techniques in Maghara, Syria. Top left: stone walls, bottom left: vegetation strips, right: semi-circular terraces. Photos: E.H. van der Zanden

The farmers in Maghara have been experimenting with SWC techniques such as semi-circular terraces around trees, continuous stone walls and vegetative strips (see Figure 2-2). A survey in September 2009 has indentified 22 farmers using these techniques (Table 2-1). Three of these farmers also used grape intercropping. However, the impacts of those measurements at hill slope and watershed levels have not been quantified so far (Van der Zanden, 2009).

Table 2-1 Soil water conservation techniques practiced by farmers in Maghara, Syria

SWC techniques	*Nr. of farmers*
Semi-circular terraces	10
Stone walls	5
Combination (Semi-c. terraces/stone walls/ veg. strips)	5
Vegetation strips	2
Total	22

Because of the existence of SWC techniques in the village, the village was chosen as a benchmark site for a project by the UNDP (United Nations Development Programme), which is titled "Land and Water Management, Diversification and Micro-Credits to Combat Land Degradation and Improve Livelihoods in the Mountains of Afrin". This project aims at sustainable and productive use of land and water resources in degraded mountain watersheds in combination with stable livelihoods in the olive mountains of northwest Syria. The project, which started in 2008, gives farmers the opportunity to get a microcredit to invest in land management or job diversification. The project is executed by the Integrated Land and Water Management Unit of the International Center for Agricultural Research in the Dry Areas (ICARDA).

In Maghara, the field management differs per farmer. In general the main periods for soil tillage are autumn, winter and spring. The most common practice is to use a fadhan; a single-furrow metal plow drawn by a mule. In general, the fadhan is used for steep and irregular fields, while mechanized tillage is used for the larger and easier accessible fields. Some farmers practice contour plowing, while others go for the erosion generating top down way of plowing. In general, most farmers don’t use pest and weed control but use some fertilizer or manure. However, the field management is limited due to the lack of economical possibilities. The UNDP project has changed this for some farmers, who use the money to add manure or nutrient rich soil to the areas around the trees. The harvesting season is generally from the end of October to the end of December, sometimes into January during late years, and is generally done by handwork with family members with nets under the tree and ground collection. The collection is by hand, since the manpower is relatively cheap but is time consuming since the speed of collection is only 6-20 kg/h/worker. (Bruggeman et al., 2005; Abdine et al., 2007).

2.2 The revised MMF model

The MMF model is a process-based model developed by Morgan et al. (1984) to predict annual soil loss from field sized areas on hill slopes. In this study, the revised version of the MMF model (RMMF) was used. The most important change in the revised MMF model is that soil particle detachment by raindrop impact includes canopy height and leaf drainage and that detachment by overland flow is added. In 2008, Morgan & Duzant (2008) made modifications to the RMMF model to include the effect of vegetation and crop cover on the soil loss. In this study, several elements of Morgan & Duzant (2008) were incorporated in the RMMF model.

Water phase

In the water phase, the amount of surface runoff and the kinetic energy of rainfall is calculated, which are the inputs for the sediment phase. It therefore requires rainfall related input, such as the rainfall intensity (I, mm h^{-1}) and average annual rainfall (R, mm).

The kinetic energy of rainfall (E, J m^{-1}) is calculated for the direct trough fall (DT; mm) and the leaf drainage (LD; mm) separately, using the equation for kinetic energy of rainfall by Zanchi & Torri (1980). The leaf drainage is the rainfall which falls on the canopy cover, the direct trough fall is the rainfall which directly reaches the ground. PH is plant height (m).

$$KE(DT) = DT\left(9.81 + 11.25\log(I)\right) \tag{1}$$

$$KE(LD) = LD\left(15.8 + PH^{0.5} - 5.87\right) \tag{2}$$

The annual surface runoff (Q; mm) is calculated using a relation between annual rainfall, and the mean number of rain days (RN) and moisture storage capacity (Rc; mm):

$$Q = R\exp\frac{-RC}{(R/RN)} \tag{3}$$

The RC is a function of the bulk density (BD; Mg m^{-3}), soil moisture content at field capacity (MS; w/w), effective hydrological depth (EHD; m), and ratio of actual to potential evapotranspiration (E_t/E_o).

$$RC = 1000\,MS\,BD\,EHD\left(\frac{E_t}{E_o}\right)^{0.5} \tag{4}$$

Sediment phase

There are two forms of soil particle detachment that are calculated in the RMMF model; soil detachment by raindrop impact and by runoff detachment. The soil particle detachment that is caused by raindrop impact (F; kg m^{-2}) is calculated as a function of kinetic energy of rainfall (KE; J m^{-2}) and soil erodibility (K; g J^{-1}). The values for soil erodibility are different for three texture classes (t); clay, silt and sand. The initial values of K were 0.1, 0.5 and 0.3 g J^{-1} for clay, silt and sand respectively, based on data from Quansah (1982). Included is the influence of the stone cover (ST; fraction), since this will protect the soil from detachment. The calculations are done separately for the three texture classes, using the fraction of the texture class (f).

$$F_t = K_t f_t (1 - ST) KE\, 10^{-3} \tag{5}$$

For the soil particle detachment by runoff (H; kg m^{-2}), an experimental function is used that combines the fraction of the texture class (f), runoff (Q; mm), slope steepness (S; °), soil resistance (Z), ground cover (GC; fraction) and detachability of the soil by runoff (DR; g mm^{-1}). H is calculated separately for each texture class. Equation 7 gives the total annual detachment rate.

$$H_t = DR_t f_t Q^{1.5} \sin^{0.3} S (1 - (GC + ST)) 10^{-3} \tag{6}$$

$$\sum_{t=1}^{3} (H_t + F_t) \tag{7}$$

The annual transport capacity of overland flow (TC; kg m^{-2}) is a function of the surface runoff (Q), crop cover and management factor (C), which is taken as the product of the C and P factors of the Universal Soil Loss Equation, and the slope (Morgan, 2001).

$$TC = C\,Q^2 \sin S\, 10^{-3} \tag{8}$$

The transport capacity of surface runoff is compared with total annual detachment rate and the lower of the two is taken as the annual soil loss (kg m^{-2}).

Spatial adjustments

A spatially distributed modelling approach is most suitable to simulate the high heterogeneity in the field. Since the RMMF model is not spatially distributed, the model had to be adjusted. In this study, the grid based and open source GIS software PCRaster (van Deursen, 1995) was chosen as modelling software.

Since PCRaster is grid based, all input variables had to be supplied in map form covering all grid cells. A small grid cell size of 0.2 m was chosen for this study, to allow for spatial variability in the data. The digital elevation model (DEM) however is most restricting in this respect, since it is based on a 2 x 2 m grid and thus has a lower spatial resolution than the grid size selected for modelling. The calculations of runoff and erosion were done for every grid cell and routed along the local drainage direction network (LDD). The LDD algorithm in PCRaster is based on the steepest down slope gradient in the neighbouring cells.

The accumulation of the runoff along the local drainage direction network (LDD) can be calculated in different ways. In this study, it was calculated using the method proposed by Morgan (2001) for the RMMF model, which has no reinfiltration of runoff from the upper drainage area (equation 4). In this approach, the runoff in mm is converted to volume per unit width (m^2) and then accumulated over the LDD network. The calculated runoff in m^2 is afterwards converted back to millimetres using the length of the flow path (FL; m), see equation 8. In equation 4, the runoff (Q) and rainfall (R) are in millimetres.

$$Q_{mm} = \left(Q_{m^2} / FL\right) 1000 \qquad (9)$$

Sensitivity analysis

A sensitivity analysis was used to test the variation in the output of the model, as result of the variation in the input of the model. Therefore it can be used to determine the input parameters with the most effect on the runoff and soil loss predictions. When conducting a sensitivity analysis, all other parameters are constant, expect the parameter of interest. Here, the approach was to use an average linear sensitivity (ALS) coefficient, which gives a ratio of the relative change in output to a relative change in input. All values were normalized, which makes this approach suitable for comparing parameters with different units.

$$ALS = \frac{\dfrac{O_2 - O_1}{\bar{O}}}{\dfrac{I_2 - I_1}{\bar{I}}} \qquad (10)$$

O_1 and O_2 are model output values, which are obtained using the I_1 and I_2 input values. $\bar{O}$ and $\bar{I}$ are the respective mean values, normalizing the values (Morgan & Duzant, 2008).

2.3 Site characteristics

After a GIS mapping of the farmers in Maghara using SWC techniques, three suitable sites were selected for the field research (see Figure 2-3).

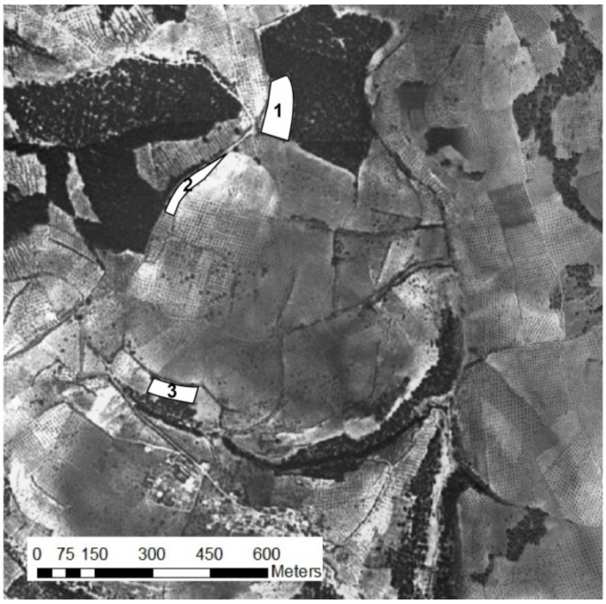


Figure 2-3 Three selected study sites around Maghara, Syria.

The three fields have almost similar conditions for soil type and tillage techniques (Table 2-2). All three fields were selected to have clear upper boundaries. Each field forms a paired plot, consisting of an area with only olive tree rows and an area with semi-circular terraces. This enabled to quantify the effect of the semi-circular terraces on the surface runoff and sediment load.

Table 2-2 General characteristics of the three study sites in Maghara, Syria.

Field	1	2	3
Area [m^2]	5808	3353	3435
Semi-circular terraces	33	18	25
Nr. of trees	143	63	58
Slope angle	11 ~ 12°	18 ~22°	19°
Soil type	silt loam	loam	clay loam
Tillage type	fadhan	fadhan	fadhan
Fertilizer	chemical/manure	chemical/manure	chemical/manure
Upper field	asphalted road	agricultural land	agricultural land
Border barrier	hedge and road	inexistent	hedge

2.4 Data collection

In this study several different erosion measuring methods are applied. On the field scale, a visual assessment of erosion was undertaken. The technique used is the so-called Assessment of Current Erosion Damage (ACED; Herweg, 1996). For one field, this data was supplemented with surface runoff and soil loss measurements from unbounded plots, using Gerlach troughs for collection.

2.4.1 Assessment of Current Erosion Damage

The Assessment of Current Erosion Damage (ACED) method is a "rough field method" identifies biophysical factors influencing erosion and erosion symptoms. An estimation of the rill and gully erosion is made by taking a number of measurements of the depth and width of rills and gullies to get the average cross-section. Together with the length of the rill, the volume of soil displaced from the rill can be calculated and can be converted to mass using the bulk density of the soil. When the period is known in which the rill has formed, a rate of soil loss can be estimated (Herweg, 1996).

Figure 2-4 Measurement of rills for the ACED erosion assessment method in field 2. Photo: E.H. van der Zanden

The ACED data collection was done in all the selected fields at the beginning of November, 4, 11 and 19 November 2009, and in the end of January, 26 and 27 January 2010 (Figure 2-4). These two surveys were used to compare the situation at the start of the research with the situation after a number of rainstorm events.

2.4.2 Unbounded runoff plots

Actual measurements of surface runoff and soil loss using unbounded plots were done at one field, number 3, only. One of the advantages of unbounded plots versus bounded plots is that it resembles the natural condition as closely as possible. Boix-Fayos et al. (2007) also note that closed plots suffer from detachment-limited conditions for soil loss, since there is an exhaustion of available material over time.

The field was divided into 4 different areas of approximately the same width. Two of the areas had semi-circular terraces, while the other two had no conservation practices. The surface runoff, including sediment load, was collected at the end of the hill slope for plot 1, 2 and 4. The collection was done using Gerlach troughs, named after their inventor. Gerlach troughs are simple metal gutters, in this situation of 2 m width and 0.1 m length, with closed sides and a movable lid (Morgan, 2006). The collection 'envelope' was connected with an outlet pipe to a collecting container. The gutter was dug into the soil and connected to five splitters, of which one was connected with a pipe to a collecting container on the downstream side. To make sure that no overflowing would take place during extreme weather events, the tanks were connected by a spillover system to additional tanks (Figure 2-5).

Figure 2-5 The experimental set-up for surface runoff and soil loss measurements in field 3. Left: Gerlach trough set-up Right: Small collectors. Photos: E.H. van der Zanden

The troughs were placed at the bottom of the site. To see the effect of the slope on the runoff and sediment loss, one of the areas without SWC techniques had 8 small collectors. These collectors, based on the Gerlach trough principle and with a gutter of 0.2 m in width and 0.05 m in length, were placed pair wise from the upper site to the bottom of the profile (Figure 2-6). The collectors were placed outside each others downslope path, to ensure an undisturbed flow from the slope crest to the trough. These small collectors were used to evaluate the possible variation of erosion and surface runoff along the slope. On the fields with conservation techniques, four small collectors were placed to have an indication of the runoff and soil loss both incoming in the semi-circle terrace as well leaking through the structure.

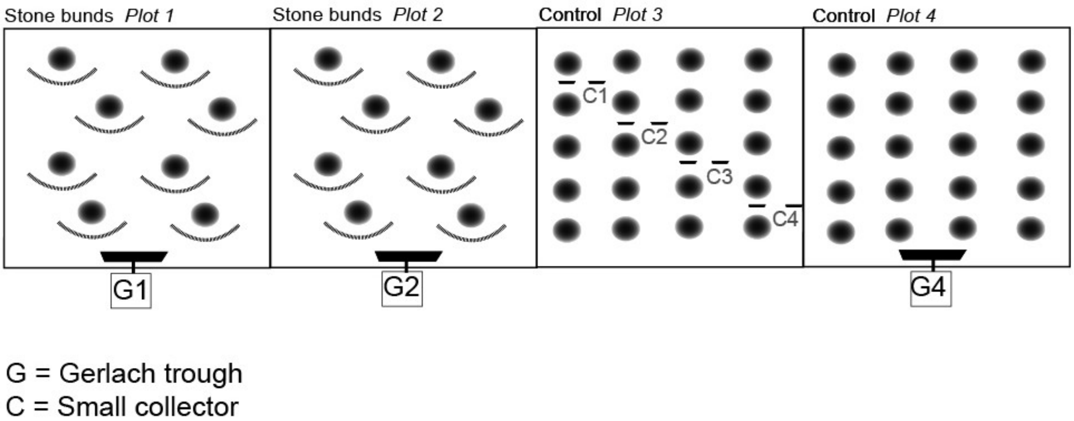


Figure 2-6 Schematic experimental set-up for surface runoff and soil loss measurements in field 3.

The plots were constructed such that it was still possible to apply cultivation and other farm operations. The collection of the runoff samples was done after each rain storm. The samples were collected in 300 ml plastic bottles after stirring the mixture vigorously to avoid the settling of large soil particles and to keep the materials in suspension for estimating runoff and soil loss. Later on, the samples were analyzed in the Soil and Water laboratory of ICARDA to determine the sediment concentration.

Meteorological data for Maghara were collected from a weather station which was located 50 meters from the study site. This weather station was placed in September 2009 and registered rainfall data at 5 minutes interval, including temperature, wind speed and direction, and humidity.

2.4.3 Meteorological data

Meteorological data for Maghara were recorded from September 2009 on at the meteorlogical station and were suplemented with long term rainfall data records for Yakhour. The village of Yakhour is located 5.1 km from Maghara and has rainfall records available for the period between November 2000 to present. This weather station registered rainfall data at hourly intervals, together with other meteorological data such as temperature, wind speed, wind direction and humidity. The separation between rainfall events was done according to the method of the RUSLE erosion guide, which regards rainstorms that are at least 6 hours distant from previous or next events as separated events (Wischmeier & Smith, 1978).

A variable which was derived from the precipitation records is the antecedent rainfall. It gives an indication for the relative wetness or dryness of the soil. Antecedent moisture conditions (AMC) are high when there has been a lot of recent rainfall and the soil is moist. To categorize the rainfall events with AMC values, the categorization of National Engineering Handbook (1964) was used with the dormant season values (Table 2-3).

Table 2-3 Antecedent rainfall limits for antecedent moisture condition classes, based on dormant season values of the National Engineering Handbook (NEH-4, 1964)

AMC group	Total 5-day antecedent rainfall [mm]
I	<13
II	13 to 28
III	>28

2.4.4 Soil sampling and laboratory analysis

The different soil parameters needed for the modelling were based on soil samples, which were taken on 9 November 2009. All main plots were sampled from the upper soil layer (0-20 cm) for the upper, middle and lower parts of the plot at the start of the fieldwork period to determine soil characteristics. At each area of the plots, three combined soil samples were taken along the contour with a distance of 10 meter and mixed. For field 1 and 2, soil samples were taken for the area with semi-circular terraces and for the part without conservation practices, which makes six samples for every field. However, for field 3 the four different areas under investigation were all sampled for the lower, middle and upper slope.

A separated part of the soil samples were sieved trough various mesh sizes (10, 5, 4, 2, 1, 0.5 and 0.1 mm) with minimum vibration to determine the aggregate size distribution. For this, a Retsch 3D series sieve shaker was used (Bruggeman et al., 2005). In the laboratory, the pipette-gravimetric method was used to determine the quantity of the silt, sand and clay fractions (Ryan et al., 2001). The proportion of stone cover was calculated based a ratio between the fine soil fraction and the total soil volume (PSU, 2010).

The soil samples were also used to determine the soil moisture content, bulk density and the porosity. The soil moisture content was measured at field capacity in the laboratory, using standardized methods for field capacity moisture determination for pF 2,5 (Ryan et al., 2001; Hesse, 1971). The bulk density is the mass of soil particles divided by the total volume they occupy. In this study, the excavation method was used (Blake & Hartge, 1986). The porosity is the percentage of a body of sediment or rock that consists of open spaces and therefore also determines the amount of water that sediments can hold. For the sampling, an aluminum core was used and the free pore space was determined in the laboratory (Carter & Gregorich, 2008).

2.4.5 Field parameters

Several parameters were measured in the field. The most important ones were the elevation, slope steepness and several vegetation parameters. The slope was measured in the field, using a geographical compass and could be compared to the slope generated from the digital elevation model (DEM) in ArcGIS. The digital elevation model (DEM) was measured in the field on a 2 meter grid, using a tilting level.

Several vegetation parameters were surveyed, including an estimation of the canopy cover, the ground cover, the leaf area index and the plant height. For field 3, these parameters were observed per olive tree and a detailed ground cover map was made. For field 1 and 2, these parameters were based on samples of 20 trees and average ground cover.

2.4.6 Parameters based on literature

Although much of the input for the RMMF model was derived from rainfall and soil measurements, some of the parameters were too complicated or time consuming to measure in the field. The values of these parameters were based on relevant literature and calibrated during the modelling phase. For soil parameters, the soil detachability index, the effective hydrological depth, the cohesion of the surface soil and the C-factor were based on literature values.

The soil detachability index (*K*) was used for with different values for sand, silt and clay, based on Quansah (1982). However, especially the values for the clay fraction were used with care, since the detachability of clay is high variability per clay type and aggregate stability.

The crop cover management factor (C) of the RMMF model combines the cover (C) and support (P) factors of the Universal Soil Loss Equation. The value used in this study was based on the work of Gomez et al. (2003), who calculated crop cover management factors for different soil management scenario's for olive orchards.

