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ORIGINAL PAPER

Soil loss and run-off in young forest stands as affected by site preparation technique: a study in NE Portugal

**Tomás de Figueiredo · Felícia Fonseca ·
Afonso Martins**

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Abstract Soil loss rates currently recorded in forests are very low. Nevertheless, that may not be the case during stand installation and early tree growth stage, when soil is disturbed and scarcely covered. Site preparation techniques, performed to improve soil conditions for plant growth, should help reducing this erosion potential. In this study, several site preparation techniques were applied prior to installing a mixed stand (*Pseudotsuga mensiezii* and *Castanea sativa*) and a subsequent monitoring scheme of run-off and soil loss ran for 2 years in order to compare their effectiveness for erosion control. The experimental area, near Macedo de Cavaleiros, NE Portugal, at 700 m elevation, with annual means of 656 mm rainfall and 12°C temperature, has Mediterranean climatic conditions. Experimental design comprised three blocks, corresponding to different topographical positions (near flat plateau, moderate slope shoulder and steep mid-slope), where eight treatments were randomly distributed in plots with 375 m^2 area: (1) Original soil control (no intervention on the original abandoned field); (2) No subsoiling, no ploughing, plantation with hole digger; (3) Subsoiling over the whole area, with covering shovel; (4) No subsoiling, contour bunds shaped by two plough passes; (5) Subsoiling in future plantation rows, contour bunds shaped by two plough passes; (6) Subsoiling over the whole area, contour bunds shaped by two plough passes; (7) Subsoiling over the whole area, contour ploughing over the whole area; and (8) Potential erosion (subsoiling over the whole area, ploughing downhill). Sediment and water exported from small plots (2.5 m^2 average area), two replicates per treatment and block, were collected after each rainfall erosion event, in a total of 21, summing 1,876-mm precipitation in 2 years. Mean annual run-off and soil loss in the original soil were 3.4 mm and 11.6 g m^{-2}, respectively. In treatments 2–7, values were higher 3–7 times, for run-off, and 5–12 times, for soil loss. Potential erosion averages 2.3 t ha^{-1} $year^{-1}$. Soil loss and run-off tend to increase with tillage intensity associated with site preparation technique, even though average two-year losses, in all cases, are below tolerable rates. Soil loss and run-off rates decreased with time, becoming globally negligible after 2 years. Slight and moderate soil disturbance intensity site preparation techniques reduce erosion rates to 30% of potential erosion, halving the critical period when above tolerance rates may occur.

Keywords Run-off · Erosion · Site preparation · *Castanea sativa* · *Pseudotsuga menziesii*

Introduction

Forest systems have the lowest soil loss rates recorded, and they are most effective for preventing accelerated erosion, thus heavily contributing to soil protection (Morgan 2005;

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T. de Figueiredo (✉) · F. Fonseca
Centro de Investigação de Montanha (CIMO),
Instituto Politécnico de Bragança/Escola Superior Agrária,
Campus de Sta Apolónia, Apartado 1172,
5301-855 Bragança, Portugal
e-mail: tomasfig@ipb.pt

A. Martins
Universidade de Trás-os-Montes e Alto Douro, Apartado 1013,
5001-911 Vila Real, Portugal
e-mail: amartins@utad.pt

Cerdan et al. 2010). In addition, and when it concerns water erosion, forests have highly performing regulatory functions on the water cycle among others, a relevant ecosystem service forests provide, especially in Mediterranean environments characterized by high temporal contrasts in weather conditions (Hamilton 2008; Schleppi 2011; Ben-Hur et al. 2011). Water erosion is a serious problem in the context of land degradation and desertification processes in the Mediterranean region, contributing to a significant reduction in vegetation growth, siltation of water courses and deltas formation in coastal areas (Andreu et al. 1998; Kosmas et al. 2000).

In cultivated forests, together with post-fire hazardous conditions and logging operations, installation is one of the periods of stand's lifetime when forests may fail to fulfil their accepted reference role as resource conservation systems (Dissmeyer and Foster 1984; Ferreira et al. 2008; Llovet et al. 2009). Site preparation, plantation and the first stages of stand development are taken as critical, because canopy cover is scarce or virtually nil and ground vegetation may be insufficient for controlling erosion (Lucci and Della Lena 1994). It should be added that, in NE Portugal, woodlands are commonly set on sloping marginal areas, with a high erosion risk potential, which can turn into actual severe soil losses when vegetation cover is scarce (Agroconsultores e Coba 1991; de Figueiredo and Fonseca 1997). Actually, young forest stands were identified as areas of accelerated erosion in NE Portugal (Agroconsultores e Coba 1991); however, even though based on sound field assessments, this was never experimentally verified. A large majority of studies is conducted in mature well-developed stands, and so the installation phase is less understood, meaning that important components of the initial dynamics of these systems are often lacking.

Furthermore, as low quality soils commonly dominate in areas selected for stand installation, site preparation is considered a necessary step towards a successful plantation and techniques are devised to improve soil conditions for plant growth; besides, most techniques are also intended to control erosion (Alves 1988; Zwolinski and Donald 1995; Querejeta et al. 2001; Alcázar et al. 2002; Piatek et al. 2003). However, site preparation for afforestation currently lacks accurate planning based on sound experimental results driving to techniques most adequate to each situation and respecting stand productivity and ecosystem sustainability requirements. On the other hand, site preparation techniques induce a visible disturbance on soils, which strengthens the idea that, in the first stages of stand development, a high erosion risk prevails in afforested areas. Experimental results validating this idea in Portugal are still very scarce (Nunes et al. 2011). Mechanical operations associated with site preparation imply important disturbance due to heavy machinery normally used in forestry (Alcázar et al. 2002). Disturbance means parent material breakdown by deep subsurface tillage, necessary to improve rooting depth in shallow soils (Fonseca et al. 2011). As a consequence, it increases rock fragment content in the profile and eventually at surface if tillage reverses soil layers as it is also normally the case of surface tillage. As well, microrelief changes are an even or spatially oriented consequence of site preparation operations. All these features have direct effects on the erosional response of such areas (Takken et al. 2001; Govers et al. 2006; Alvarez-Mozos et al. 2011).

However, not all features mentioned relate to this response with a similar pattern or sign, as some show opposite trends in the relationship with erosion, as it is the case of surface roughness and aggregate stability as affected by tillage-induced soil disturbance (Gómez et al. 2005; Guzha 2004; Armand et al. 2009; Alvarez-Mozos et al. 2011). Hence, site preparation techniques are a complex combination of actions with contradicting effects on the erosional response of areas under afforestation plans. This is a topic with very limited discussion in literature, and consistent information, experimentally derived, is lacking on best practices to be recommended according to local site conditions, as these may determine the global result of such combinations, or, stated in other terms, adequacy and performance of site preparation techniques selected.

A research was conducted so as to clarify some current ideas concerning water erosion on young forest stands, under the site conditions commonly found in NE Portugal. This paper aims at presenting and discussing research results, focused in comparing the effectiveness of different site preparation techniques in erosion control on the first stages of forest stands development.

Materials and methods

The experimental area is located in Macedo de Cavaleiros, 40 km SW of Bragança, NE Portugal, at 41°35′N, 6°57′W, and an elevation ranging from 660 to 701 m. The area depicts a rolling topography (Photo 1). Average annual temperature and precipitation are 12°C and 656 mm, respectively, with typically Mediterranean seasonal distribution (Agroconsultores e Coba 1991; INMG 1991). According to FAO/UNESCO (1988), soils are dystric Cambisols and dystric Leptosols developed on schist, in the area characterized as sandy-loam, with high stoniness (higher in the latter ones, which occur in steeper slopes), normally acid, moderate to poor in organic matter content, with low to very low P and low to moderate K contents (Agroconsultores e Coba 1991; Fonseca 2005). A small part of the experimental field in a plateau is covered by

Photo 1 Experimental area: general view after site preparation (contour bunds freshly shaped, with evident soil disturbance and exposed rock fragments) (*centre*); machinery operating and some implements used (heavy plough and ripper) (*bottom*); microplots for erosion monitoring in different treatments, at different moments (*right*)

soils derived from a shallow tertiary sedimentary deposit, resting over the schist basement. These soils have higher silt, clay and organic matter contents, are more acid and have lower P and K, than the ones previously described, as shown by data from samples collected on 48 profiles before site preparation operations, and differences found are statistically significant ($P < 0.05$) (Fonseca 2005).