The effective hydrological depth of soil replaces the rooting depth of the original MMF model. The EHD is used as the soil depth where the soil moisture storage capacity controls surface runoff generation. The EHD is influenced by plant cover, root depth and density and effective soil depth. Morgan (2001) gives guide values for the EHD (Table 2-4). The EHD was modified in the calibration of the model.

Table 2-4 Guide values for effective hydrological depth based on Morgan (2001)

Condition	*EHD [m]*
Bare shallow soils on steep slopes; crusted soils	0.05
Bare soil without surface crust: no impermeable barrier in top 0,2 m	0.09
Row crops (e.g. wheat, barley, maize, beans, rice)	0.12
Row crops intercropped with legumes/grasses	0.15
Mature forest, dense secondary forest	0.20

The cohesion of the surface soil (COH) is often measured in the field by using a torvane (Morgan, 2001). Since a torvane was unavailable, the values were based on the experimental results of De Baets et al. (2008), who calculated transport capacity efficiencies and corresponding soil cohesion values using the EUROSEM model for soils with different amounts of plant roots. All calculations were based on the same soil type, silt loam, which is representative for the sites in this study.

Two meteorological factors of the MMF model were based on previous studies, namely the ratio of actual to potential evapotranspiration and the intensity of erosive rain. The ratio of actual to potential evapotranspiration was estimated using CropWat 8.0. CROPWAT 8.0 is a computer program, developed by the Land and Water Development division of FAO, for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. Also, it includes climatic data for calculation of reference evapotranspiration (ETo) (FAO, 2009).

2.4.7 Statistical analysis of rainfall data

A correlation analysis and preliminary statistical examination of the rainfall, runoff and erosion results was performed to explore the hydrological relationships at the site. One of the main factors used for the analysis of the rainfall data, is the rainfall erosivity index.

To review the data and to detect trends and uncertainties, descriptive statistics were calculated for all variables. Examined were the minimum value, maximum value, the mean, the standard deviation, the variance and the skewness. Variables with a low N (<7 samples) or a high skewness (>3.5) were excluded for further statistical analysis. After close examination of the descriptive statistics and the skewness factors, it was decided to remove the data of December 30, 2009, since these values were based on daily precipitation values due to malfunctioning of the data logger.

2.4.7.1 Rainfall erosivity index

Soil is mainly detached by splash erosion, which is caused by the kinetic energy of raindrops (the product of mass and fall velocity squared). One of the most widely used methods to describe this relation between soil detachment and rainfall intensity was developed by Wischmeier and Smith (1958), which multiplies the storm kinetic energy, with a measure of the maximum rainfall intensity, correcting for the detachment efficiency for different rainfall intensities (van Dijk et al., 2002).

In the method of Wischmeier and Smith, the rainfall erosion index is mainly expressed by the EI_{30} parameter, which is assumed to have a linear relationship with soil loss (Wishmeier, 1959; Renard et al., 1997). The EI_{30} values are the product of the storm kinetic energy (E) and the maximum 30 minute intensity (I_{30}), therefore giving an indication of the combination of total energy and peak intensity in a rainstorm. The EI_{30} values for individual storms are directly additive (Renard et al., 1997). In later research, also the maximum intensities for different time spans were used. For instance, the EI_5 was a better index for Mediterranean climates which have more short storms with high intensities (Uson & Ramos, 2001).

Of crucial importance for the calculation of the kinetic energy of the rainfall is the relationship between rainfall intensity and kinetic energy. The kinetic energy is strongly dependent on the drop terminal velocity and consequently the drop size distribution. Since the drop size distribution of natural rainfall is different per climate regime and geographic location, the equation of Zanchi & Torri (1980) based on data in Central Italy was chosen, see equation 11. This relationship is suitable for a Mediterranean climate and based on rainfall events between 1 and

140 mm h^{-1}. The rainstorm kinetic energy (E) is in MJ/ha/mm, the rainfall intensity (I) is in mm/hr.

$$E = 0.0981 + 0.1125 * \log_{10}(I) \quad (11)$$

2.4.8 Comparison between the ACED and RMMF erosion maps

To compare the ACED erosion map with the RMMF soil loss map for field 3, both maps were reclassified into five erosion classes, from very low to very high. The ACED erosion map was therefore first divided into areas of equal soil loss. The number of elements per erosion class in the ACED map was taken as criterion for the RMMF map, since the purpose of the comparison was on the identification of the erosion areas, instead of quantitative erosion measurement (based on Vigiak et al., 2005). The agreement between the RMMF soil loss map and the ACED erosion map was calculated using the weighted kappa coefficient of the error matrix (Cohen, 1968). One class difference between the ACED and the RMMF erosion classes was regarded as acceptable, with weight factors equal to 1, to account for the classification uncertainties in both maps. The other class differences had weight factors that were based on the linear distance between the classes. Kappa coefficients were calculated with kappa.exe software (Bonnardel, 1995).

3 Results and discussion

3.1 Rainfall trends Yakhour

The longest set of rainfall data close to Maghara was measured at the Yakhour metrological station, located 5.1 km from Maghara, since November 2000. The rainfall data for Yakhour, with an average annual rainfall of 576 mm in 96 rainfall days, showed that the area has a typical Mediterranean climate where most of the yearly rainfall falls during the winter season (Figure 3-1). This is coupled with 4 to 6 months in the summer without precipitation, except an occasional thunderstorm. These measurements are consistent with the mechanisms of rainfall detected by Dennett et al. (1984). The amount of annual rainfall had a standard deviation above 100 mm, similar to Dennett et al. (1984), which indicates that the rainfall is highly variable from year to year.

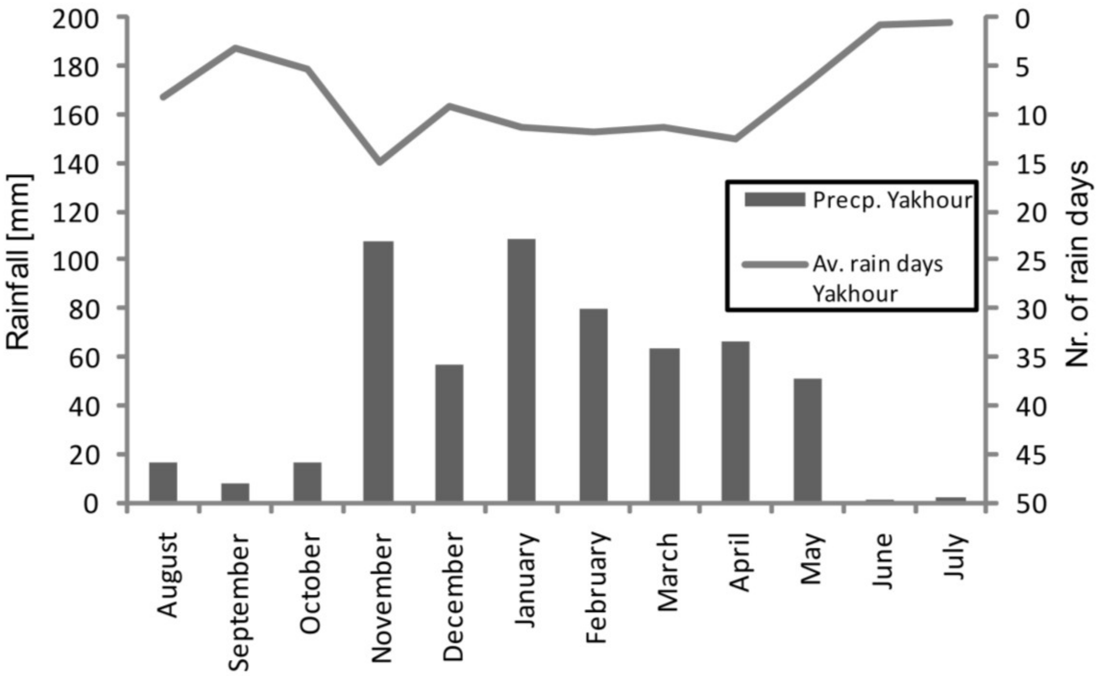


Figure 3-1 Rainfall depth and average number of rainfall days based on rainfall records of 2000 to 2009 for Yakhour, Syria.

3.2 Rainfall trends Maghara

Table 3-1 shows the events that were observed during the measurement period at the meteorological station of Maghara. The results showed a predominance of 71% of storms with less than 10 mm rainfall, with one rainfall event above 50 mm in total. The rainfall intensity data shows that the I_{10} (maximum intensity of 10 minutes) is on average above 10 mm/h. Therefore the intensity can be regarded as generally moderate to high (>30 mm/h). Although the series was not complete, the results showed an example of a typical seasonal Mediterranean pattern, which is characterized by a high inter-annual variability (Dennet et al., 1984).

In this study, storms with rainfall under 10 mm and a low intensity also generated considerable sediment loss. This contradicts the method of the RUSLE soil erosion guide by Renard et al. (1997) to make a distinction between erosive storms (>13 mm, or at least 6.35 mm in a 15 minute period) and other events. Therefore this distinction is used here.

Table 3-1 Rainstorm events and their associated characteristics based on rainfall measurements in Maghara, Syria, between November 2009 and March 2010

Rainfall variables	*Rainfall events category [mm]*					
	0-10	10-20	20-30	30-40	40-50	50-60†
Number of events	17	2	4	0	0	1
Average rainfall depth [mm]	5.2	19.4	25.2			51.7
Storm duration [hrs]	11.3	24.0	27.3			18.0
Kinetic energy KE [J m^{-2}]*	0.9	3.5	3.7			9.1
Rainfall erosivity (EI_{30}) [J mm m^{-2} h^{-1}]*	5.7	51.8	42.7			160.3
Rainfall erosivity (EI_{15}) [J mm m^{-2} h^{-1}]*	9.2	83.6	34.0			-
Rainfall erosivity (EI_{10}) [J mm m^{-2} h^{-1}]*	11.9	83.6	37.0			-
Rainfall erosivity (EI_5) [J mm m^{-2} h^{-1}]*	41.3	107.2	21.4			-
Rainfall intensity (I_{30}) [mm h^{-1}]	4.3	12.9	9.8			14.2
Rainfall intensity (I_{15}) [mm h^{-1}]	6.5	20.6	8.8			-
Rainfall intensity (I_{10}) [mm h^{-1}]	8.1	20.7	9.6			-
Rainfall intensity (I_5) [mm h^{-1}]	10.7	26.4	12.0			-
Antecedent rainfall [mm in 5 days]	10.1	19.4	20.2			43.3
Antecedent moisture condition	1.4	2	2			3

All values represent the mean different rain events under each category. *The kinetic energy and erosivity are based on the Wischmeier and Smith equation (Wischmeier and Smith, 1978). †For this event, only data with 30 minute intervals were measured.

It is important to note that not all rainfall events were recorded with 5 minute intervals, due to a series of powerl failures that occurred at the meteorological station. However, almost all events were at least recorded with hourly data, with exception of the period of 20 December 2009 until 3 January 2010. A linear regression analysis between EI_{30} based on hourly and 5 minute data for the same rainfall events was used to estimate the EI_{30} for the hourly recorded events in the period with missing data (Appendix 7.3.2).

Not incorporated in Table 3-1 is a high rainfall period from October, 26 to November, 3 2009, since this was before the installation of the Maghara meteorological station. The rainfall measured at the nearby station of Yakhour consisted of a series of 6 rainstorms which in total generated 132.1 mm rainfall (approximately 23% of yearly rainfall). Field observations indicated that it can be assumed that Maghara experienced similar levels of rainfall, although no comparable meteorological measurements exist (Figure 3-1).

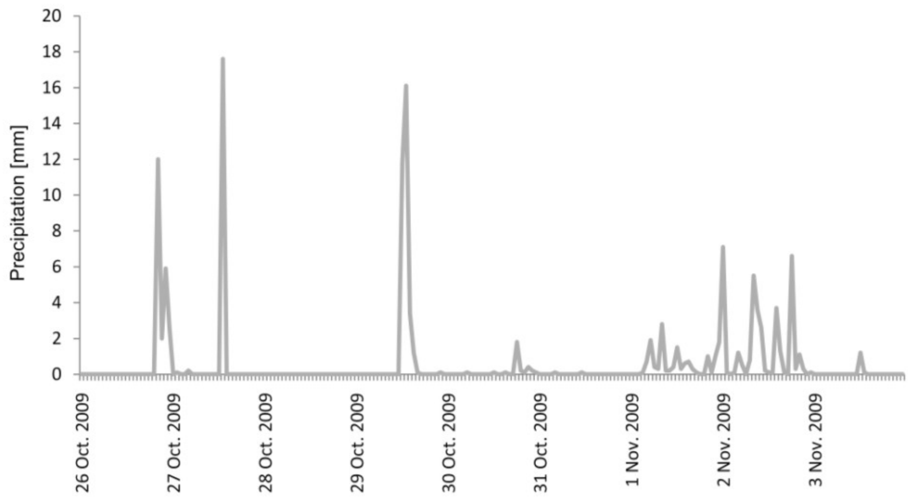


Figure 3-2 Measured rainfall values between October, 26 and November,3, 2009 measured at Yakhour, Syria.

3.3 Field parameter results

3.3.1 Soil parameters

The results of the soil samples show, in general, that the soil characteristics of the three different fields are quite comparable (Table 3-2). Although the three fields have a slightly different soil type, with field 3 having a lower silt and higher clay content, these differences are of minor influence on erosion characteristics in general. The high silt content (>40%) and the lower clay content make the soils highly erodible (Morgan, 2006).

A comparison between the texture in the different fields with regard to soil management shows that there is no clear difference between the sites with SWC techniques and the ones without. One exception is for the clay fraction in field 2, which is probably due to natural variation (Appendix 7.4.1).

Table 3-2 Soil texture properties and USDA classification of soils for the three experimental fields at Maghara, Syria

Field	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Stone fragments (%)*	*USDA classification*
1	23	51	26	7	silt loam
2	26	47	27	9	loam
3	31	41	28	11	clay loam

The values for soil moisture at field capacity and bulk density show small heterogeneity at the field scale (Table 3-3). For soil moisture, these values are as expected based on values for loam (Morgan, 2006). The bulk density is for all fields lower than the indicated value of 1.3 for these soil types (Morgan, 2006), indicating well-aggregated and porous soils. This is reflected in the aggregate distribution results, showing an average of 14% for aggregates larger than 4 mm (Appendix 7.4.2).

Table 3-3 Average soil moisture and bulk density for the three experimental fields at Maghara, Syria

	Soil properties	
Field	*Soil moisture (% w/w)*	*Bulk density (Mg m^{-3})*
1	0,20	1,15
2	0,18	1,00
3	0,19	0,93

3.3.2 Vegetation parameters

The vegetation parameters in Table 3-4 showed that the fields are highly comparable. The biggest difference is in olive tree age, with field 1 and field 2 having a mixture of older trees and newly planted trees, with an approximate age of 80 years versus 1.5 years. Field 3 has trees of approximately 60 years.

All fields had a sparse vegetation cover, with the fields having an average olive tree canopy coverage of <10% (see Table 3-4). Field 1 and 2 had olive trees planted in a regular grid, while field 3 had a less clear tree pattern. The ground cover consisted in all fields of weed and grass undergrowth, although field 1 also had some grape intercropping. In comparison, the ground cover in field 3 was clearly higher than the other fields. The ground cover is representative for February and has developed from mid-December onwards. Before mid-December, the ground cover was not developed yet due to a lack of precipitation.

Table 3-4 Tree density and average plant height, canopy cover and ground cover for the three experimental fields at Maghara, Syria. Measured on December, 14 and 15, 2009.

Field	*Tree density (nr/ha)*	*Canopy cover (%)*	*Ground cover (%)*	*Plant height (m)**
1	246	8	15	0.28
2	188	9	15	0.31
3	169	2	21	0.34

* Plant height is the field average of the tree and undergrowth length

3.4 Visual erosion assessment

The results of Assessment of Current Erosion Damage (ACED) show the rates of erosion based on the visual erosion features at the sites. Extensive rill networks and water erosion damage was observed during the field surveys (Table 3-5). Field 3 had less deep and wide rills, but still showed clear erosion damage in the field. The rill maps can be found in the Appendix, 7.2.2 to 7.2.6.

When a comparison between the average length, width and depth of the erosion rills was made, it showed that the rills were longer for all fields without soil conservation measures. This demonstrates that the soil conservation structures were intermitting and/or diverting the rill flow and consequently reduced the rill length. The same pattern was not visible from the results of the average rill width and depth. The semi-circle terraces therefore seem not effective in reducing the incisive power of the surface runoff (Appendix 7.2.3).

The results from the surveys show clearly that all the fields in this study suffered extensively from rill erosion (Table 3-5). Field 3 had the lowest erosion rates, but had still erosion varying from 5.3 – 11.8 ton/ha for the period from the last tillage in the end of spring until January 2010. The water erosion in field 1 and field 2 was more comparable and was severe, with values ranging from 38.5 – 89.9 ton/ha for the same period.

Table 3-5 Erosion rates based on the ACED method at Maghara, Syria.

Field	*Survey*[*]	*Treatment*	*Sediment loss [ton/ha]*
1	Nov. ‘09	SWC	38.5
		non-SWC	65.7
	Jan. ‘10	SWC	0.0[†]
		non-SWC	5.5[†]
2	Nov. ‘09	SWC	57.0
		non-SWC	82.0
	Jan. ’10	SWC	44.4
		non-SWC	89.9
3	Nov. ‘09	SWC	11.8
		non-SWC	5.3
	Jan. ‘10	SWC	7.3
		non-SWC	5.9

[*]Survey 1: Begin of November 2009, Survey 2: End of January 2010
[†]On 21-01-2010 Field 1 was tilled.

It is important to stress the influence of an extreme event in early November on the erosion results of survey 1. From October, 26 to November, 3 2009 a series of 6 rainstorms took place which in total generated 132.1 mm rainfall at the Yakhour meteorological station. This event generated 23% of the yearly rainfall and had a moderate to high intensity (maximum 17.6 mm/h). Although these data were recorded in Yakhour, it can be assumed that Maghara experienced similar levels of rainfall. An extreme event like this, which is one of the characteristics of a Mediterranean climate, therefore dominates the erosion values.

The comparibility of the results between survey 1 and survey 2 is complicated, since the second measurement is lower at several sites, most notably the areas with semi-circular terraces in Field 1 and Field 2. This could be the effect of assessment, since the ACED method has an error in soil loss estimates of 15 to 30% (Herweg, 1996). However, the most likely reason is a fade out effect, since the fields were used by the farmers, most notably for harvesting the olives, and as grazing land for goats and sheep in the period between the two assessments. This active use of the area has decreased the depth and forms of the rills by a certain extent.

The ACED survey results show very clear the reducing effect of the semi-circular conservation structures on soil loss for field 1 and 2 (Table 3-5). The data showed that the highest rates of erosion were obtained at the areas without any conservation structures. Significantly lower rates were found at the parts with conservation structures, with the amounts being between 49.4 – 69.5% of the non-SWC sediment losses. However, the results show a clear difference between field 3 in comparison with field 1 and 2, since the soil loss rates of field 3 are almost negligible compared to the other two fields. The main reason for this difference is the high spatial heterogeneity in field 3. Small areas with vegetation, olive trees planted without a clear pattern and a variability in slope angle along the hill slope in field 3 are likely to have affected the surface runoff and soil loss. Field 2 and 3 both have trees in a grid and a more uniform hill slope. Another factor that influenced the result in field 3 is that in one of the non-SWC sites, one large rill exposing bedrock was present, which most likely has influenced the number of newly formed rills. Therefore, although the reducing effect of the semi-circular conservation structures is not observed in field 3, the results confirmed this effect on soil loss rates in fields with high soil erosion rates.

However, although the data suggests that semi-circular terraces have a general decreasing effect on soil loss, the field assessment showed severe rills in these areas. Especially in field 2 several rills were found around the conservation structures, since many of them are filled with sediment, which prevents the runoff from decreasing speed at the semi-circular terraces (Appendix 7.2.5). In all fields runoff often had preferential pathways, influenced by the micro topography, between the semi-circular structures.