The area was originally a cereal field, abandoned and left for about 10 years to natural vegetation recover. Prior to site preparation operations, in mid-Autumn, a heavy disc

Table 1 Tested treatments representing site preparation techniques and two controls, ranked from lowest to highest intensity of soil disturbance

Treatment	Description of site preparation operations	Soil disturbance		
		Depth (cm)	Area (%)	Class
No_D	Control: Original soil condition. No disturbance No intervention on the original abandoned field	–	0%	None
Lo_D1	No subsoiling, no ploughing, plantation with hole digger, down to 60 cm depth	SS—60 p	10–14%	Slight
Lo_D2	Subsoiling over the whole area, with covering shovel	SS 70	22–25%	Slight
Mo_D1	No subsoiling, contour (ditch-)bunds shaped by two plough passes	S—90	49–52%	Moderate
Mo_D2	Subsoiling in future plantation rows, contour (ditch-)bunds shaped by two plough passes	SS—70 r S—90	49–52%	Moderate
Hi_D1	Subsoiling over the whole area, contour (ditch-)bunds shaped by two plough passes	SS—70 S—90	70–75%	Intensive
Hi_D2	Subsoiling over the whole area, contour ploughing over the whole area	SS—70 S—90	95–100%	Intensive
Max_D	Control: Potential erosion Maximum disturbance. Subsoiling over the whole area, ploughing downhill	SS—70 S—30	100%	Total

SS Subsurface operation, *S* Surface operation, *p* point disturbance (plantation holes), *r* row disturbance (subsoiler path) harrowing was performed in the area, in order to reduce or eliminate existing shrub vegetation.

Experimental design comprised three blocks, where eight treatments were randomly distributed on experimental plots (Table 1). Treatments ranked second to seventh are site preparation techniques that represent increasing machinery operation and soil disturbance, from slight (Lo_D) to moderate (Mo_D) intense (Hi_D), two sub-levels each. Treatments No_D and Max_D are references for comparing the effects of site preparation techniques either with the original condition (abandoned field, no tillage) or with the potential erosion condition (vegetation clearance by tillage downhill). Site preparation techniques under test were selected among a set of commonly applied in afforestation schemes, yet with no consistent experimental base for such options. Furthermore, they combine three levels of subsurface interventions (none, in future tree rows, in the whole plot, with a ripper) and surface reshaping (with a cover shovel, light plough or a heavy plough forming contour bunds) (Photo 1), the former testing plant response under different root growth limitations (also in view enhancing soil protection by vegetation) and the latter representing different ground configuration and surface soil disturbance (also in view controlling hydrological and erosional response). Marginal land, non-suitable for agriculture, is normally where afforested areas are planned or actually set, in a wide range of topographical conditions, including the steep slopes common in forest landscapes. Treatments performance under such conditions was reliably tested accounting for with block as an experimental design factor, besides treatment. The three blocks mentioned correspond to different topographical positions as follows: I—near flat plateau (6 ± 2% slope gradient); II—moderate shoulder slope (12 ± 3%); and III—steep mid-slope (22 ± 5%).

Each one of the 24 experimental plots has an area of 375 m^2 (25 m wide by 15 m long, downslope). Plantation was performed in early spring, 3 months after site preparation operations, with *Pseudotsuga mensiezii* and *Castanea sativa*, in alternate contour rows. Distances between plants and rows are 2 and 4 m, respectively. In plots with treatment Max_D (potential erosion), plantation was made only on half the plots' width, with a hole digger, thus allowing an insight, in the longer term, into plot response under such reference conditions, with and without forest plant cover (only the latter is considered in data analysis). Plots with treatment No_D (original condition) were not planted.

For monitoring soil and water losses, microplots were installed in each one of the experimental plots (Photo 1). All fixed onto the ground, metal plates provide upper and lateral microplot boundaries and a metal gutter the lower one, where water and sediment concentrate. Losses are conveyed through a flexible hose to a 10-l plastic tank, placed downslope in a hole and covered. Tanks were painted black to avoid algae invasion. Two replicates were placed randomly on each experimental plot, except in the cases of Max_D, where they were four (two in each one of the planted and non-planted half plot). Microplots have a fixed 1 m width, their length varying with local ground configuration, from 2.3 to 2.9 m. Length of microplots was determined by ground configuration of treatments with contour bunds (Mo_D1, Mo_D2 and Hi_D1), in which surface water flow and sediment transport are locally bounded up-slope by the bund crest and down-slope by the ditch. To allow comparison, all other treatments with no such microtopographical constraint adopted similar microplot size, ensuring in any case a clearly defined contributing area. In treatment Hi_D2 experimental plots, the high surface ground roughness after site preparation was such that erosion monitoring was discarded.

Water and sediment exported from microplots were collected after each period of precipitation, named hereafter as an event. Outdoor operations comprised collecting sediment trapped on microplot gutter and replacing filled tanks by empty and clean ones. Indoor operations included oven-drying (105°C) and weighting sediment collected on microplot gutter, measuring tank water volume, with a graduated bucket, and sampling after thorough stirring of water in the bucket, with a 100-ml beaker, oven-dried afterwards for sediment dry-mass determination. Run-off was calculated from measured water volume and soil loss from sediment concentration in run-off water volume plus the mass of sediment collected in the gutter, divided in both cases by microplot area (run-off expressed in mm equivalent height, soil loss expressed in g m^{-2}).

An automatic weather station, placed on the experimental site, records meteorological data (precipitation, relative humidity, temperature and wind speed) at 10-min time step. Erosivity indexes, computed with rainfall data, included kinetic energy, estimates according to Wischmeier and Smith (1978) and combinations of rainfall parameters (intensities for durations ranging from 10 min to 24 h, amount and kinetic energy).

Soil profile observations and sampling in pits opened after site preparation provided the initial state picture of soil physical conditions. In all treatments but those with contour bunds, profiles were 2 per experimental plot, while in those with contour bunds (MoD_1, Mo_D2 and Hi_D1), they were 6, because site preparation imposed 3 different situations—the bund, the plantation row and the area between plantation rows (from bund foot to ditch).

Also after installation, surface rock fragment cover was assessed in 6 randomly distributed replicates in each experimental plot, using a 50-cm side quadrat with a 2 × 2 cm grid placed onto the ground, where the grid-crossings' match with rock-covered surface was counted.

Ground microtopographical configuration after site preparation was assessed on the basis of down-slope transects obtained from measurements of vertical distances to ground surface, taken at 10 cm horizontal steps, from a levelled 3-m-long aluminium ruler fixed over the microplot. Ground surface profiles obtained, two per microplot, allowed computing random roughness (RR) as the standard deviation of detrended elevations (Allmaras et al. 1966; van Wesemael et al. 1996), with trend determined by linear regression over the entire microplot length or over the two separate sections of the profile, in the case of treatments with contour bunds (Mo_D1, Mo_D2 and Hi_D1). Slopes of the linear fit, in %, are adopted as the ground local slope gradient and pooled to compute average slope gradient of experimental plots and blocks. As well, ground surface profiles allowed the calculation of roughness ratio (RFR; Morgan et al. 1998a), as the per cent excess of actual surface ground length over the straight-line length, both taken from upper to lower microplot edges.

Besides assessment performed at start, vegetation cover was monitored during the experimental period. Observations were done during winter dormancy (January), and at the end of spring (May) and summer (September) along the experimental period. In the first year (2002), orthogonal colour photos of all microplots were taken and treated to estimate vegetation-covered surfaces. However, due to the high cover proportion provided by adventitious vegetation, in the following years, field visual observations using comparison charts were preferred (Godron 1983).

Results presented in this paper report on run-off water and sediment collected during the first 2 years of experiments, beginning March 2002. Data were treated and analysed applying standard statistical techniques, as two-way ANOVA (blocks and treatments), and Tukey test for mean separation, correlation and regression.

Results

Run-off and soil loss annual rates

Total precipitation recorded in the two-year experimental period was 1,876 mm, distributed in 21 events (Fig. 1). Long-term average annual precipitation in the area is 656 mm (30 years of records at Macedo de Cavaleiros, a reference pluviometric station 5 km from experimental area; INMG 1991). Average of the two-year experimental period was 143% of the long-term average, with 186 and 101% in the first and the second year, respectively. Effectiveness of site preparation techniques in erosion control was, therefore, tested for above average rainfall conditions.

Expressed as annual averages, run-off and soil loss in the original abandoned field (No_D, no disturbance) were 3.5 mm and 11.6 g m^{-2}, respectively (Figs. 2, 3). Run-off values in plots under different site preparation techniques ranged from 8.4 mm (Mo_D2) to 24.8 mm (Hi_D1), meaning 2.5–7 times higher than in the original soil and vegetation cover conditions (Fig. 2). For soil loss, annual average ranged from 58 to 133 g m^{-2} in those same treatments, meaning 5–12 times higher rates than in the original conditions (Fig. 3). In treatment labelled as Max_D (maximum disturbance), annual averages computed were 28.6 mm for run-off and 227 g m^{-2} for soil loss, corresponding to maximum potential erosion losses on the local soil and topographical setting and in short-range climatic conditions.