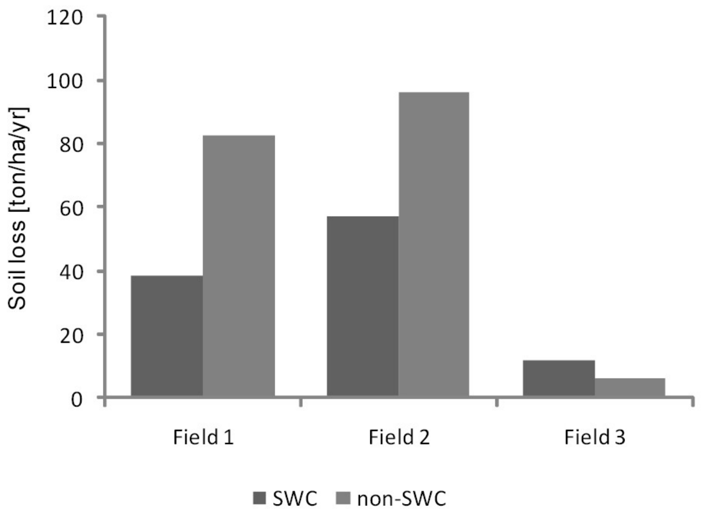


Figure 3-3 Annual soil loss for all fields.

Using the outcomes of the visual erosion method in combination with the formation period of the rills gives an indication for the annual rate of soil loss. Since the measurement period in this research is restricted to the start of the rainfall period, the estimation of the annual erosion is approximate. The ACED incorporated the results of the first part of the rainfall period, including the extreme November event. This can be regarded as the soil erosion since the end of spring, since there has been no tillage or major soil disturbance since the spring period (Sakai, 2010). The second survey was at the end of January, therefore reporting the rill formation as a result of the low intensity rainfall events between November and January. However, also decreased rill erosion was observed in this period, mainly due to the fade-out effect. Under the premise that the soil erosion rate during the last part of the rainy season is similar to the rate measured between the beginning of November and the end of December, an estimation of the soil loss in the remaining period could be made based on the rainfall. The resulting annual erosion rates for field 1 and 2 were very high, with field 1 and 2 having approximately the same annual soil loss of 67 ton/ha/yr. Field 3 has a much lower soil loss of 9 ton/ha/yr (Figure 3-3).

3.5 Surface runoff and soil erosion

Data from the Gerlach troughs and small collectors were collected eleven times during the research period. The period of data acquisition was from November 2009 until April 2010. In total 24 rainfall events have been recorded, which were sampled on 10 sampling dates. Not all rainfall events could be sampled separately, because of the location and travel time, but also since separated events didn’t always generate enough surface runoff to be sampled. From October 26 to November 3, 2009, the first series of erosive events of the 2009-2010 season occurred, but unfortunately the installation of the equipment was not finished yet. During the period of data acquisition minor sampling problems occurred. On December 20 two small collectors and one Gerlach trough had been displaced and were repaired again. Further in the research, the small collectors were three times disturbed.

The data in Figure 3-4 shows the surface runoff, soil loss and sediment concentration per rainfall event. In the results, the Gerlach troughs are listed as their number in the experimental set-up (G1, G2 and G4). The average values of the small collectors in plot 3 are listed separately (Coll. 3 av.). The most striking observation from the data is the large difference in surface runoff and soil loss between the Gerlach trough observations and the small collectors.

For surface runoff, it is clear that the small collector values were substantially higher, with a factor between 1.6 and 4.6, and had a higher variability than the Gerlach troughs. The small collectors generated 186.8 m^3/ha surface runoff on average in the measurement period, while the average Gerlach collectors generated 55.9 m^3/ha runoff. There was no consistent influence of the position of the small collectors along the slope visible in the surface runoff generation records.

When the surface runoff values for the separate precipitation events were compared, there was no clear visible influence of the precipitation depth on the surface runoff. Especially the surface runoff peak at January 22, 2001 was high compared to the precipitation event, while the runoff at March 2, 2010 was low compared to the total of rainfall.

The temporal pattern of the soil loss rates was in general comparable with the surface runoff values, but there were several differences. The amounts of soil loss measured showed, like the runoff, a high variability for the four different plots. Again, the highest amounts of soil loss was always found for the smaller collectors. Plot 4 clearly generated the lowest amounts of soil loss. The small collectors on average generated 53.7 mg/m^2 soil loss in the measurement period, while the Gerlach collectors generated 6.2 mg/m^2 soil loss on average. The highest soil loss amounts were measured at February 22 and March 11, 2010, which corresponded with surface runoff values in the middle to higher segment. The highest amount of runoff was obtained on January, 22, 2010, although for the soil loss rates this date was not exceptionally high.

The sediment concentration [g/L] was measured for every sampled rainstorm and formed the basis of the determination of the total sediment load. The results showed that the sediment concentration usually had a low variance and had measured values between 0 – 3 g/L. However, higher values were obtained 22 February and 11 March 2010, with values between 0 and 9 m/L. For the small collectors, the values varied between 0.5 – 20 g/L on these dates. The measured sediment concentrations are comparable to literature findings. For instance, Taguas et al. (2009) found sediment concentration between 5 g/l and 20 g/l.

Annual values

Based on the average amount of surface runoff per millimetre of rainfall, a value for the annual runoff was calculated. When the Gerlach trough measurements were used, the annual expected surface runoff value was approximately 244 m^3/ha with a range between 56 and 459 m^3/ha. Based on the small collectors, the annual expected surface runoff was approximately 879 m^3/ha with a range between 300 and 1171 m^3/ha. These results are relatively low compared to a study by Bruggeman et al. (2005) in Yakhour, where values between 508 and 2909 m3/ha per year were recorded in the period between 2000 and 2004. Therefore, the runoff values based on the small collectors seem a better indicator of the surface runoff.

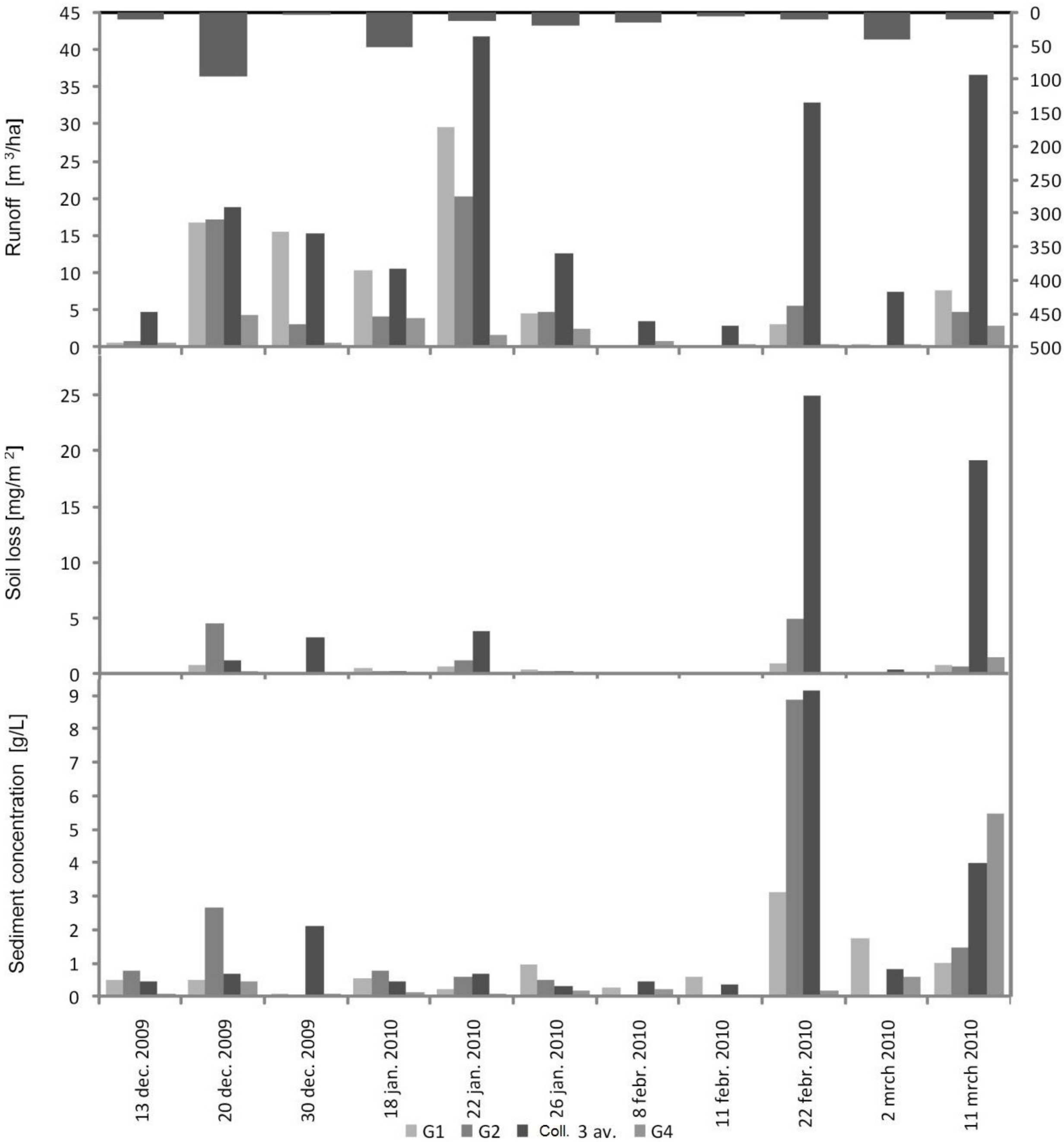


Figure 3-4 Runoff, soil loss and sediment concentration per rainfall event for Gerlach troughs and small collector measurements in field 3.

The annual erosion rates based on the Gerlach trough data varied from 0.08 to 0.38 ton/ha. The values of the annual soil loss based on the small collectors gave an average of 5.9 ton/ha, with a range of 0.4 to 11.1 ton/ha. This is on average a factor 3.3 higher than the Gerlach trough results. The Gerlach values differ greatly from the results of the ACED survey. These results show clearly that all fields in this study suffered extensively from rill erosion. The annual erosion rates for the three fields are all high, with field 1 and 2 having approximately the same annual rate of 67 ton/ha. Field 3 experienced less erosion, but still had an estimated annual rate of 9 ton/ha.

Geographically the most comparable study was conducted by Bruggeman et al. (2005), where values between 11.9-81 ton/ha/yr were recorded for a situation with conventional tillage. Other authors performed studies in Spain and recorded soil erosion rates. Gomez et al. (2004) reported a soil loss of 8.5 ton/ha/yr, while Francia et al. (2006) observed an erosion rate of 25.6 ton/ha/yr. Taguas et al. (2009) recorded a much lower rate of 1.3 ton/ha/yr, blaming the lower values partly on a dry period occurring just before the measurement period.

Based on the results of the different measurement techniques compared with the literature results, it has been concluded that the small collectors give a clearly better indication of the erosion values in the fields than the Gerlach troughs. The low values of the Gerlach troughs were thought to be the result of spatial variability within the plots. As a result, it was impossible to directly compare the results from plot 3 with the other plots. Further, the very low results for soil loss for plot 4, as a result of a presiously established rill on bedrock, made it impossible to compare the SWC and non-SWC influence for the measurements based on the Gerlach troughs and the small collectors.

3.5.1 Runoff coefficients

The runoff coefficient is the percentage of precipitation that appears as surface runoff. To get more information about the influence of the determined catchment size, the runoff coefficients were calculated for the measured catchments in comparison to a length based method. This length based method took the slope length as the basis for the catchment size, multiplying this with the width of the Gerlach troughs. For the small collectors, the catchment size was always determined by the collector width multiplied by the slope length.

Table 3-6 shows that the small collectors clearly had the highest runoff coefficients, with an average difference of a factor 3.6 between the small collectors and the Gerlach trough results. This was expected based on the higher influence of spatial variability on the Gerlach troughs. For one of the small collector pairs (3), the highest values measured within the measurement period indicate that the measurement of the collector catchment was too small, since the runoff coefficient exceeded 100% for one rainfall event.

The lowest values were found for plot 4, showing that the rainfall that is transported through the rill on bedrock in this plot was only a small amount of the total rainfall on the plot. This result suggests that most of the surface runoff in this plot infiltrated or left the plot through other rills.

The results of the runoff coefficients compared by rainstorm showed a great variability in runoff coefficient per rainfall event, with the events of December 30, 2009, January 22, 2010 and February 22, 2010 having the highest runoff coefficients for all plots (Appendix 7.3.5). This generally corresponds with the surface runoff results.

Table 3-6 Average runoff coefficients for the measured versus length based catchment size determination for field 3.

	Average runoff coefficient (%)	
Plot	*Measured catchment*	*Length based catchment*
G1	8.0	23.1
G2	3.8	10.8
Coll. 3 av.	15.3	15.3
G4	1.0	2.5

The runoff coefficient is a runoff parameter which is often used as a comparison between studies, since it eliminates the influence of the specific runoff events. In a review by Gomez (2005) on runoff coefficients in olive orchards in Spain, including the work of Gomez et al. (2002), Francia et al,. (2000) and Raglione et al. (2000), it appears that mechanically tilled fields have a highly variable runoff, with values ranging between 3 – 26%. When looking to comparable studies, Gomez et al. (2002) reported a runoff coefficient of 10.4% for conventional tillage in olive orchards. Gomez et al. (2004) reported a runoff coefficient of 18.4% for a year with comparable soil loss with this study (10,1 ton/ha/yr). In the years when the soil loss was a factor 10 smaller, the reported runoff coefficients were 1.6-2.1%. These results suggest that the values of the length based catchment are plausible or at least more plausible than the measured catchment sizes. The large uncertainty of the 'real' catchment area, something essential to unbound plot measurements, still remains.

3.5.2 Factors influencing runoff and soil loss

A clear result from the surface runoff and erosion data is that the values for the small collectors, with an average catchment area of 4.7 m^2 were much higher than the average values from the Gerlach troughs, with an average size of 196 m^2. The annual rates for runoff and soil loss were a factor 3.5 higher for the small collectors than for the Gerlach troughs. This is the result of a scale issue within erosion research, since soil loss data derived from plots of different scales are influenced by the scale of the measurement. This is the result of the fact that different processes are measured at plots of different sizes. Several authors have estimated scale ratios between plot sizes. Boix-Fayos et al. (2007) showed that for a study in SE Spain the surface runoff per unit area measured at large plots was always lower than for smaller plots, with a factor of 5.6 between catchment and a 30m^2 plot scale and a factor of 1.4 between 30m^2 and 1m^2 plot scale.

The main factor influencing the spatial variability of soil loss, is the influence of vegetation on the surface runoff generation and the sediment entrapment on the hillslope. Olive trees control the spatial variation of infiltration, which is more complex on larger scales than on plot scale. This is reflected by the work of Gomez et al. (1999), who reported more infiltration under areas below olive trees. Cammeraat (2002) and Taguas (2009) concluded that for olive orchards, the density of olive trees, the size of canopies and the distance to the main channel are all explanatory factors that strongly influenced the measurements and created scale problems. In this study, the hillslope had a large spatial variability with small depressions along the flowpath. Further, the infiltration was variable due to the olive trees and semi-circular terraces that intermitted the flowpath. The semi-circular terraces also worked as a sedimentation zone. These factors most likely have influenced the surface runoff and soil loss rates for the Gerlach troughs, while the small collectors had higher values as a result of more homogenous conditions. However, the small plots only represented a part of the high spatial variability of surface elements in semi-arid systems. This is reflected in the small collectors measurements, which are high on average, but also contain several low values, due to intermittent streams and a spatial variable pattern of surface runoff/runon on the slopes.

A second factor which influenced the hillslope surface runoff and soil loss values is the actual size of the runoff generating area. Cammeraat (2004) showed that high spatial variability creates smaller runoff generating areas than previously expected based on hill slope length, due to the interplay of bare surface runoff generating areas with infiltration areas. In his research, only bare area connected to the overland flow collectors produced surface runoff that was actually measured, which was also limited to a minimum rainfall depth and intensity.

Therefore, he suggested the 'variable source theory' based on Hewlett and Hibbert (1967) for semi-arid areas, which proposes that the area of land yielding surface water to surface runoff and eventually streamflow varies with time, depending on the extent of the saturated zone. These processes are expected to have also influenced the outcome of this study, since the high spatial variability most likely resulted in infiltration along the slope. As a result, the actual runoff generating areas were smaller than expected, which is reflected in the results from the average runoff coefficients, where the measured catchment sizes appeared to be too large. Further, it is assumed that the surface runoff values (and consequently the soil loss values) were influenced by variable runoff generating areas in time, depending on the extent of the saturated zone generated by the rainfall depth and rainstorm duration.

During this study, the limited measurement period was a major factor that influenced the surface runoff and the soil loss results. As noted by Fleskens & Stroosnijder (2007), doing erosion measurements is largely a matter of luck. Although an advantage of using natural rain and wind events are the representativeness of the conditions, the disadvantage is the unpredictability (Stroosnijder, 2005). Especially the effect of capturing high intensity erosive events is large, as demonstrated by Francia Martinez et al. (2000), whose erosion rates would be a factor 10 lower when the single most erosive storm was not captured. In this research, this could explain the large differences between the ACED and the small collector measurement results, since the ACED measurement period included a high intensity rainstorm event of 23% of the yearly rainfall.

3.6 Statistical analysis

3.6.1 Precipitation and antecedent moisture condition

The correlation results (Table 3-7) for the small collectors show that they are not correlated with the rainfall depth. However, as expected, the antecedent moisture condition (AMC) influenced the surface runoff values, which corresponds with the proposed 'variable source theory' related to a variable saturated zone. This relation between AMC and surface runoff is also reflected in the Gerlach trough results.

The Gerlach trough results show that plot G4 had a clearly different pattern of surface runoff, being closely related to both the antecedent moisture condition (AMC) and the rainfall depth. These results suggest that plot G4 is highly influenced by rainfall values, making it respond distinctively different than the other plots.

Table 3-7 Correlation values for precipitation (Pearson) and antecedent moisture condition (Spearman) for the different plots on field 3.

		Surface runoff	*Sed.concentration*	*Soil loss*
Precipitation	*G1*	0.28	-0.16	0.26
	G2	0.40	-0.08	0.41
	Coll. 3 av.	-0.13	-0.26	-0.30
	G4	**0.69***	-0.18	-0.09
AMC	*G1*	**0.79*** *	-0.03	0.46
	G2	0.52	-0.16	0.41
	Coll. 3 av.	**0.68***	0.13	0.50
	G4	**0.70***	0.08	**0.73***

** Significant at P <0.05 * Significant at P <0.10

3.6.2 Erosivity indices and rainfall intensity

The erosivity index (EI) was calculated for different maximum rainfall intensities, based on 5, 10, 15 and 30 minutes. When a correlation is made between the rainfall depth and the rainfall erosivities, it is clear that the values based on the 30-minute maximum intensity (I_{30}) are the most representative for the rainfall values. The significant correlation between rainfall depth and EI_{30} has a correlation coefficient of 0.94 (P<0.05). This explains the similarity between the correlations of the precipitation and the EI_{30} with respect to runoff, soil loss and sediment concentration.

One of the goals to calculate the erosivity indices was to see the influence on soil loss, since there is an expected significant linear relationship between these factors (Morgan, 2006). The results for the small collectors showed a clear positive relationship between the EI and the soil loss results, with most significant values for EI_5 (Table 3-8). This relationship is also reflected in the Gerlach trough results, with significant results for G1 and a similar pattern for the remaining plots. Table 3-9 further shows that for the small collectors, the correlation results of the surface runoff with the values of EI_{15}, E_{10} and EI_5 explain most of the runoff results.

High positive Pearson correlation coefficients were also found for the relationship between the mean concentration of sediment and the EI_{15}, E_{10} and EI_5, with a significant correlation between the small collectors and the EI_5 (0.83; P<0.10). This indicates a positive relationship between sediment concentration and the erosivity index.

Table 3-8 Pearson correlation coefficients (r) between erosivity indices (EI), maximum rainfall intensities and the different plots on field 3.