Differences between blocks are not statistically significant for either run-off or soil loss annual values ($P > 0.05$) and, on the contrary, treatment was an experimental design

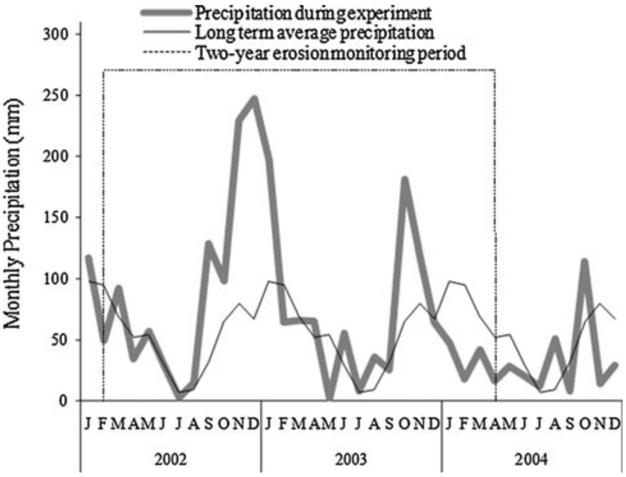

Fig. 1 Monthly precipitation during erosion monitoring, recorded at the experimental area, compared with long-term average precipitation (Fonseca 2005; INMG 1991)

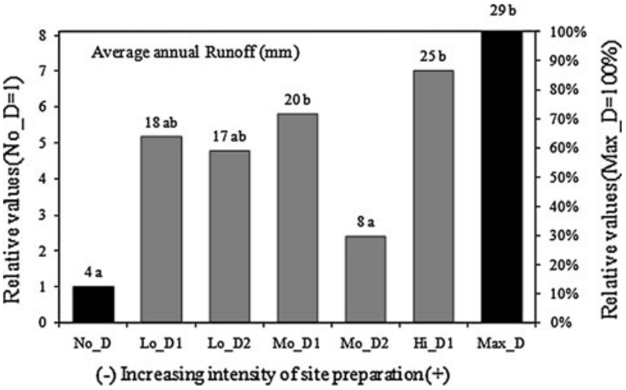

Fig. 2 Global annual average run-off after two years in treatments tested: values relative to controls (in ordinates, controls in *dark columns*) and measured values (on *column top*). Averages followed by the same letter are not significantly different (Tukey, $P < 0.05$, $n = 6$ in each treatment)

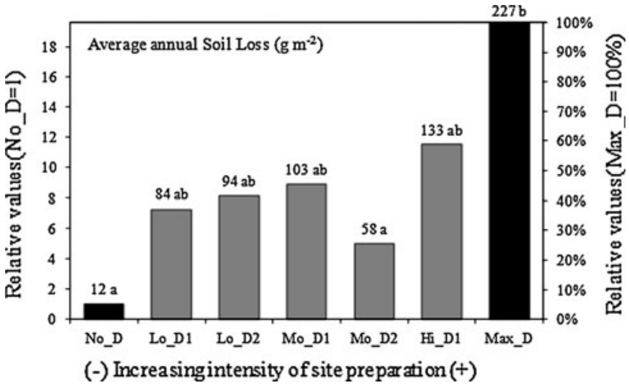

Fig. 3 Global annual average soil loss after 2 years in treatments tested: values relative to controls (in ordinates, controls in *dark columns*) and measured values (on *column top*). Averages followed by the *same letter* are not significantly different (Tukey, $P < 0.05$, $n = 6$ in each treatment)

factor significantly affecting annual rates of the two variables monitored. For run-off, Mo_D2, a moderate disturbance contour bund treatment, did not significantly differ from the original condition (No_D), while Mo_D1 and Hi_D1 (the other contour bund treatments with moderate and high disturbance, respectively) did not differ from Max_D (the potential erosion control treatment), all these three with means significantly different from those of the former ones (Fig. 2). Treatments with low disturbance (Lo_D1 and Lo_D2) rank in a transitional position in treatment average annual run-off results. For soil loss annual average values computed for treatments, and as in the case of run-off, Mo_D2 did not significantly differ from No_D, while significant differences are found between the two control treatments (No_D and Max_D). All other treatments rank in a transitional position (Fig. 3).

In both variables, run-off and soil loss, the trend in treatment annual results is similar, as soil and water losses tend to increase with increasing soil disturbance due to mechanical operations associated with site preparation techniques applied. In fact, with the exception of Mo_D2, increments in treatment annual average soil and water losses are observed from lower to higher site preparation intensity, accounting for 8 mm and 0.5 t ha^{-1} for run-off and soil loss, respectively. These figures have a practical relevance when compared with the maximum potential annual losses of 29 mm and 2.3 t ha^{-1} computed for Max_D (potential erosion treatment), of which they roughly represent 25%. As stressed above, treatment Mo_D2 drifts from the trend mentioned, as results are much lower than expected for the group of treatments with contour bunds as part of site preparation and moderate to high disturbance intensity (including also Mo_D1 and Hi_D1; Figs. 2, 3). No actual explanation for such results can, however, be devised from data analysis or empirical interpretations.

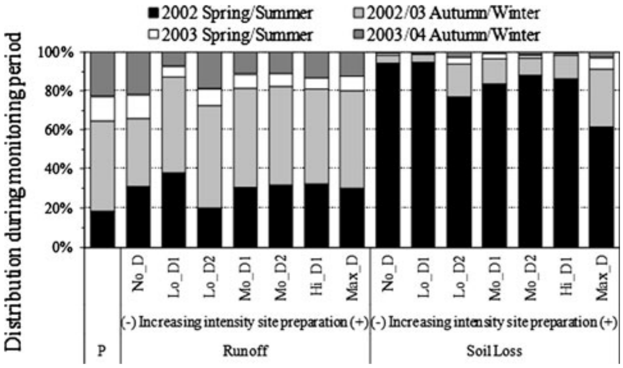

Fig. 4 Semester relative distribution of precipitation (P), run-off and soil loss in treatments tested, during the 2-year experimental period

Regardless differences between treatments, it should be noted that, for the tested conditions, soil loss rates averaged around an equivalent to 1 t ha^{-1} year^{-1} and run-off around 20 mm year^{-1}, meaning a 2% run-off coefficient. Site preparation techniques tested are erosion control effective, reducing soil loss rates to a range of 26–59% of the local potential, with an average of 42%, and this was achieved in a most critical stage of forest stand development, under above local average rainfalls (Fig. 3). The contribution of site preparation techniques for water conservation through run-off reduction is less expressive than that of erosion control (61% in average with a range from 28 to 86%) (Fig. 2). Nevertheless, considering the very low global run-off coefficients computed and the fact that evapotranspiration is seemingly low at experimental plot scale, due to the still low contribution of forest species planted, the positive effects of site preparation techniques tested on water storage cannot be neglected.

Run-off and soil loss temporal distribution

Rainfalls during the experimental period followed the typical Mediterranean seasonal distribution, with month totals above long-term averages in most of the two-year time span (Fig. 1). Autumn and winter (the wet season) contributed with more precipitation to the total (69%) than did spring and summer (the dry season), in spite of the rainy spring 2002 (Figs. 1, 4).

Microplots response to these precipitations yielded a similar yet biased pattern of seasonal distribution in the case of run-off, but not in the case of soil loss. In fact, autumn and winter account for 62% of total run-off water losses, an average for all treatments monitored, ranging from 57% to 71% in treatments Lo_D1 and Lo_D2, respectively (Fig. 4). Furthermore, the first year run-off, in average, summed 80% of the total in 2 years, ranging from 66% in No_D to 87% in Lo_D1. The first semester rains received on microplots (spring/summer 2002) induced between 77% (Lo_D2) and 94% (Lo_D1) of total soil loss recorded in 2 years, but in Max_D, it merely exceeded 60% (Fig. 4). It should be stressed that in Max_D soil loss rates were, in absolute terms, significantly higher than in the other treatments. Those first rains corresponded to less than 20% of total precipitation in 2 years (Fig. 4). Values indicated rise up to an average of 97%, with a range from 91% (Max_D) to 99% (Lo_D1), if the first two semesters are considered (Fig. 4). No clear trend in results is found for seasonal distribution of run-off and soil loss as affected by treatment.

Results presented here above are the aggregate outcome of event level data effectively collected during the monitoring period. Water erosion was the single cause of sediment export from microplots, meaning that run-off and soil loss temporal distribution strictly depends on precipitation. In all treatments, cumulative run-off relates quasi-linearly with cumulative precipitation, with a very high and significant correlation between the two variables (r ranging from 0.965 to 0.995; Fonseca 2005), but this is not the case of soil loss. Figure 5 plots soil loss against precipitation, for all treatments, both expressed in cumulative terms. Soil loss rates rise up until cumulative rainfall reaches about 350 mm and decline thereafter. Soil loss rates at the end of the two-year period were actually very low in most microplots. All treatments follow the same pattern of temporal evolution, yet with different magnitude losses, as reported for annual rates.