		Surface runoff		*Sed. concentration*		*Soil loss*	
Time (min.)[†]		*EI*	*I*	*EI*	*I*	*EI*	*I*
30	*G1*	0.37	0.50	-0.15	-0.13	0.46	0.61
	G2	0.52	0.61	0.05	0.06	0.59	0.62
	Coll. 3 av.	0.04	0.22	-0.11	-0.02	-0.11	-0.01
	G4	**0.76***	**0.83****	-0.06	0.01	0.04	0.12
15	*G1*	0.59	0.74	0.69	0.60	**0.81***	**0.92****
	G2	0.67	**0.80***	0.58	0.55	0.61	0.66
	Coll. 3 av.	**0.91****	**0.99****	0.72	**0.77***	**0.84***	**0.91****
	G4	0.33	0.45	0.65	0.70	0.63	0.71
10	*G1*	0.63	0.75	0.66	0.56	**0.84***	**0.91****
	G2	0.69	**0.78***	0.56	0.52	0.62	0.64
	Coll. 3 av.	**0.94****	**0.99****	0.73	0.75	**0.86***	**0.93****
	G4	0.37	0.47	0.68	0.72	0.67	0.71
5	*G1*	0.58	0.70	0.73	0.63	**0.88****	**0.93****
	G2	0.72	**0.79***	0.69	0.63	0.74	0.72
	Coll. 3 av.	**0.95****	**0.99****	**0.83***	**0.82***	**0.93****	0.95
	G4	0.28	0.39	0.57	0.64	0.58	0.66

[†]The time in minutes indicates the period for which the maximum rainfall intensity was determined. **Significant at P<0.05 *Significant at P<0.10

The same relationships as between erosivity indices and surface runoff, soil loss and sediment concentration were found for rainfall intensity values. However, the relationships were more apparent since the Pearson correlation values are higher. In general, the maximum EI_5 and I_5 values gave the highest correlations. This result is expected by Uson & Ramos (2001) for "short duration storms in Mediterranean countries", since these tend to be of high intensity.

Since the maximum rainfall intensity is highly contributing to the EI values, the correlation results strongly suggest that the rainfall intensity is the driving factor influencing the surface runoff generation, sediment concentration and soil loss. This result agrees with Francia et al. (2006), who found significant correlations between I_{30}, soil erosion and the coefficient of runoff. Taguas et al. (2009) found the same results for runoff generation, but introduced a separate influence for sediment load being influenced mainly by rainfall depth. This pattern is not reflected in the Maghara data, except for plot G4.

In conclusion, the outcomes from the field erosion measurement and the statistical analysis show that the small collectors give a clearly better indication of the surface runoff and soil erosion values in the field, than the Gerlach troughs. The values of the small collectors were on average 3.5 times higher that the Gerlach trough measurements. This difference is largely influenced by the scale effect between the different catchment sizes of the Gerlach troughs and the small collectors. The small collectors had an annual expected surface runoff of 879 m^3/ha and annual soil loss of 5.9 ton/ha. The ACED measurements gave an annual expected soil loss of 9 ton/ha. The ACED results also showed the reduction of soil loss caused by the semi-circular terraces in field 1 and 2. Field 3 had clearly different general characteristics. Therefore, although the effect was not observed in field 3, the results confirm the reducing effect of conservation structures on soil loss rates in fields with high soil erosion rates.

The statistical analysis showed that Gerlach trough measurements had in general the same correlations with rainfall intensity and erosivity as the small collectors, indicating a common process of surface runoff and soil loss generation. This outcome confirms the idea that the actual size of the runoff generating area and the vegetation play an important role on surface runoff and soil loss generation for different plot scales. The correlations among rainfall, runoff and sediment showed that that the rainfall intensity is the driving factor influencing the runoff and sediment load.

3.7 Model results

The RMMF model has been applied to field 3 only, using detailed input maps for most of the parameters (Appendix 7.6.1).

3.7.1 Model application and calibration

The model input variables were based on measured values in the field, otherwise values proposed by Morgan (2001) were used (Table 3-9).

Table 3-9 Average parameter values used in the RMMF model for field 3.

Parameter	*Value**
Mean annual rainfall (mm)	576.3
Rainfall intensity	30,0
Mean annual number of rain days	95.9
Et/Eo ratio	0.34
Effective hydrological depth	0.05
C factor (-)	0.34
Slope angle (°)*	18,4
Soil moisture (% w/w)*	0.2
Bulk density (Mg m^3)*	0,7
Stone fragments (proportion)*	0.1
Permanent interception (proportion)*	0.2
Canopy cover (proportion)*	0.0
Ground cover (proportion)*	0.2
Plant height (m)*	0.3
Detachability of clay particles by rain (RDC)[1]	0.1
Detachability of silt particles by rain (RDZ)[1]	0.5
Detachability of sand particles by rain (RDS)[1]	0.3

*These base values are the mean values of a spatial varying parameter
[1]Detachability values in g/J for rainfall and in g/mm for runoff

One of the most uncertain input parameters of the RMMF model application was the effective hydrological depth (EHD), since this value is not measurable in the field but has a large influence on the modeling outcomes. Figure 3-5 shows the influence of the EHD on the runoff and the soil loss results of the RMMF model. Based on these outcomes, the value of 0.05 was chosen, which resembles the guide value by Morgan (2001) for bare shallow soils on steep slopes, with crusted soils. This is compatible with the field observations.

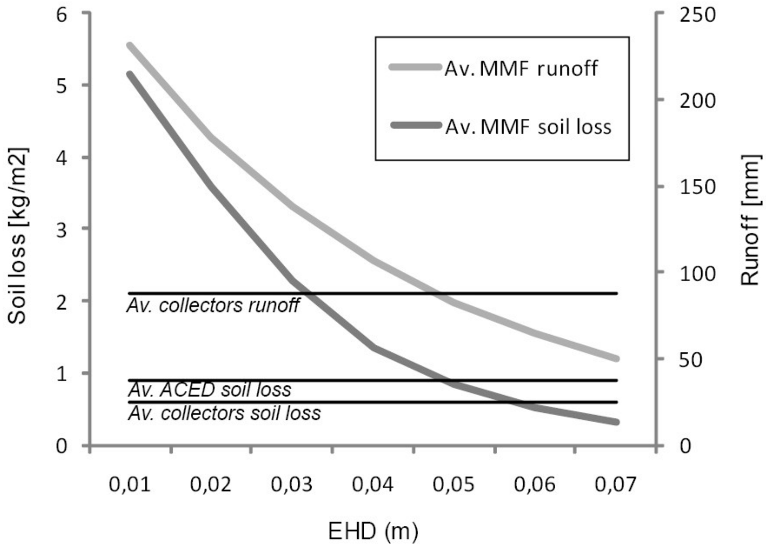


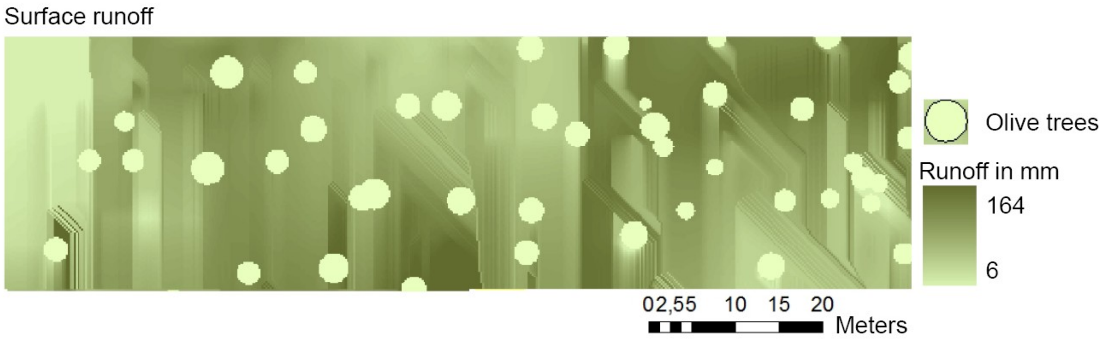
Figure 3-5. Influence of the effective hydrological depth (EHD) on RMMF surface runoff and soil loss values compared to ACED and small collectors results

Model outcomes

The model results (Table 3-10) show that the mean volume of overland flow calculated by the model is 82.6 mm per year, while the average annual soil loss is 0.8 kg/m^2 (8 ton/ha/yr). The model calculated more detachment, which indicates that the annual erosion is transport limited. However, it is possible that single or high intensity events are detachment limited, which has been observed in other studies (Martinez – Mena et al., 2002).

Table 3-10 RMMF model output, with values per grid cell, for parameters based on field 3.

	Min	*Max*	*Mean*	*St. deviation*
Soil moisture storage capacity (RC; mm)	4.2	8.6	6.1	0.8
Volume overland flow (Q; mm)	6	164	82.6	25.1
Particle detachment by raindrop impact (F; kg/m^2)	0.9	4.9	3.2	0.7
Particle detachment by runoff (H; kg/m^2)	0	1.9	0.5	0.3
Transport capacity overland flow (TC; kg/m^2)	0	5.0	0.9	0.6
Annual soil loss (ASL; kg/m^2)	0	5.0	0.8	0.6



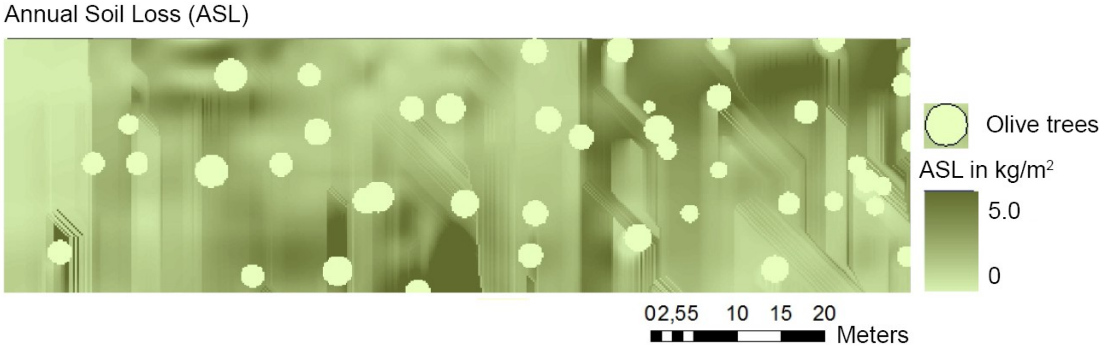


Figure 3-6 RMMF model output: runoff and annual soil loss maps for field 3, including olive tree positions and ACED erosive areas.

The outcomes from the RMMF model (Figure 3-6) show the flow pattern on the slope, with tree canopy's clearly influencing the amount of runoff and soil loss, especially in the right part without soil conservation methods. Visual comparison of the flow pattern with the rill observations in the field showed that the model simulation fairly resembles the field situation. However, the flow pattern after 60 meter to the right is suddenly intensified. This was not reflected in the field observations.

Table 3-11 Error matrix with number of pixels for the comparison of the ACED and RMMF erosion maps for field 3 . 1. Kappa coefficient weights; 2. RMMF error matrix

	ACED erosion map				
	Very low	*Low*	*Moderate*	*High*	*Very high*
1. Weights					
Very low	1	1	0.5	0.25	0
Low	1	1	1	0.5	0.25
Moderate	0.5	1	1	1	0.5
High	0.25	0.5	1	1	1
Very high	0	0.25	0.5	1	1
RMMF map					
Very low	12520	4515	4	4858	0
Low	1676	1169	0	1879	0
Moderate	100	113	1	111	0
High	1202	3236	112	3201	675
Very high	96	835	28	2036	24

The comparison of the RMMF erosion map with the ACED erosion map showed that 44% of the pixels were correctly classified and 24% were acceptably classified (i.e. one class difference). Table 3-11 shows the misclassification errors.

The weighted kappa coefficient of the error matrix was 0.165 which indicates a slight agreement between two maps, according to Landis and Koch (1977). As indicated already by the visual erosion inspection, the agreement between the two maps is much higher for the first 60 meters. This part has a weighted kappa coefficient of 0.340, which is a fair agreement between two maps.

The comparison between the RMMF map and the ACED map showed that the erosion on lower part, the bottom 15 meters, of the field was generally underestimated by the model. The higher parts were in general overestimated, especially for the area without soil conservation structures. The overestimation at the top part of the fields is most probably caused by the mechanism of surface runoff accumulation, which does not account for reinfiltration along slopes. High reinfiltration rates are however expected in the field, due to the carbonate rock type and slope heterogeneity. The RMMF model has also been applied to the field with a reinfiltration flow accumulation algorithm, but the results were unsatisfying. The modeled surface runoff outcome values were too low to be realistic.

Most of the errors in the model prediction are most likely the result of a low spatial resolution of the DEM and the different size of classification units between the two maps. The flow pattern of the RMMF map was the result of the DEM and the local drainage direction map. Therefore, the grid size of the DEM has a large influence on the resulting flow pattern. Since the field is very heterogeneous, the 2m DEM has not specified several local flow directions. Secondly, while the ACED erosion maps are made to give an indication of areas with erosion features, the locations of the rills were recorded very specific. Although the rills were converted to approximate erosion zones for the map comparison, it is still possible that the high level of detail of the maps leads to more mismatches. A comparison between aggregated elements of the same size in both maps could give better erosion results (see Vigiak et al., 2005).

When the RMMF model outcomes were compared with the measured values for erosion and surface runoff, it is clear that the RMMF model is very well suited for erosion prediction at field scale. The model results indicated an average surface runoff of 826 m^3/ha, which is a good representation of the expected annual surface runoff of 879 m^3/ha, based on the small collectors. These values correspond with an average annual soil loss of 0.8 kg/m^2 (8 ton/ha/yr) for the RMMF model, compared with 5.9 – 9 ton/ha/yr for small collectors and ACED measurements respectively. Again, the model outcomes reflect the measured soil loss values really well. However, the comparison between the ACED erosion maps and the RMMF model outcomes show that inner-field erosion pattern prediction is difficult, since it is dependent on the DEM resolution and local reinfiltration patterns.

3.7.2 Sensitivity analysis

There are different approaches in choosing the variation of the parameters for a sensitivity analysis. However, the base values chosen most often represent the field values or expected values in the field. The procedure adopted here is the approach proposed by Favis-Mortlock and Smith (1990) to vary the base value by ±10%. This approach was chosen due to a limited period of field information, which would make it difficult to verify suitable extreme values and the ends of the field data ranges.

The analysis is conducted with a focus on changes in runoff and soil loss values. To review the change, both the mean value change and the change on a selected slope element of 0.04 m^2 within the model were evaluated. The results are highly comparable, with differences probably due to rounding off of values.

Figure 3-7 shows the results of the sensitivity analysis. The parameter which clearly has the most effect on both the runoff and the soil loss values is the mean annual rainfall. It is followed by four parameters with the same influence on the data; the number of rain days (RN), soil moisture (SM), bulk density (BD) and the effective hydrological depth (EHD). The values of the average linear sensitivity for the runoff show that the model output is highly sensitive (ALS > 1.0) to parameters related to rainfall and soil moisture storage, including interception and evaporation. Runoff is moderately sensitive (ALS ≥ 0.5 < 1,0) to slope and ground cover. Soil loss is also highly sensitive to rainfall and soil moisture storage parameters, together with slope, interception, evaporation and ground cover. Soil loss is moderately sensitive to the C-factor.

These general pattern of the results are expected on the basis of the model and are in line with earlier sensitivity analysis results of MMF model (Morgan et al., 1984; Morgan & Duzant, 2008). However, the results show the importance of correct input values, especially for mean annual rainfall and soil values which determine the soil moisture storage capacity. The results confirm that care is needed for the selection of the EHD, which we based on Figure 3-5, since the EHD has the same influence as bulk density and soil moisture on the model outcomes, yet is not possible to measure in the field.

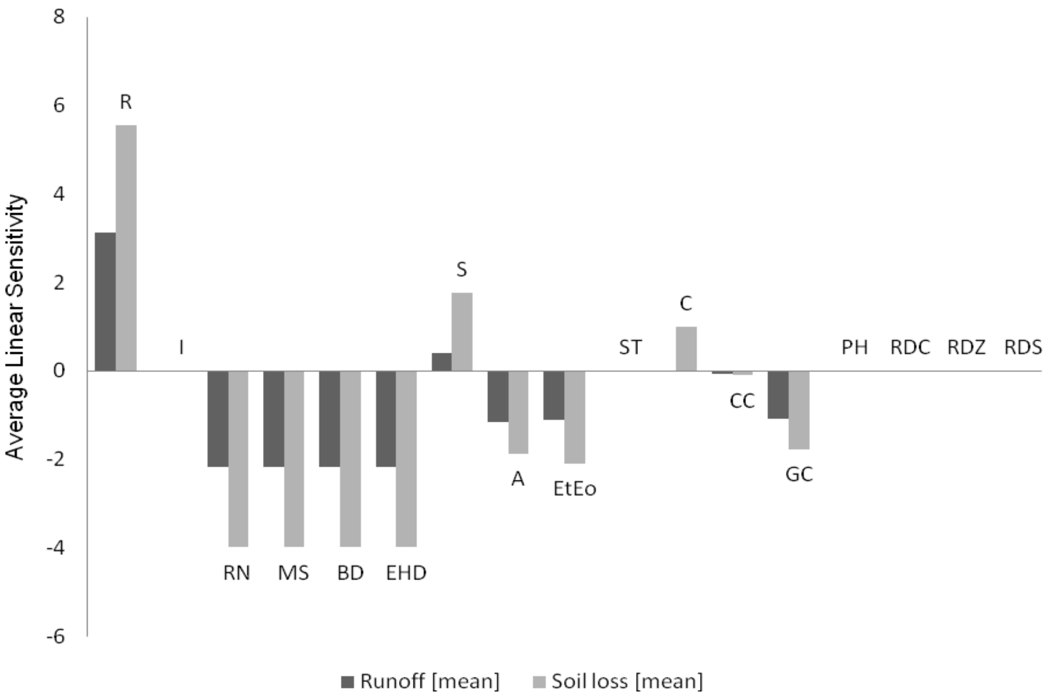


Figure 3-7 Values of average linear sensitivity for selected input parameters for field 3.

4 Conclusion

This study was located in northwest Syria, in an olive rich area with highly erodible soils. The land use changed in the beginning of the 20th century from forest to olive plantations, increasing erosion rates. In most places, the soil depths have been reduced to a depth of less than 25 cm, under which the limestone bedrock is found. The field observations showed that the area has high erosion levels and is severely damaged, even more clear in multiple fields were large areas are just plain bedrock.

The general objective of this study was to quantify the amount of hill slope erosion on a hill slope scale for an olive orchard with soil conservation structures in northwest Syria. As a conclusion, the three separated research objects are used to outline the results.

(1) To quantify the amount of hill slope erosion on a field scale

Based on the results of the different measurement techniques compared with the literature results, it has been concluded that the small collectors give a clearly better indication of the surface runoff and soil erosion values in the fields than the Gerlach troughs. The values of the small collectors were on average 3.5 times higher than the Gerlach trough measurements. The low values of the Gerlach troughs were thought to be the result of a scale effect in erosion studies and the spatial heterogenity within the plots.

The surface runoff measured with the small collectors indicated an annual expected runoff of approximately 879 m^3/ha. Despite the uncertainty of the determination of the catchment area, the results of the runoff coefficient appear to be plausible, with an average of 15.3 % for the small collectors. The annual soil loss rates based on the small collectors gave an average of 5.9 ton/ha. The ACED survey results for the same field, field 3, are 5.3 – 11.8 ton/ha, with an expected annual average of 9 ton/ha/yr.

Correlations among rainfall, runoff and sediment showed that the rainfall intensity is the driving factor influencing the runoff and sediment load. Unexpected runoff results are sometimes also explained by the Antecedent Soil Moisture (AMC).