Figure 5 also depicts the critical period when the peak in erosion rates occurred. It corresponds to the steepest slopes in curves plotted and includes the third and most erosive event of the series of 21 recorded. In Max_D (potential erosion), the highest rate treatment, the critical period lasted longer than in the remainder (until the 6th event, at the end of the first monitoring semester).

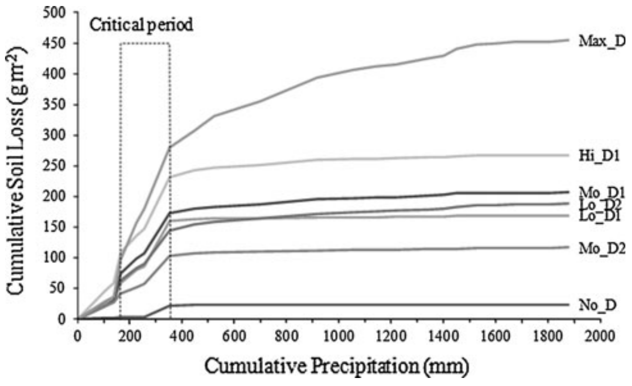

Fig. 5 Temporal evolution of treatments erosional response to rainfalls during the two-year experimental period and critical period when soil loss tolerance was exceeded in Max_D treatment (soil loss and precipitation accumulated since forest stand installation)

Factors affecting plot erosional response

A number of factors were studied in order to contribute to explain results presented so far: rainfall erosivity and surface conditions characterized by microtopography, rock fragment cover and vegetation cover, as also addressed to in studies carried out similar ecological conditions (e.g. Ruiz-Sinoga et al. 2010).

Rainfall erosivity

Several erosivity indexes were computed at event level and correlated with both run-off and soil loss data series, either with all plot data assembled (global area response) or with treatments per se. Figures 4 and 5 express time changes in plot response to precipitation. As so, independent analysis was performed with event data in groups corresponding to the four semesters of the experimental period. It should be noted that rainfall kinetic energy is highly correlated with precipitation at event level ($r = 0.983$) and curves depicted in Fig. 5 may be drawn with that variable in abscissa. This would help deriving directly from those curves erodibility changes in time.

For the global erosional response of the experimental area, index better correlated with run-off and soil loss in the spring/summer semesters was the event maximum 1-h rainfall intensity (I1 h), with correlation coefficients higher than 0.952 (Table 2). The index did not perform equally well in the wet semesters, where event precipitation amount, in the first year, and again I1 h, in the second one, were best correlated with run-off ($r = 0.915$ and $r = 0.989$, respectively), while poor correlations with soil loss were obtained for indexes computed ($r < 0.783$ and $r < 0.589$, in the second and fourth semester, respectively).

Table 2 Correlation of rainfall erosivity indexes (best correlated and EI30) with run-off and with soil loss global values, computed at event level, for each semester of the experimental period

Parameter	Spring/ Summer 2002	Autumn/ Winter 2002/2003	Spring/ Summer 2003	Autumn/ Winter 2003/2004
Number of events	6	7	3	5
Correlation coefficient with run-off				
I1 h	0.952**	–	0.994 ns	0.989**
Pev	–	0.915**	–	–
EI30	0.802 ns	0.851*	0.614 ns	0.730 ns
Correlation coefficient with soil loss				
I1 h	0.966**	–	0.984 ns	–
I20′	–	0.783*	–	–
Pch	–	–	–	0.589 ns
EI30	0.859*	0.635 ns	0.667 ns	0.412 ns

EI30 (Wischmeier and Smith 1978) did not perform so well as an erosivity index in this experiment (best correlation obtained for with the first semester soil loss, $r = 0.856$). As expected from Fig. 5, for the same index, correlation declines from the first to the fourth semester. Indexes involving rainfall intensity tended to better correlate with soil loss and run-off in treatments with soil disturbance, while for No_D (original soil), a better correlation was obtained with precipitation (Fonseca 2005).