The average soil loss results, of approximately 9 ton/ha/yr for field 3, and 67 ton/ha/yr for field 1 and 2 have a large influence on the development of the area. Van-Camp et al. (2004) showed that only small soil losses are tolerable on shallow soils on steep slopes. When erosion rates are exceeding 1 ton/ha/yr, something which is clearly the case in this area, the processes could be irreversible within a time span of 50-100 years. Therefore soil and water conservation is of a core importance for (olive) farmers in Northwest Syria on the long term.

(2) To assess the suitability of the soil conservation structures, which were applied during the field observation period

The outcomes of the ACED measurements show that, for field 1 and 2, there is a clear reduction of soil loss caused by the semi-circular conservation structures (49.4 – 69.5% of the non-SWC sediment losses). This effect was not observed for field 3. However, field 3 had clearly different general characteristics e.g. a higher spatial heterogeneity, which made it difficult to compare the results between the fields. Since the ACED measurements are executed under intense rainfall conditions, we conclude that, although the specific extent of the erosion remains under discussion, the data suggests a (strong) decrease of soil erosion due to rill forming in fields with semi-circular terraces.

Although the semi-circular terraces have an reducing effect on the soil erosion in the SWC fields when compared to the control sites, the semi-circular terraces did not stop rill forming since there is enough space between the terraces to make preferential paths for runoff. An important management note for the semi-circular terraces is also the sedimentation of the terraces. When semi-circular terraces become filled-up, the effect is minimal. This situation happened with several semi-circular terraces in field 2.

In general, conservation practices such as stone terraces, semi-circular bunds or contour ridges will increase soil moisture content within the fields. Previous results, in addition with the research of this study on semi-circular bunds suggest also a reduction effect on runoff and sedimentation. However, when choosing a particular technique other factors are also important, such as climate, land use and topography. Also, soil management options should be evaluated on other aspects then erosion, e.g. water balance or olive tree productivity. Highly important is also the tradition and willingness of farmers to start establishing soil and water conservation structures.

(3) To model the measured amounts of hill slope erosion in olive orchards using the Morgan, Morgan and Finney (MMF) erosion model.

The RMMF model is used to model the annual surface runoff and soil loss for field 3. The model results showed that the RMMF model is very well suited for erosion prediction at field scale. The mean volume of overland flow predicted by the model had a value of 82,6 mm per year (826 m^3/ha), which is a good representation of the annual surface runoff of 879 m^3/ha, based on the small collectors. The model calculated an average annual soil loss of 0,8 kg/m^2 (8 ton/ha/yr). This corresponded very well with the field data of 5.9 – 9 ton/ha/yr for small collectors and ACED measurements respectively.

The model results showed that most of the spatial parameters found in the field are reflected in the model output maps. The weighted kappa coefficient of the error matrix was 0.165 (slight), which was higher when only the first 60 meters were taken into account (0.340; fair). The low spatial resolution of the DEM and the different sizes of classification units of the ACED erosion maps and the RMMF soil loss map are expected to explain the errors in the model prediction. Therefore, the RMMF is less suitable for inner-field erosion pattern prediction, since this is dependent on model factors such as the DEM resolution and on the local reinfiltration patterns.

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شكرا

7 Appendix

7.1 Data collection Gerlach troughs and collectors

7.1.1 Sampling form Gerlach troughs and collectors

Field sampling - Emma van der Zanden

Date		Observer		
Gerlach troughs		Time	Water depth [cm] *Tank 1**	Water depth [cm] *Tank 2**
	G1			
	G2			
	G3			
	G4			
		Time	Water amount [ml]	
Plastic bottles	C1-L			
	C1-R			
	C2-L			
	C2-R			
	C3-L			
	C3-R			
	C4-L			
	C4-R			
	C5-L			
	C5-R			
	C6-L			
	C6-R			

*<u>*Tank 1*</u> is the main Gerlach trough tank, <u>*Tank 2*</u> is the connected overflow tank

N.B The sampling form contains Gerlach trough G3 and small collectors C5 and C6, which are not used for further analysis.

7.1.2 Water and sediment sampling manual

Fieldwork sampling - Emma van der Zanden

Sampling takes place after every rainfall event

Necessary equipment for every sampling
- 16 collection bottles
- Permanent marker
- Plastic pin (at least 60 cm)
- Plastic cylinder, for measuring 2 litres
- Handpump
- Sponge
- Plastic bags
- Measurement tape
- Pipe wrench

Measurements
Sediment concentration and runoff

When taking sample from Gerlach trough:
1. Measure the depth of the water in the Gerlach trough with the measurement tape, report on form.
2. Stir the collection water in the troughs with the plastic pin
3. Take sample with the collection bottle.
4. Write with the permanent marker the code of the collector and the collection time/date (see form)
5. Empty the trough by opening the outlets with an pipe wrench
6. Clean the left over material/water in the trough with the sponge.
7. Check the collector of the Gerlach trough for sediment, if necessary; clean with sponge and/or water (use the plastic bag to block the connection pipe).

When taking sample from plastic bottles:
1. Stir the collection water in the bottles with the plastic pin
2. Empty the plastic bottle with the handpump in the plastic cylinder
3. Measure the amount of water (if necessary, fill the cylinder to 2 litre and empty, then adding the new amount) and report on form
4. Take a sample with the collection bottle
5. Write with the permanent marker the code of the collector and the collection time/date
6. Clean the remaining sediment/water from the plastic bottle with the sponge
7. Check the collector of the plastic bottles for dirt/blocking stones, if necessary; clean with sponge and remove the stones.

7.1.3 Original data Gerlach troughs and small collectors

N.B The original data from the Gerlach troughs and small collectors contains G3, C5 and C6, which are not used for further analysis.

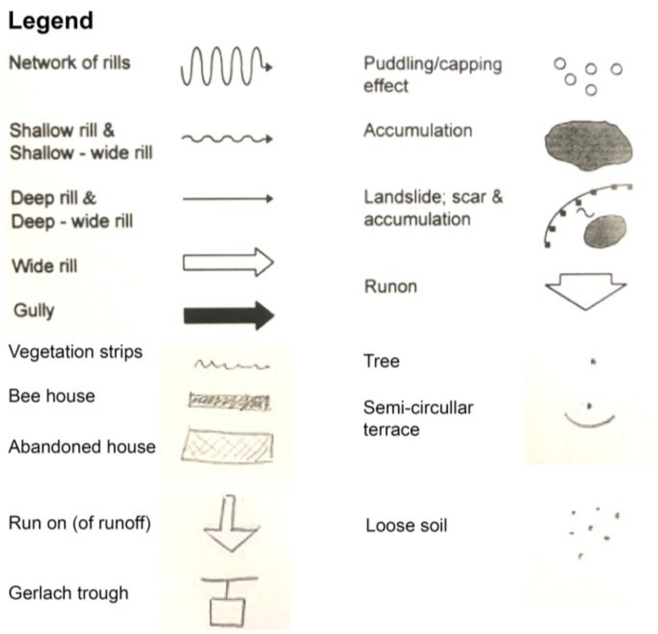
Date	*Time*	*Water depth [cm]*	*Water amount [ml]*	*Sed. Concentr. [gr/L]*	*Comments*
7 dec. 2009			0		Not enough water + sediment to s
13 dec. 2009					
G1	18.55		12500	0.5	
G2	19.15		14500	0.78	
G3	19.15		0		
G4	11.45		7750	0.08	
G4	19.3		11750	0.11	
C1-L	20.15		0		
C1-R	20.15		1125	1.19	
C2-L	19.50		0		
C2-R	20.00		3125	0.12	
C3-L	19.50		1250	0.26	
C3-R	19.50		100	0.66	
C4-L	19.35		4875	0.26	
C4-R	19.40		1875	0.28	
C5-L	20.55		0		
C5-R	20.55		0		
C6-L	18.50		0		
C6-R	18.50		750	0.16	
20 dec. 2009					
G1	12.05	13	391250	0.51	Cm's and amount of one bottle
G2	12.10	11	330000	2.67	
G3	12.10		0		Pipe broken
G4	12.15	3	90000	0.48	
C1-L	12.40		3375	0.95	
C1-R	12.40		750	1.58	
C2-L			0		
C2-R	12.30		3000	0.11	
C3-L	12.30		16500	0.71	
C3-R	12.30		11250	1.18	
C4-L	12.20		7000	0.12	
C4-R	12.20		5250	0.13	
C5-L	12.45		13500	1.89	
C5-R			0		Space under collector
C6-L	12.00		625	1.86	
C6-R			0		Space under collector
30 dec. 2009					
G1	11.00	12	360000	0.1	
G2	11.00	2	60000		
G3	11.00	0	0		
G4	11.00		13000	0.11	
C1-L	11.00		2500	2.33	
C1-R	11.00		500	2.99	
C2-L	11.00		3500	2.05	
C2-R	11.00		1500	0.26	
C3-L	11.00		15250	4.58	
C3-R	11.00		9250	1.93	
C4-L	11.00		1750	1.22	
C4-R	11.00		1375	1.44	
C5-L	11.00		12500	0.2	
C5-R	11.00		750	3.6	
C6-L	11.00		7250	3.9	
C6-R	11.00		0		
18 jan. 2010					
G1	10.50	8	240000	0.53	
G2	11.05	2.7	81000	0.8	
G3	11.05	0	0		
G4	11.15	2.7	81000	0.13	
C1-L	11.35		3750	0.35	
C1-R	11.35		0		
C2-L	11.30		2000	0.46	
C2-R	11.30		0		
C3-L	11.25		750	1.14	
C3-R	11.25		6125	0.29	
C4-L	11.20		7000	0.22	
C4-R	11.20		7500	0.31	
C5-L	11.40		3500	0.31	
C5-R	11.40		0		
C6-L	11.40		2250	0.42	
C6-R	11.40		750	0.86	

Date	Time	Water depth [cm]	Water amount [ml]	Sed. Concentr. [gr/L]	Comments
22 jan. 2010					
G1	10.00	23	690000	0.25	
G2	10.30	13	390000	0.59	
G3	10.45		37000	0.26	No stirring
G4	10.50		34250	0.08	Now levelled. 7 cm uplift on lo
C1-L	11.15		7625	0.54	
C1-R	11.15		0		
C2-L	11.10		14750	0.77	
C2-R	11.10		6750	0.94	
C3-L	11.05		34500	0.82	
C3-R	11.05		11250	1.03	
C4-L	11.00		13000	0.28	
C4-R	11.00		15250	0.54	
C5-L	11.2		88357	0.74	
C5-R	11.2		0		
C6-L	10.15		20500	1.22	
C6-R	10.15		56750	1.51	
26 jan. 2010					
G1	09.20	3.5	105000	0.98	
G2	09.30	3	90000	0.49	
G3	09.35	0	0	0	
G4	09.35	1.7	51000	0.17	
C1-L	09.55		0		
C1-R	09.55		0		
C2-L	09.55		1750	0.54	
C2-R	09.50		4250	0.16	
C3-L	09.50		12375	0.3	
C3-R	09.50		7375	0.26	
C4-L	09.45		4750	0.3	
C4-R	09.45		4500	0.23	
C5-L	10.00		19000	0.31	
C5-R	10.00		0		
C6-L	10.05		400	0.22	
C6-R	10.05		4125	0.44	
8 febr. 2010					
G1	10.15		6000	0.28	
G2	10.15		0		
G3	10.15		0		
G4	10.30		18750	0.24	
C1-L	10.40		0		Too little to sample. cleaned
C1-R	10.40		0		Too little to sample. cleaned
C2-L	10.35		700	0.82	
C2-R	10.35		2250	0.34	
C3-L	10.30		2500	0.29	
C3-R	10.30		2750	0.36	
C4-L	10.20		0		Violated; emptied and fixed
C4-R	10.20		0		Violated; emptied and fixed
C5-L	10.50		0		
C5-R	10.50		0		
C6-L	10.50		0		
C6-R	10.50		0		
11 febr. 2010					
G1	09.15		4000	0.61	
G2	09.20		0		
G3	09.20		0		
G4	09.30		10500	0.07	
C1-L	10.00		500		Bottle broken. no sample
C1-R	10.00		0		
C2-L	09.50		1250	0.41	
C2-R	09.50		1125	0.24	
C3-L	09.45		875	0.36	
C3-R	09.45		750	0.69	
C4-L	09.40		1250	0.3	
C4-R	09.40		1500	0.23	
C5-L	09.40		0		

Date	Time	Water depth [cm]	Water amount [ml]	Sed. Concentr. [gr/L]	Comments
22 febr. 2010					
G1	11.05	4.8	72000	3.1	
G2	11.10	4.5	108000	8.87	
G3	11.15		12750	4.39	
G4	11.20		9500	0.18	
C1-L	11.50		17750	7.33	
C1-R	11.50		4750	9.23	
C2-L	11.45		6750	13.53	
C2-R	11.45		6375	7.75	
C3-L	11.30		11375	19.95	
C3-R	11.35		875	1.88	
C4-L	11.25		1750	5.52	
C4-R	11.25		1250	7.88	
C5-L	12.00		16750	15.48	
C5-R	12.00		0		
C6-L	12.00		0		
C6-R	12.00		0		
2 mrt. 2010					
G1	10.00		7500	1.74	
G2	10.00		0		
G3	10.00		0		
G4	10.15		7500	0.58	
C1-L	10.30		0		
C1-R	10.30		0		
C2-L	10.30		2500	0.89	
C2-R	10.30		0		
C3-L	10.30		3500	0.48	
C3-R	10.30		4250	0.57	
C4-L	10.30		7500	0.57	
C4-R	10.30		6000	1.61	
C5-L	10.30		0		
C5-R	10.30		0		
C6-L	10.30		0		
C6-R	10.30		0		
11 mrt. 2010					
G1		12	180000	1.01	No time recorded
G2		6	90000	1.48	
G3		3	45000	3.73	
G4		4	60000	5.45	
C1-L			11500	7.83	
C1-R			10500	6.71	
C2-L			6500	3.5	
C2-R			10000	3.65	
C3-L			12500	1.69	
C3-R			6000	1.29	
C4-L			1250	3.31	
C4-R			2250	4.09	
C5-L			20000	8.94	
C5-R			0		
C6-L			35000	12.26	
C6-R			0		

7.2 Original data ACED assessment

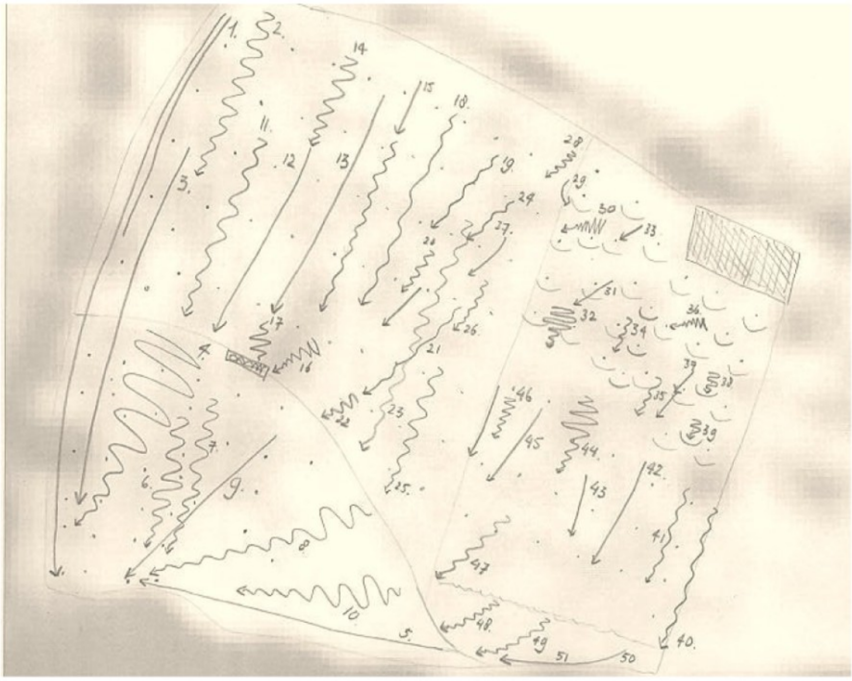
7.2.1 Legend rill survey maps



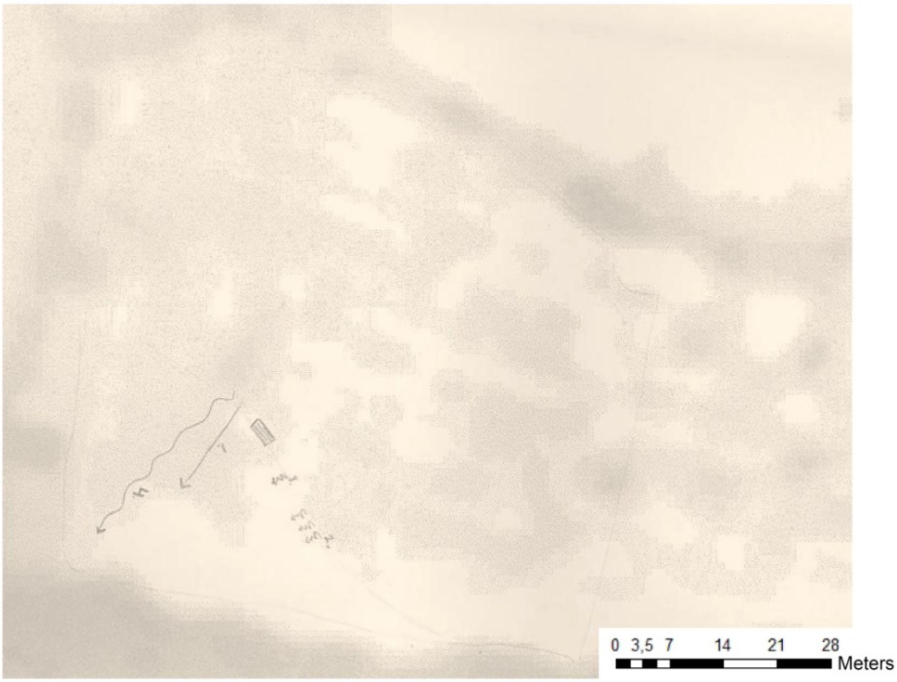
7.2.2 Rill survey maps

Field 1

Rill survey 1

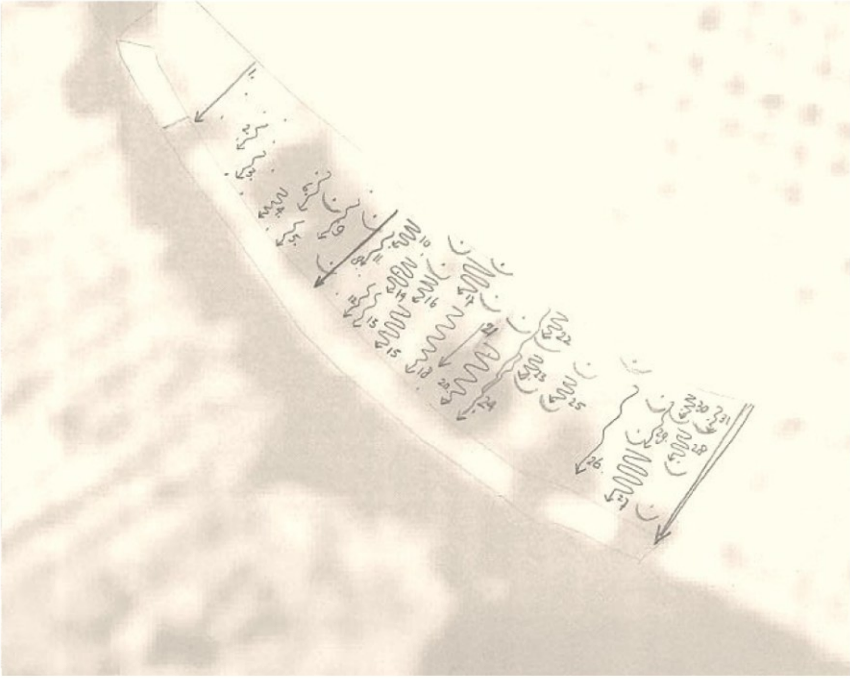


Rill survey 2

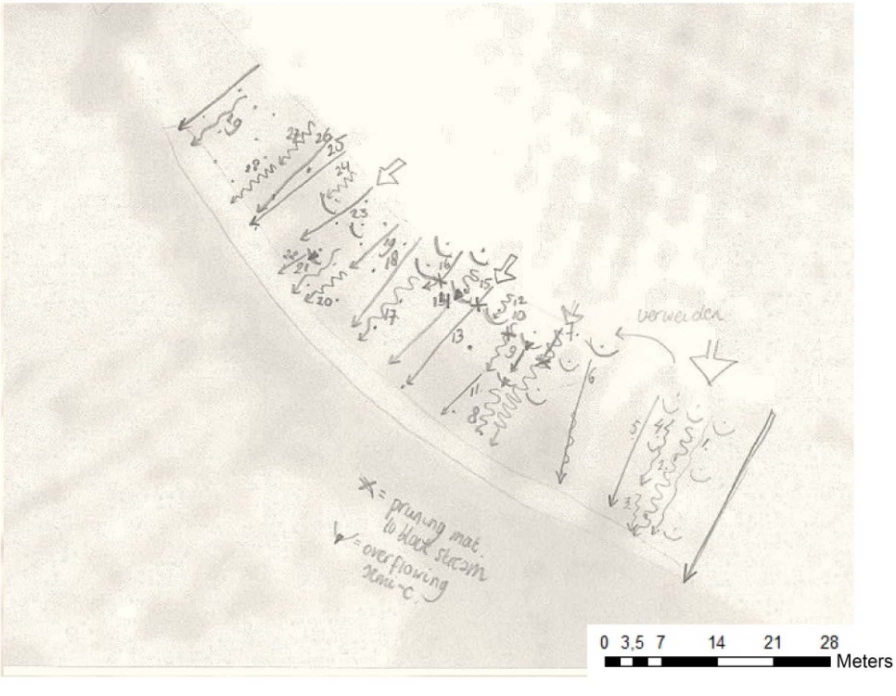


Field 2

Rill survey 1



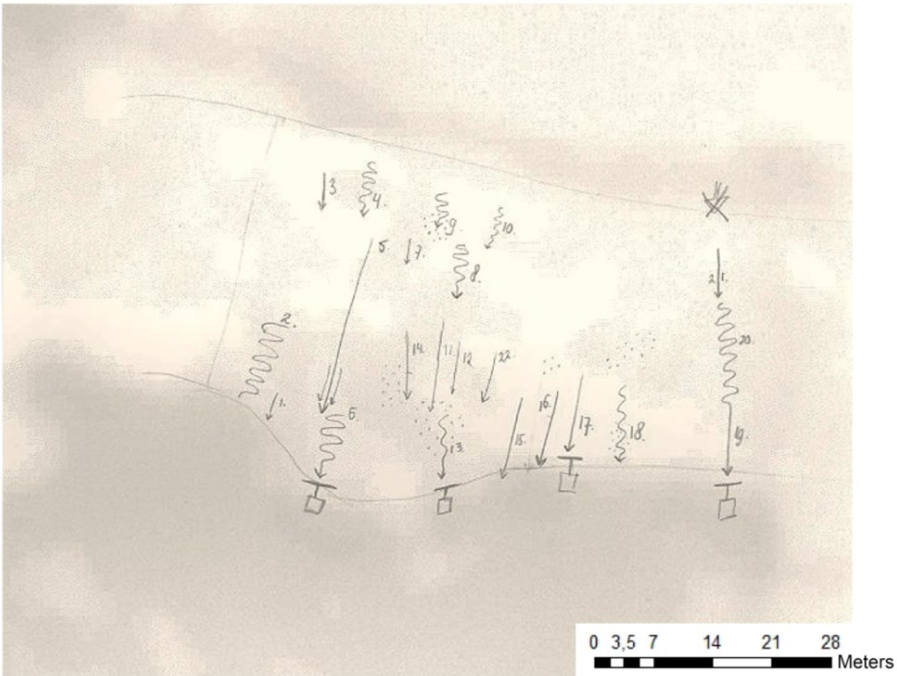
Rill survey 2



Field 3

Rill survey 1

Rill survey 2



7.2.3 Overview ACED outcomes

Area	Date	Field size [m2]	Soil Loss Sum [m3]	Area of actual damage Sum [m2]	Area of actual damage as % of Field Size [%]	Soil loss Sum/ha [m3/ha]	Soil loss per area of actual damage [m3/ha]
Field2	19-11-2009	5808,0	28,5	325,8	5,6	49,1	874,8
	27-01-2010		1,8	24,6	0,4	3,1	732,8
Field3	4 & 11-11-2009	3353,4	22,3	185,3	5,5	66,5	1203,5
	26-01-2010		19,3	152,2	4,5	57,7	1270,3
Field6	4-11-2009	3435,0	3,1	38,8	1,1	8,9	789,9
	27-01-2010		2,4	31,2	0,9	7,0	774,7

Area	Date	Treatment	Field size [m2]	Soil Loss Sum [m3]	Area of actual damage Sum [m2]	Area of actual damage as % of Field Size [%]	Soil loss per area of actual damage [m3/ha]	Soil loss Sum/ha [m3/ha]
Field2	19-11-2009	SWC	2048	6,8	79,7	0,0	857,4	33,4
		non-SWC	3760	21,7	246,1	0,1	880,5	57,6
	27-01-2010	SWC	2048	0,0	0,0	0,0	0,0	0,0
		non-SWC	3760	1,8	24,6	0,0	732,8	4,8
Field3	4 & 11-11-2009	SWC	2518,5	16,1	133,8	0,1	1205,7	64,0
		non-SWC	834,9	6,2	51,5	0,1	1197,8	73,9
	26-01-2010	SWC	2518,5	12,6	288,2	0,1	436,2	49,9
		non-SWC	834,9	6,8	49,3	0,1	1371,3	81,0
Field6	4-11-2009	SWC	1718	2,0	19,8	0,0	1005,5	11,6
		non-SWC	1718	1,1	19,0	0,0	564,8	6,2
	27-01-2010	SWC	1718	1,2	19,0	0,0	645,2	7,1
		non-SWC	1718	1,2	12,2	0,0	975,8	6,9

7.2.4 Rills field 1

Date	No. on map	No. of rills	Av. length [m]	Av. width [m]	Av. depth [m]	Field size [m²]	Soil loss [m³]	Sum s.loss [m³]
19-11-2009								
	1	1	23.4	20	6		0.28	
		2	46.0	35	4.5		1.45	
	2	4	12.8	15	5		0.38	
		2	7.5	12	8		0.14	
		1	4.5	13	7		0.04	
	3	1	29.4	23	11		0.74	
	4	5	27.9	25	10		3.49	
		9	3.0	25	10		0.68	
	5	2	46.0	25	8		1.84	
	6						0.00	
	7	6	23.4	19	15		4.00	
	8	1	21.1	28	15		0.89	
	9	1	21.1	25	8		0.42	
	10	9	5.3	27	6		0.77	
		6	10.6	20	11		1.39	
	11	1	9.8	14	8		0.11	
		4	12.1	16	8		0.62	
	12	1	18.9	17	8		0.26	
	13	1	6.0	16	9		0.09	
		3	9.0	12	7		0.23	
	14	2	8.3	10	10		0.17	
	15	1	6.8	10	3		0.02	
		3	6.0	12	9		0.20	
		2	5.3	15	8		0.13	
	16	4	8.3	20	8		0.53	
	17	2	3.8	16	6		0.07	
	18	1	13.6	14	11		0.21	
		1	8.3	12	8		0.08	
		1	12.8	10	3.5		0.04	
	19	1	6.0	10	12		0.07	
	20	2	8.3	8	8		0.11	
		1	6.8	10	7		0.05	
		1	3.0	11	6		0.02	
	21	1	24.1	12	9		0.26	
	22	3	6.8	11	7		0.16	
	23	3	12.8	11	10		0.42	
		3	6.8	15	9		0.27	
		1	4.5	10	5		0.02	
	24	1	12.1	28	11		0.37	
	25	1	8.3	25	5		0.10	
		4	10.6	12	6		0.30	
	26	2	9.0	12	8		0.17	
	27	1	8.3	11	6		0.05	
	28	2	2.3	7	4		0.01	
	Totals Non-SWC					3760		21.67
	29	1	2.3	7	3		0.00	
	30	3	6.8	12	2		0.05	
	31	1	6.0	10	5		0.03	
	32	3	3.0	8	5		0.04	
		1	3.0	10	4		0.01	
	33	1	3.0	12	2		0.01	
		2	1.5	9	3		0.01	
	34	1	5.3	9	4		0.02	
		4	2.3	9	4		0.03	
	35	2	3.8	9	3		0.02	
	36	3	6.0	20	1		0.04	
	37	1	9.0	7	8		0.05	
		2	4.5	6	3		0.02	
	38	1	3.0	9	3		0.01	
		2	1.5	8	3		0.01	
	39	2	2.6	9	4		0.02	
		2	5.3	13	3		0.04	
	40	5	7.5	12	5		0.23	
		2	12.1	14	5		0.17	
	41	2	11.3	15	4		0.14	
		2	2.3	7	3		0.01	
	42	4	19.6	12	9		0.85	
	43	2	8.3	11	8		0.15	
	44	10	2.3	5	3		0.03	
	45	3	12.1	9	6		0.20	
	46	2	2.3	5	12		0.03	
	47	2	19.6	15	19		1.12	
	48	3	12.1	24	10		0.87	
	49	5	12.1	20	9		1.09	
	50	1	10.6	20	7		0.15	
	51	2	15.8	30	15		1.43	
	Totals SWC					2048		6.83
27-1-2010	NB: Ploughing (animal. contour) on 6-1-2010							
	1	1	21.1	13	8		0.22	
	2	3	3.8	40	12		0.54	
	3	5	3.8	15	6		0.17	
	4	2	36.2	20	6		0.87	
	Total Non-SWC					3760		1.80

7.2.5 Rills field 2

Date	No. on map	No. of rills	Av. length [m]	Av. width [m]	Av. depth [m]	Field size [m^2]	Soil loss [m^3]	Sum s.loss [m^3]
4-11-2009 Part 1	1	2	26.60	22	12		1.40	
	2	2	6.00	4	5		0.02	
	3	1	9.20	6	4		0.02	
		1	6.70	6	4		0.02	
	4	1	16.20	15	15		0.36	
		4	4.10	10	9		0.15	
	5	1	19.70	15	11		0.33	
	6	1	18.10	16	10		0.29	
		1	7.10	10	8		0.06	
	7	1	25.60	22	18		1.01	
		1	18.30	14	10		0.26	
		1	2.00	14	10		0.03	
	8	1	28.10	55	12		1.85	
		1	9.60	16	11		0.17	
		1	6.50	9	5		0.03	
	9	1	13.00	13	10		0.17	
Totals Non-SWC						834.90		6.17
	10	4	10.00	15	10		0.60	
	11	2	18.00	10	8		0.29	
		2	7.50	9	8		0.11	
	12	1	23.90	15	10		0.36	
		1	12.90	16	7		0.14	
	13	1	7.40	12	10		0.09	
		1	1.50	12	10		0.02	
	14	5	3.00	6	4		0.04	
	15	4	8.00	42	8		1.08	
		4	7.50	27	12		0.97	
	16	2	8.00	30	13		0.62	
	17	3	5.50	25	15		0.62	
	18	2	20.00	25	13		1.30	
11-11-2009								
Part 2 (Continuation of 04/11/2009)								
	20	4	9.43	25	13		1.23	
	21	1	16.59	25	13		0.54	
	22	4	5.66	30	10		0.68	
	23	1	6.03	30	9		0.16	
		2	2.26	23	10		0.10	
	24	1	12.06	26	12		0.38	
		1	15.08	26	12		0.47	
		1	3.77	26	12		0.12	
	25	1	6.79	9	4		0.02	
	26	1	21.49	27	16		0.93	
	27	6	8.29	25	18		2.24	
	28	4	7.54	25	11		0.83	
	29	2	17.34	20	12		0.83	
	30	4	5.66	22	15		0.75	
	31	5	4.52	23	12		0.62	
Totals SWC						2518.50		16.13
26-1-2010	1	2	23.37	18	9		0.76	
	2	3	6.79	30	10		0.61	
	2	3	9.80	15	9		0.40	
	3	2	9.80	20	15		0.59	
	4	3	14.33	18	10		0.75	
	5	2	6.79	15	7		0.14	
		1	7.54	16	12		0.14	
	6	2	7.54	16	8		0.19	
		1	9.80	25	10		0.25	
	7	1	23.37	20	24		1.12	
		2	15.08	25	11		0.83	
	8	2	8.29	25	12		0.50	
	9	1	5.66	30	14		0.24	
	10	2	7.54	20	12		0.36	
	11	1	15.08	20	10		0.30	
	12	3	3.77	10	3		0.03	
	13	1	23.37	16	13		0.49	
	14	1	15.08	30	13		0.59	
	15	3	7.54	20	12		0.54	
	16	2	5.66	21	12		0.29	
	17	2	12.82	30	6		0.46	
	18	1	19.23	28	9		0.48	
	19	1	15.83	32	35		1.77	
	20	2	9.80	30	13		0.74	
Totals SWC						2518.50		12.57
	21	3	8.29	19	12		0.57	
	22	1	8.29	47	6		0.23	
	23	1	15.08	65	15		1.47	
	24	2	5.28	15	10		0.16	
	25	1	23.37	25	20		1.17	
	26	1	23.37	28	14		0.92	
	27	3	7.54	16	15		0.54	
	28	3	15.83	23	13		1.42	
	29	2	13.20	9	12		0.29	
Totals Non-SWC						834.90		6.76

7.2.6 Rills field 3

Date	No. on map	No. of rills	Av. length [m]	Av. width [m]	Av. depth [m]	Field size [m²]	Soil loss [m³]	Sum s.loss [m³]
44-11-2009	1	2	15	14	8		0.34	
		4	6.5	10	8		0.21	
	2	1	7.3	8	4		0.02	
	3	4	5.8	11	6		0.15	
	4	1	5.2	12	5		0.03	
	5	1	13.2	9	9		0.11	
		2	4.4	8	4		0.03	
	6	8	1.5	6	6		0.04	
	7	1	40.9	9	22		0.81	
		2	3.1	7	15		0.07	
	8	3	1.1	8	10		0.03	
		2	5.3	9	10		0.10	
	9	3	1.6	11	3		0.02	
	10	1	5	9	7		0.03	
	11	1	3.2	6	6		0.01	
		2	1.2	5	4		0.00	
Totals SWC						1717.50		1.99
	12	1	6.3	10	4		0.03	
	13	2	6.6	6	4		0.03	
	14	2	7	8	3		0.03	
	15	1	7.8	8	5		0.03	
		2	6	6	2		0.01	
	16	1	9.7	12	6		0.07	
		1	4.9	8	4		0.02	
		2	1	8	4		0.01	
	17	2	7	7	5		0.05	
	18	1	41.7	12	9		0.45	
	19	3	1.6	9	6		0.03	
	20	3	0.7	4	3		0.00	
	21	1	4.2	8.5	5		0.02	
	22	4	1.4	6	3.5		0.01	
		1	3.2	6	3		0.01	
	23	1	6.9	6	2.5		0.01	
	24	2	2.2	9	4		0.02	
	25	2	7	8	7		0.08	
		2	1	8	7		0.01	
	26	1	5	4	3		0.01	
	27	1	7.2	9	4		0.03	
	28	1	21.9	9	4		0.08	
	29	1	10.6	10	5		0.05	
Totals Non-SWC						1717.50		1.07
27-1-2010	1	1	3.02	8	6		0.01	
	2	3	14.33	10	6		0.26	
	3	1	1.51	14	4		0.01	
	4	1	3.77	19	5		0.04	
	5	1	11.31	14	10		0.16	
		2	3.02	14	10		0.08	
	6	1	3.77	25	6		0.06	
		5	4.52	13	6		0.18	
	7	1	2.26	6	3		0.00	
	8	2	5.28	12	8		0.10	
	9	2	2.26	12	5		0.03	
	10	1	4.52	14	3		0.02	
	11	1	9.80	10	6		0.06	
	12	1	5.28	13	5		0.03	
	13	1	8.29	13	6		0.06	
	14	1	4.52	11	8		0.04	
	15	2	6.79	10	6		0.08	
Totals SWC						1717.50		1.22
	16	1	6.79	12	11		0.09	
	17	1	9.05	13	10		0.12	
	18	2	9.80	11	10		0.22	
	19	1	14.33	20	11		0.32	
	20	3	15.08	10	9		0.41	
	21	1	3.77	10	6		0.02	
	22	1	3.02	10	8		0.02	
Totals Non-SWC						1717.50		1.19

7.3 Rainfall records

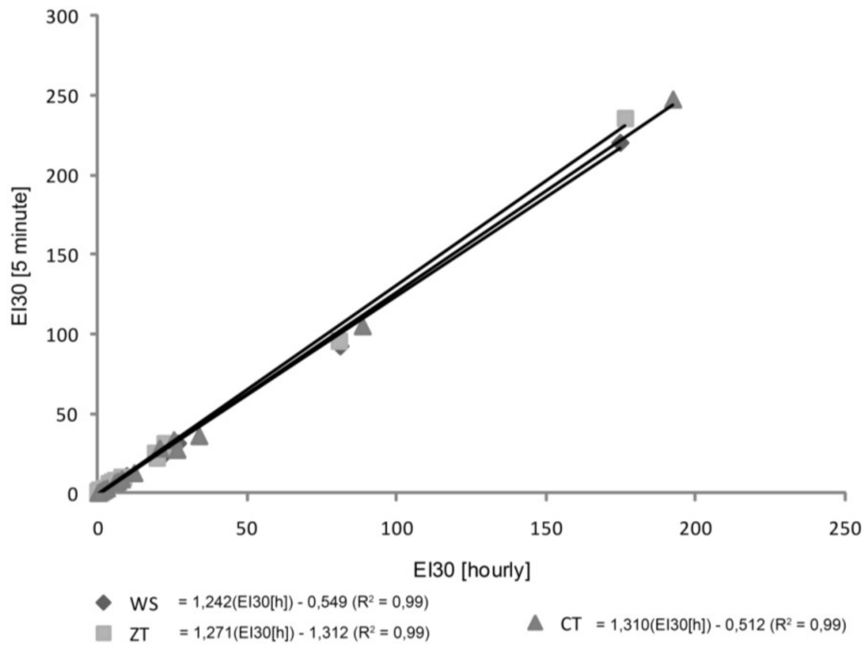
7.3.1 Rainfall record Yakhour

Long term rainfall data records, available for the period between November 2000 to autumn 2009, were used from the weather station in Yakhour village which is located 5.1 km from Maghara. The table gives the calculation of the average rainfall days and average yearly rainfall from these records.

Months	*Days [total]*	*Full year data*	*Rainfall days*	*Average rainfall days*	*Sum rainfall [mm]*	*Average [mm]*
January	186	6	68	11.3	652.8	108.8
February	159	6	71	11.8	481.3	80.2
March	279	9	102	11.3	573.3	63.7
April	150	5	63	12.6	333.3	66.7
May	155	5	34	6.8	255.3	51.1
June	180	6	4	0.7	0.8	0.1
July	217	7	4	0.6	10.6	1.5
August	186	6	49	8.2	96.1	16.0
September	180	6	19	3.2	47.0	7.8
October	217	7	37	5.3	115.3	16.5
November	210	7	105	15.0	751.8	107.4
December	186	6	55	9.2	339.2	56.5
Total				95.9		576.3

7.3.2 EI_{30} regression from hourly to 5-minute data

Not all rainfall events were recorded with 5 minute intervals, due to a series of electrical failures that occurred at the metrological station. However, almost all events are at least recorded with hourly data, with exception of the period of 20 December 2009 until 3 January 2010. A linear regression analysis between EI_{30} based on hourly and 5 minute data for the same rainfall events provided a useful method to give a close estimation of the EI_{30} for the 5 minute recorded EI_{30} events. The correlation of the hourly EI_{30} and the EI_{15}, EI_{10} and EI_5 results gave unrealistic results, therefore these estimations are not used. WS: Wischmeier & Smith (1978), ZT: Zanchi & Torri (1980) and CT: Coutinho & Tomas (1995).



7.3.3 Erosivity index for all rainstorms

The calculations are made for three different relationships between kinetic energy of rain and rainfall intensity; Wischmeier & Smith (1978), Zanchi & Torri (1980) and Coutinho & Tomas (1995).

Date	Duration [hrs]	Precipitation [mm]	Wischmeier & Smith, 1978 EI30 [hourly]	E30	E15	E10	E5	Zanchi & Torri, 1980 EI30 [hourly]	E30	E15	E10	E5	Coutinho & Tomas, 1995 EI30 [hourly]	E30	E15	E10	E5
25-10-2009	3	5,6	5,24	*5,95*				5,11	*6,18*				5,62	*5,83*			
26-10-2009	2	10,6	10,63	*12,65*				10,47	*13,21*				11,14	*12,85*			
28/10/2009	3	15,9	36,99	*45,39*				37,39	*48,47*				39,51	*48,91*			
1-11-200918	5	4,74	6,03	8,15	9,57	12,76	4,23	5,89	7,96	9,35	12,47	5,93	6,63	8,97	10,53	14,04	
12-11-2009	10	27	174,94	220,58	427,71	617,36	1113,67	176,50	235,33	911,92	2632,53	9495,98	192,59	247,68	480,26	693,21	1250,50
4-12-2009	34	6,8	0,70	1,01	1,01	1,01	1,01	0,46	0,86	0,86	0,86	0,86	1,32	1,33	1,33	1,33	1,33
10-12-2009	15	5,1	1,51	2,07	2,37	2,66	4,44	1,15	1,90	2,17	2,44	4,06	2,34	2,44	2,79	3,13	5,22
15/12/2009 - 16/12/2009	33	23,6	26,81	31,54	40,55	45,06	58,58	23,59	29,69	38,18	42,42	55,15	34,07	36,07	46,38	51,53	66,99
17/12/2009 - 18/12/2009	25	19,5	81,18	92,63	153,26	151,57	197,05	80,92	95,66	158,28	156,54	203,50	88,75	105,12	173,93	172,02	223,63
18/12/2009	18	51,7	129,48	*160,26*				126,45	*165,14*				139,00	*175,36*			
20-12-2009	unknown	1,5															
28-12-2009	unknown	1,8															
12/01/2010 - 13/01/2010	30	28,8	44,72	*55,00*				40,45	*52,47*				54,51	*67,97*			
17/01/2010 - 18/01/2010	21	22,6	48,72	*59,97*				45,56	*59,17*				56,75	*70,82*			
19-1-2010	10	6	2,61	*2,70*				2,31	*2,51*				3,25	*2,82*			
22-1-2009	7	6,3	5,79	6,96	8,08	8,75	9,43	5,30	6,81	7,91	8,56	9,22	6,84	7,51	8,72	9,45	10,18
23/01/2010	23	19,2	9,69	11,00	13,89	15,63	17,37	8,45	10,14	12,81	14,41	16,02	12,36	12,77	16,14	18,15	20,17
29-1-2010	17	5,3	0,90	1,10	1,38	1,24	1,65	0,70	0,95	1,19	1,07	1,43	1,39	1,42	1,77	1,59	2,13
31-1-2010	15	1,8	0,14	0,24	0,39	0,59	0,88	0,08	0,22	0,34	0,52	0,78	0,29	0,30	0,49	0,73	1,10
3-2-2010 8	8,9	6,75	8,03	10,12	12,50	16,07	6,05	7,70	9,69	11,97	15,39	8,25	8,87	11,17	13,80	17,75	
9-2-2010 23	6,7	0,83	1,20	1,37	1,54	2,05	0,55	1,02	1,17	1,31	1,75	1,51	1,56	1,78	2,01	2,68	
19-2-2010	4	7,6	19,58	24,18	42,75	56,77	90,40	19,44	25,36	44,84	59,55	94,83	20,91	28,33	50,09	66,52	105,94
22-2-2010	3	2,6	1,78	2,20	3,64	3,73	5,18	1,64	2,18	3,60	3,69	3,41	2,08	2,43	4,01	4,11	3,80
23-2-2010	3	2,5	0,67	0,77	0,84	0,84	0,84	0,56	0,69	0,76	0,76	0,76	0,91	0,94	1,02	1,02	1,02
25-2-2010	4	5,4	2,62	2,78	2,94	3,44	3,93	2,36	2,57	2,72	3,17	3,63	3,17	3,21	3,40	3,97	4,54
25-2-2010	21	8,3	1,34	1,73	2,16	2,60	2,60	1,00	1,50	1,87	2,25	2,25	2,16	2,22	2,78	3,33	3,33
27-2-2010	25	25,7	22,04	24,17	27,39	29,01	33,84	19,88	22,63	25,65	27,15	31,68	26,75	27,41	31,07	32,90	38,38
3-3-2010 4	9,9	23,45	29,58	51,44	69,45	87,45	22,68	30,57	53,16	71,77	90,38	25,64	33,57	58,38	78,81	99,24	
5-3-2010 1	1,4	0,44	0,52	0,70	0,91	1,30	0,38	0,49	0,65	0,85	1,22	0,56	0,60	0,80	1,05	1,50	

Missing data corrected by use of regression results in *italic*.

7.3.4 Erosivity index for all sampling dates

		Wischmeier & Smith, 1978				
Sample date	Precipitation [mm]	EI30 [hourly]	E30	E15	E10	E5
13/12/2009	11.9	2.2	3.1	3.4	3.7	5.4
20/12/2009	94.8	237.5	284.4			
30/12/2009	3.3					
18/01/2010	51.4	93.4	115.0			
22/01/2010	12.3	8.4	9.7			
26/01/2010	19.2	9.7	11.0	13.9	15.6	17.4
11/02/2010	22.7	8.6	10.6	13.3	15.9	20.6
22/02/2010	10.2	21.4	26.4	46.4	60.5	95.6
02/03/2010	41.9	26.7	29.5	33.3	35.9	41.2
12/03/2010	11.3	23.9	30.1	52.1	70.4	88.8

7.3.5 Rainfall coefficients for all sampling dates

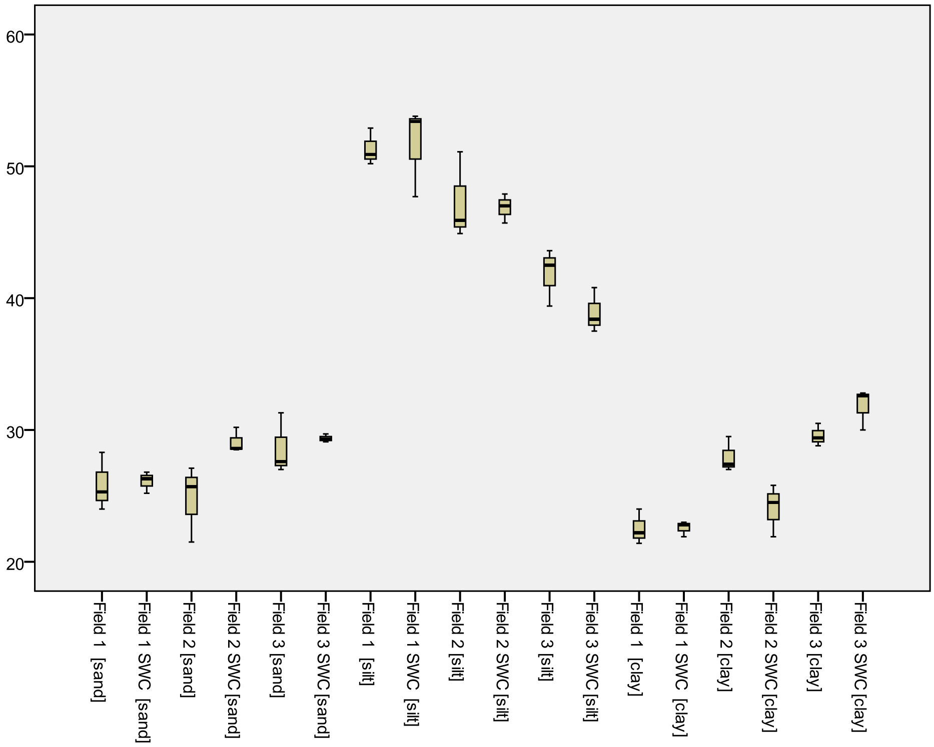
	Measured catchment				Length based catchment			
Sample date	G1	G2	Coll 3 av.	G4	G1	G2	Coll 3 av.	G4
13/12/2009	0	1	4	0	13	18	40	12
20/12/2009	2	2	2	0	51	52	20	12
30/12/2009	47	9	46	2	1357	273	463	50
18/01/2010	2	1	2	1	58	24	20	20
22/01/2010	24	17	34	1	698	476	340	35
26/01/2010	2	2	7	1	68	70	66	34
11/02/2010	0	0	2	1	5	0	21	15
22/02/2010	0	0	4	1	7	0	43	20
02/03/2010	3	6	32	0	88	159	322	12
12/03/2010	0	0	2	0	2	0	18	2
13/12/2009	7	4	32	3	198	120	324	67

7.4 Soil sampling data

7.4.1 Texture classes

The percentage of silt, sand and clay for the three fields, separated for the SWC and non-SWC areas.

%	Sand	Silt	Clay
Field 1	25.87	51.33	22.53
Field 1 with SWC	26.10	51.63	22.57
Field 2	24.77	47.30	27.97
Field 2 with SWC	29.10	46.87	24.07
Field 3	27.82	41.12	31.10
Field 3 with SWC	28.73	41.07	30.23



7.4.2 Aggregate classes

Aggregate classes for the three fields, separated for the SWC and non-SWC areas.

%	*> 10 mm*	*5.0 mm*	*4.0 mm*	*2.0 mm*	*1.0 mm*	*0.5 mm*	*0.2 mm*	*0.1 mm*	*0.05 mm*	*< 0.05*
Field 1	2.08	5.88	2.57	11.34	13.72	17.05	19.03	12.74	11.07	4.51
Field 1 with SWC	0.30	7.51	3.11	12.17	13.77	15.93	18.19	11.50	12.04	5.46
Field 2	0.49	9.58	3.84	13.39	15.30	17.67	18.70	10.10	8.57	2.36
Field 2 with SWC	0.17	8.40	3.70	13.00	15.24	17.77	18.96	10.72	9.43	2.61
Field 3	0.53	11.20	4.47	14.41	15.23	15.55	16.55	9.66	7.92	4.49
Field 3 with SWC	0.31	11.62	4.66	14.89	15.39	15.95	17.33	9.54	7.40	2.92

7.4.3 Bulk density, soil moisture and infiltration capacity

The bulk density, soil moisture and infiltration capacity for the three fields, separated for the SWC and non-SWC areas.

	MS (%)	*BD (g cm3)*	*Ks [cm/sec]*
Field 1	21.31	1.14	0.001
Field 1 with SWC	19.53	1.16	0.001
Field 2	19.16	1.11	0.001
Field 2 with SWC	17.97	0.89	0.001
Field 3	19.70	0.85	0.003
Field 3 with SWC	19.39	1.02	0.002

7.5 Vegetation

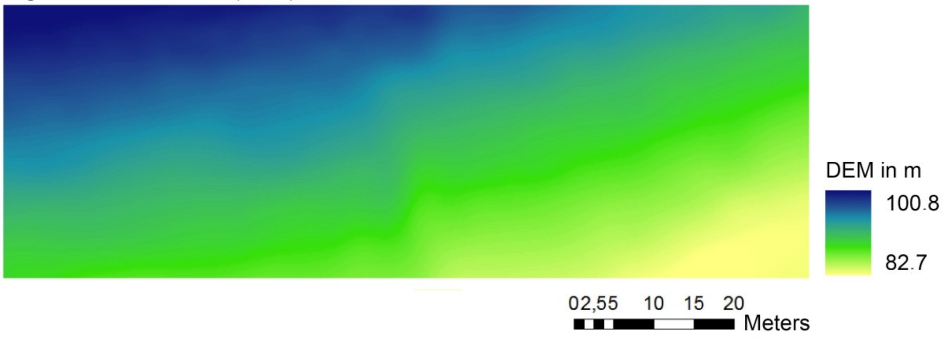
7.5.1 Trees field 3

Tree nr.	X	Y	Z	Canopy area (m^2)	Bedekkingsgraad	
1	29.2	4.4	2.1	3.4	30	
2	21.9	6.1	3.3	4.83	60	
3	12.8	9.5	2.8	4.05	60	
4	12.8	14	3.1	4.32	40	Semi-circular
5	8.8	13.1	2.9	3.42	30	Semi-circular
6	-5.1	14.6	2.60	4.2	40	
7	31.1	12.5	3.3	3.6	50	
8	31.3	21.6	2.8	4.75	40	
9	27.1	18	2.9	4.05	40	Semi-circular + Barrels (C6)
10	3.8	23.6	2.8	8.896	25	Semi-circular + pins 2
11	24.3	25.8	2.9	4.6	30	
12	32.3	29	2.9	3.5	40	
13	12.9	28.7	3	4.56	40	Semi-circular
14	3.8	31.6	3	4.5	20	Semi-circular + Barrels (C5)
15	13.6	21.6	3.35	8.99	20	Semi-circular
16	32	32.8	2.5	5.06	40	
17	34.6	39.4	2.9	6.5	30	
18	28.8	35.8	3.4	6.5	40	
19	30.8	45.4	2.9	4.68	20	
20	23.8	34.5	2.9	7.56	35	
21	26	42.7	2.9	5.46	20	
22	16.6	37.4	2.4	5.75	30	Semi-circular
23	16.9	47.5	2.7	6.5	35	Semi-circular + pins 5
24	16.2	38.6	3	8.12	30	Semi-circular
25	9.6	32.4	3	6	30	Semi-circular
26	7.2	42.1	2.4	5.2	20	Semi-circular + pins 3
27	7.2	46	2.8	7.25	35	Semi-circular + pins 4
28	30.6	50	2.5	3.6	25	
29	22.2	54.2	3	5.2	30	Semi-circular
30	1.3	54.6	2.8	5.98	25	Semi-circular
31	8.3	56	2.9	5.76	25	Semi-circular
32	10.1	59.4	2.5	5.06	50	
33	1.1	63.4	2.5	5.8	50	
34	0.3	73.7	2.8	2.7	40	
35	6	73.5	2.3	5.28	40	
36	7	66.3	1.2	1.21	30	
37	11.4	68.2	2.3	3.4	60	
38	20.4	65.2	3	6.25	50	
39	17.9	54.7	2.9	5.52	30	Semi-circular
40	17.9	70.5	1.8	2.85	30	
41	13.5	73.45	1.6	2.38	40	
42	23.6	79.2	2.6	6.16	45	
43	16.9	80.6	2.7	4.2	40	
44	7.5	82.4	2.7	5	40	
45	9.3	67.3	3	6.9	35	
46	0	85	3	5.72	35	
47	2.1	93.7	3	6.75	40	
48	4.8	92.3	3	4.2	25	
49	10.5	93.3	2.5	4.37	35	
50	13.2	101.9	2.2	3.96	30	
51	21.6	102.4	1.5	1.82	30	
52	17.5	97.3	1.7	1.43	30	
53	29.6	97	2.3	3.8	40	
54	17.2	89.4	1.8	2.88	30	
55	16.7	85.2	1.2	3.04	30	
56	14.6	88.6	2.7	4.62	60	Non-olive (Acarbie)
57	13	87.6	1.6	3.06	30	
58	22.3	92.8	2.5	3.84	40	
59	15.1	90.2	1.8	2.88	30	

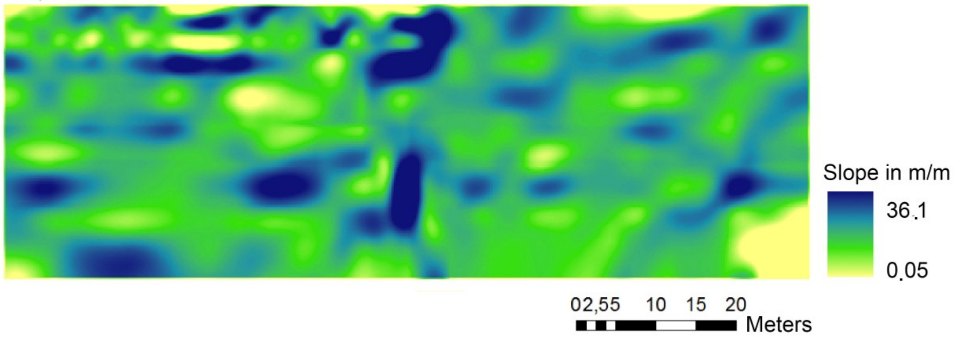
7.6 Model outcomes

7.6.1 Model input maps

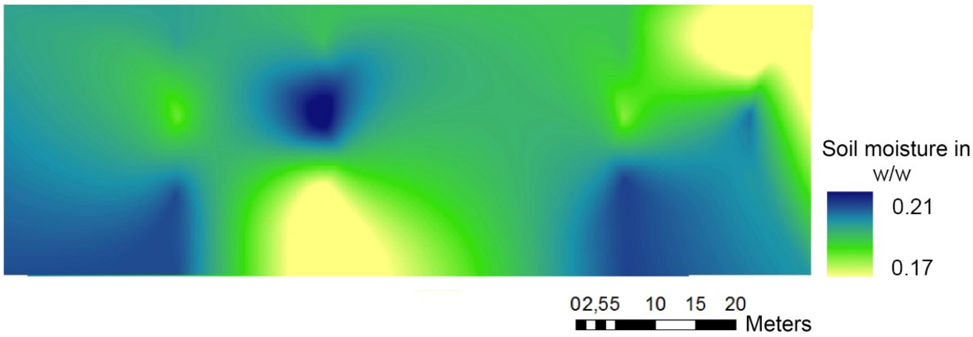
Digital Elevation Model (DEM)



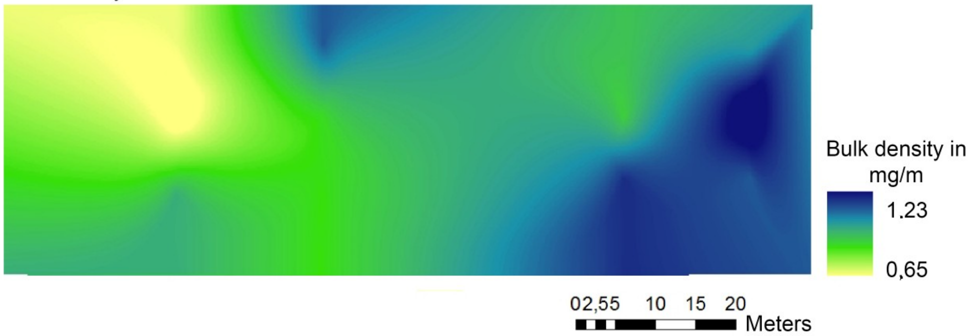
Slope

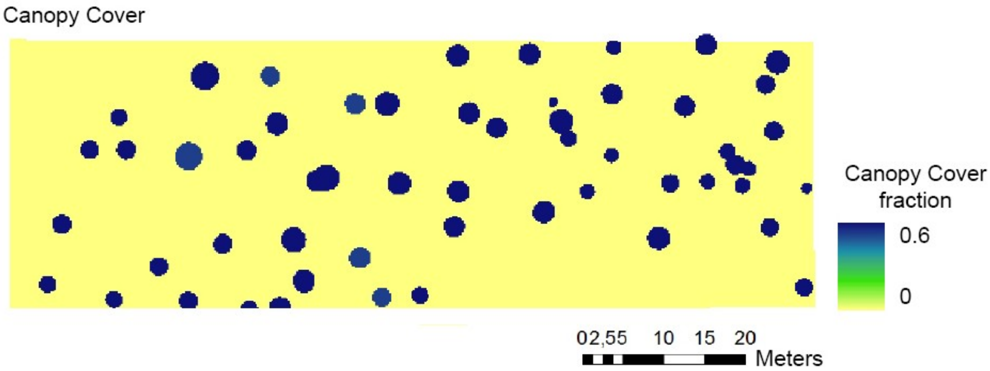


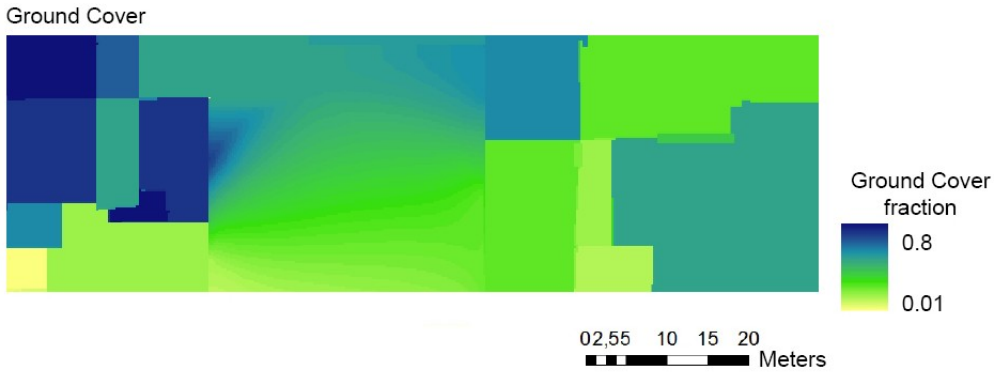
Soil moisture



Bulk density

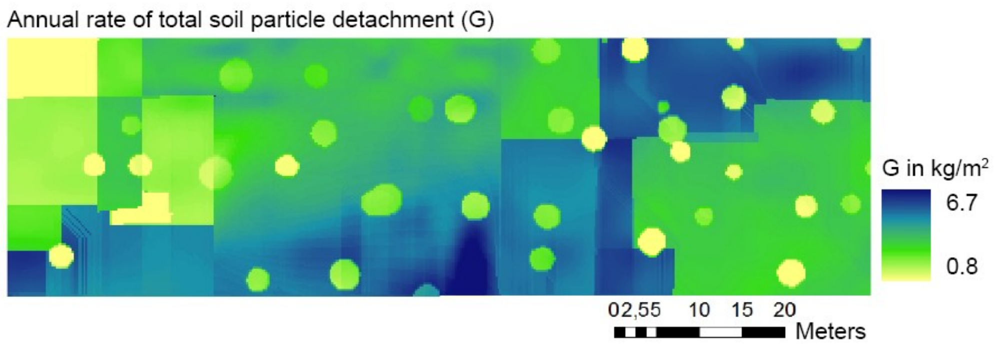


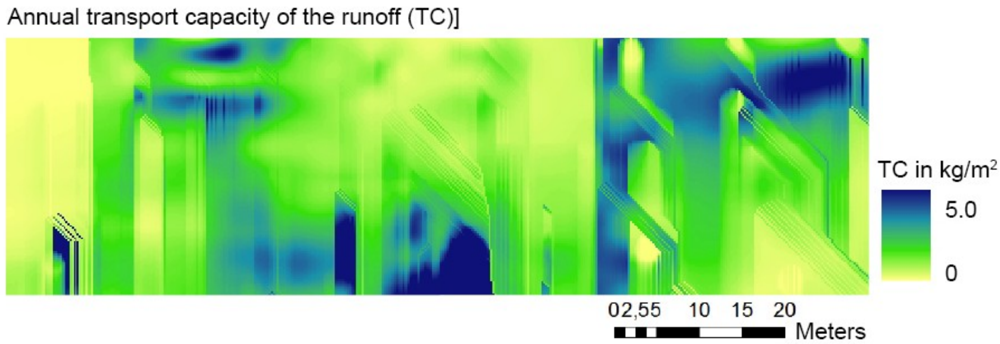




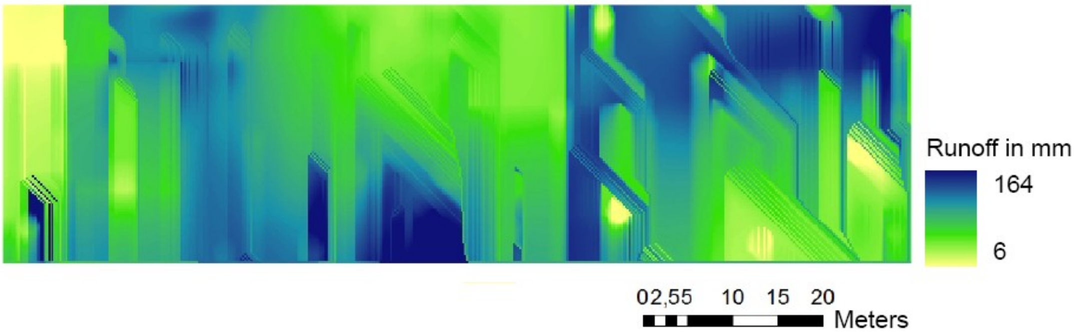
7.6.2 Model output maps

RMMF model

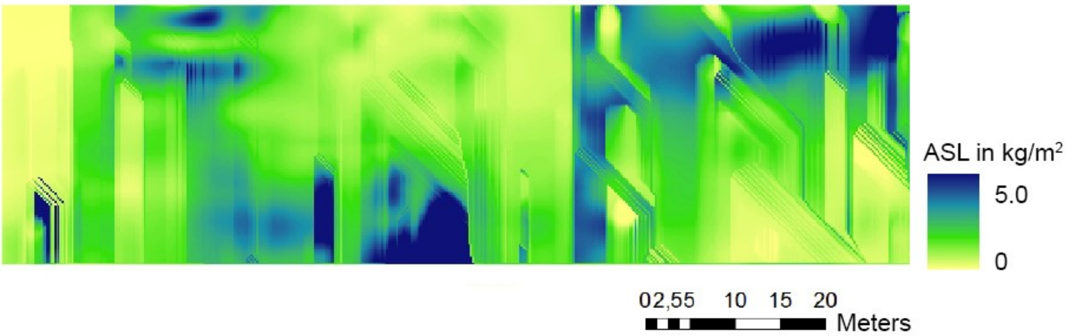




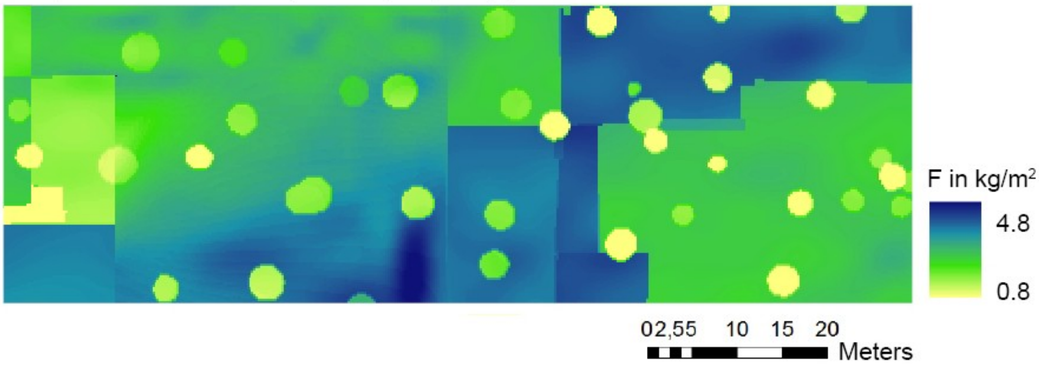
Surface runoff



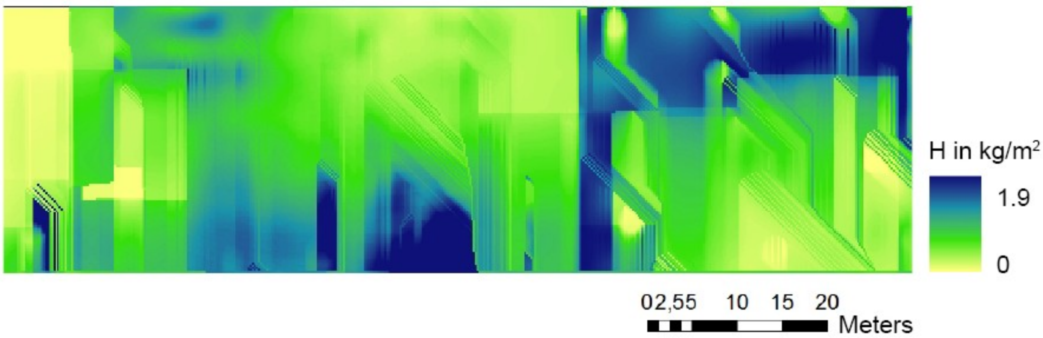
Annual Soil Loss (ASL)



Soil particle detachment by raindrop impact (F)



Transport capacity of surface runoff (H)



7.6.3 Model scripts

RMMF model (no reinfiltration)

```
 #The revised Morgan Morgan and Finney model  (spatial distributed)
       # No reinfiltration

# Emma van der Zanden

binding

# Time
 Duration = scalar(1);  # Duration of the time step in years

# Terrain
 Area = maps\clone4.map;                # Clone with area of interest
 S = maps\slope7.map;                   # Slope (m/m) (July 2010 version)
 DEM = maps\dem9.map;                   # Digital elevation model (July 2010 version)
 Flowcell1 = maps\lddnew2008.map;       # Length of flow through the cells, based on the LDD

# Soil properties
 MS = maps\soilmoisture4.map;            # Soil moisture content at field capacity [wt %]
 BD = maps\bulkdensity4.map;             # Dry bulk density (mg/m)
 KS = maps\satconductivity4.map;         # Saturated conductivity of the soil [mm/day]
 ST = maps\rock4.map;                    # Fraction of rock fragments on soil surface
 clay = maps\clay4.map;                  # Clay fraction
 silt = maps\silt4.map;                  # Silt fraction
 sand = maps\sand4.map;                  # Sand fraction

# land cover

 CC = maps\canopycover5.map;            # Proportion Canopy Cover
 GC = maps\groundcover4.map;            # Proportion Ground Cover
 PH = maps\plantheight4.map;            # Plant height [m]

  # output
 A = results\interception.map;          # Interception
 G = results\G.map;                     # Annual rate of total soil particle detachment[kg/m2]
 H = results\H.map;                     # Transport capacity of surface runoff [kg/m2]
 F = results\F.map;                     # Annual rate of detachment raindrop impact [kg/m2]
 TC = results\TC.map;                   # Raindrop impact [kg/m2]
 Q = results\Q.map;                     # Annual runoff [mm]
 ASL = results\asl.map;                 # Annual soil loss [kg/m2]
 KE = results\ke.map;                   # Total Kinetic energy [J/m]
 Qm = results\qm.map;                   # Discharge [mm]
 RO = results\ro.map;
 ER = results\er.map;
 RC1 = results\rc1.map;
 LDD = maps\ldd.map;
 Sl = results\sl.map;
 EffRain2 = results\effrain2.map;
 ASLMean = results\aslmean.map;
 ER3 = results\ER3.map;
 Q4 = results\q4.map;
 NewQ = results\newq.map;
 Qflux_m2 = results\qflux_m2.map;
 Qflux_mm = results\qflux_mm.map;
 MSMean = results\msmean.map;
 BDMean = results\bdmean.map;
```

```
STMean = results\stmean.map;
PHMean = results\phmean.map;
GCMean = results\gcmean.map;
CCMean = results\ccmean.map;
AMean = results\amean.map;
SMean = results\smean.map;
QMean = results\qmean.map;
 RC1Mean = results\rcmean.map;
FMean = results\fmean.map;
HMean = results\hmean.map;
TCMean = results\tcmean.map;
ASLSD = results\aslsd.map;
QSD = results\qsd.map;
RC1SD = results\rcsd.map;
FSD = results\fsd.map;
HSD = results\hsd.map;
TCSD = results\tcsd.map;
L2_check2 = results\L2_check2.map;
Flowcell = results\flowcell.map;
```

<u>areamap</u>
DEM;

<u>timer</u>
1 30 1;

<u>initial</u>

```
# Rainfall parameters
R = scalar(576.3);              # Total annual rainfall [mm]

RN = scalar(95.9);              # The number of rainfall days per year [days]

T = scalar(17.4);               # Mean annual temperature [Celsius]

I = scalar(30);                 # Intensity of errosive rain  [mm/hr]

EtEo = scalar(0.47)*0.9;        #Annual ratio fo actual and potential evatranspiration

E = scalar(1400);               # Annual evapotranspiration [mm] (from Bruggeman,
                                2005)

LDD = lddcreate(DEM,1E35,1E35,1E35,1E35);

# Soil parameters
EHD = scalar(0.05);             # Effective hydrological depth of soil, based on
                                Morgan (2001) [m]

K = scalar(0.7);                # Soil detachability index [g/J]

COH = scalar(10);               # (Effective) cohesion (kPa)

LP = scalar(25);                # Kirkby (1976) in [m/day]

Kc = scalar(0.1);               # Detachability of the soil - clay [g/J]

Kz = scalar(0.5);               # Detachability of the soil - silt [g/J]

Ks = scalar(0.3);               # Detachability of the soil - sand [g/J]

DRc = scalar(1.0);              # Detachability of the soil by runoff - clay [g/mm]
```

```
DRz = scalar(1.6);                          # Detachability of the soil by runoff - silt [g/mm]

DRs = scalar(1.5);                          # Detachability of the soil by runoff - sand [g/mm]

C = scalar(0.192);                          # Product of USLE's C and P factors

MS = (MS/100);                              # Correct Soil moisture from % to fraction
```

<u>Dynamic</u>

```
report LDD = LDD;                           # To check the new formed LDD

# dynamic

# Area

L = celllength();                                          # Cell length [m]

report Flowcell = if(Flowcell1 gt 0.2, 0.282843, 0.2);     # Total length of streams [m]

report L2_check2 = (accuflux(LDD, Flowcell));

# Water phase

report A = max(CC,GC);                      # Interception (proportion) by vegetation/crop cover

EffRain1 = 1-A;

report EffRain2 = (maptotal(EffRain1))/scalar(79051);

# Rainfall corrections

report Sl = 1/cos(S);                       # The effect of the slope angle [degrees]

report ER= R*(1-A)*Sl ;
                                            # Effective rainfall [mm]: total rainfall corrected by
                                            vegetation interception (and by slope, Morgan-
                                            Duzant version);

LD= ER*CC;                                  # Leaf drainage [mm]

DT= ER-LD;                                  # Direct throughfall [mm]

KEDT = DT*(9.81 + 11.25*(log10(I)));
                                            # Kinetic energy corrected for direct throughfall [J/m]
                                            using Zanchi & Torri (1980)

KELD = LD*((15.8-(PH**0.5))-5.87);          # Kinetic energy corrected for leaf drainage [J/m]

report KE = KEDT + KELD;                    # Total kinetic energy [J/m]

# Q with the old RMMF approach, without reinfiltration

report RC1 = 1000*MS*BD*EHD*(EtEo**0.5);
                                            # Soil moisture storage capacity [mm]

RO = R / RN;                                # Output: scalar

report Q4 = ER*exp(-RN*RC1/ER);             # Q in mm
```

```
report NewQ = (Q4/1000)*L;                # Q in m2

report ER3 =(ER/1000)*L;                  # Effective rainfall in m2

report Qflux_m2 = accuflux(LDD,NewQ);
                                          # Calculating distributed transport capacity from the
                                          cum. overland flow [m2]

Qflux_mm = (Qflux_m2/L2_check2)*1000; # The influx of Q in [mm]

report Qm = Qflux_mm;

# Sediment phase

Z = 1/(0.5*COH);                          # Soil resistance to erosion

# Soil particle detachment

# report F = K*KE*10**-3;
                                          # Soil particle detachment by raindrop impact
                                          [kg/m2]

Fc = Kc * clay * (1 - ST) * KE * (10**-3);
                                          # Soil particle detachment on clay fraction by
                                          raindrop impact [kg/m2]

Fz =  Kz * silt * (1 - ST) * KE * (10**-3);
                                          # Soil particle detachment on silt by raindrop impact
                                          [kg/m2]

Fs =  Ks * sand * (1 - ST) * KE * (10**-3);
                                          # Soil particle detachment on sand by raindrop
                                          impact [kg/m2]

report F = Fc + Fz + Fs;
                                          # Soil particle detachment by raindrop impact[kg/m2]

# Transport capacity

Hc = DRc * clay * Qm**1.5 * (1 - (GC + ST))* (sin(S))**0.3 * 10**-3;

Hz = DRz * silt * Qm**1.5 * (1 - (GC + ST))* (sin(S))**0.3 * 10**-3;

Hs = DRs * sand * Qm**1.5 * (1 - (GC + ST))* (sin(S))**0.3 * 10**-3;

report H = Hc + Hz + Hs;                  # Transport capacity of surface runoff [kg/m2]

Gc = Fc + Hc;

Gz = Fz + Hz;

Gs = Fs + Hs;

report G = Gc + Gz + Gs;                  # Annual rate of total soil particle detachment[kg/m2]

report TC = C * Qm**2 * sin(S) * 10**-3; # Annual transport capacity of the runoff [kg/m2]

# Annual soil loss
```

```
report ASL = min(G, TC);                    # Annual soil loss [kg/m2]

# Map means

report ASLMean = (maptotal(ASL))/scalar(79051);

report QMean = (maptotal(Qm))/scalar(79051);

report MSMean = (maptotal(MS))/scalar(79051);

report BDMean = (maptotal(BD))/scalar(79051);

report STMean = (maptotal(ST))/scalar(79051);

report PHMean = (maptotal(PH))/scalar(79051);

report GCMean = (maptotal(GC))/scalar(79051);

report CCMean = (maptotal(CC))/scalar(79051);

report AMean = (maptotal(A))/scalar(79051);

report SMean = (maptotal(S))/scalar(79051);

report RC1Mean = (maptotal(RC1))/scalar(79051);

report FMean = (maptotal(F))/scalar(79051);

report HMean = (maptotal(H))/scalar(79051);

report TCMean = (maptotal(TC))/scalar(79051);

# Standard deviation

report ASLSD = sqrt((maptotal((ASL-ASLMean)**2))/scalar(79051));

report QSD = sqrt((maptotal((Qm-QMean)**2))/scalar(79051));

report RC1SD = sqrt((maptotal((RC1-RC1Mean)**2))/scalar(79051));

report FSD = sqrt((maptotal((F-FMean)**2))/scalar(79051));

report HSD = sqrt((maptotal((H-HMean)**2))/scalar(79051));

report TCSD = sqrt((maptotal((TC-TCMean)**2))/scalar(79051));
```

RMMF model (with reinfiltration)

Note: The set-up of the model is the same, except for the part that calculates the discharge (Q) and several maps.

```
# input
PQsum = maps\pqsum.map;
Qm2 = maps\qm2.map;
Qm_m2 = maps\qm_m2.map;
Qm3 = maps\qm3.map;

# output
Qinflow = results\qinflow.map;
```

```
MapLoop = results\maploop.map;

# Q with the new RMMF approach, including reinfiltration
loop = scalar(1);
Qinflow = scalar(0);
report MapLoop = accuflux(LDD, 1);
Endloop = mapmaximum(Maploop);
# Start loop
repeat {
report PQsum = if(MapLoop eq loop, ER3 + upstream(LDD,Qinflow), PQsum);
                                # Rain + incoming Q summed in m2 and then converted back to mm
report Qm2 = if(MapLoop eq loop,(PQsum/(L2_check))*1000, QmSterk2);          # in [mm]
report Qm3 = if(MapLoop eq loop, (Qm2*exp(-RC/RO)), Qm3);                # Local runoff [mm]
Qm_m2 = if(MapLoop eq loop,((Qm/1000)*L), Qm_m2);                        # Local runoff [m2]
report Qinflow = Qm_m2;
loop = loop + 1;
} until loop eq Endloop;
report Qflux_mm = (Qm_m2/L2_check2)*1000;   # The influx of Q in [mm]
report Qm = Qflux_mm;
```