Topography and microtopography

As described in Materials and Methods, experimental design comprised the distribution of experimental plots in 3 blocks, corresponding to different topography, but, as already mentioned in this Section, results showed no significant differences between blocks either in run-off or in soil loss annual values. Furthermore, no significant correlation was obtained with both variables and microplot slope gradient, performed for each experimental semester ($r < 0.376$ in absolute values, being either positive or negative; Fonseca 2005). Among factors explaining these findings, study scale is certainly an important one because run-off generation and development are limited in such plot size, but a major contribution comes, seemingly, from microtopography.

Actually, site preparation operations left surface ground with distinct microtopographical features (Table 3). Random roughness (RR) varied from 14 to 79 mm and roughness ratio (RFR) from 0.6 to 9.1%, and treatments rank for either indexes as follows: Max_D < Lo_D1/Mo_D1/Mo_D2 < No_D < Lo_D2 < Hi_D2. The two indexes are highly correlated ($r = 0.995$; Nogueira et al. 2004), allowing direct conversion from one to the other. A visual perception of microtopography left by site preparation operations is given in Fig. 6.

Table 3 Plots surface features at stand installation: microtopography indexes (Random Roughness, RR, and Roughness Ratio, RFR), rock fragment cover and vegetation cover, average values ± standard deviation for treatments tested

Treatment (disturbance rank)	Microtopography		Rock fragment cover (%)	Vegetation cover (%)
	RR (mm)	RFR (%)		
No_D	28.6 ± 6.9	2.6 ± 0.6	18 ± 9	79 ± 6
Lo_D1	22.7 ± 4.8	1.5 ± 0.3	57 ± 5	28 ± 8
Lo_D2	47.6 ± 12.8	4.7 ± 1.3	61 ± 14	32 ± 14
Mo_D1	19.1 ± 4.8	1.5 ± 0.4	57 ± 23	32 ± 13
Mo_D2	16.4 ± 6.3	1.5 ± 0.6	61 ± 4	30 ± 8
Hi_D1	21.6 ± 4.5	2.0 ± 0.4	66 ± 6	28 ± 9
Hi_D2	78.5 ± 18.3	9.1 ± 2.1	91 ± 12	8 ± 11
Max_D	14.3 ± 4.6	0.6 ± 0.2	83 ± 1	10 ± 6

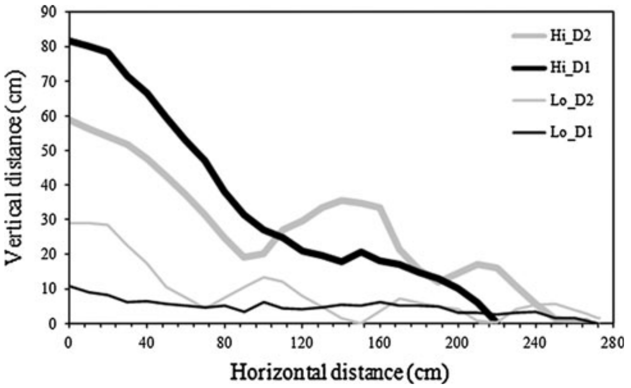

Fig. 6 Effect of site preparation techniques on microtopography: examples of microplot average ground surface profiles, corresponding to treatments with high (Hi_D1, Hi_D2) and low (Lo_D1, Lo_D2) soil disturbance (*vertical scale* magnified)

Table 4 Correlation of surface features with run-off and with soil loss treatment averages, for each semester of the experimental period: random roughness, rock fragment cover and vegetation cover ($N = 7$)

Parameter	Spring/ Summer 2002	Autumn/ Winter 2002/2003	Spring/ Summer 2003	Autumn/ Winter 2003/2004
Correlation coefficient with run-off				
Roughness	−0.480 ns	−0.359 ns	−0.124 ns	−0.539 ns
Rock cover	0.755*	0.836*	0.775*	0.543 ns
Vegetation cover	−0.763*	−0.864*	−0.777*	−0.250 ns
Correlation coefficient with soil loss				
Roughness	−0.343 ns	−0.296 ns	−0.278 ns	−0.113 ns
Rock cover	0.899**	0.699 ns	0.767*	0.671 ns
Vegetation cover	−0.868*	−0.670 ns	−0.834*	−0.712 ns

Roughness was so evidently high after site preparation that Hi_D2 plots were discarded from the erosion monitoring scheme, because, visibly, sediment transfer along the microplot would be hampered and therefore the sediment source area much smaller than that of microplot (Fig. 6). In treatments with contour bunds (Mo_D1, Mo_D2 and Hi_D1), microplots measured actually water and sediment delivered to ditch. Subsoiling with a cover shovel (Lo_D2) generated a moderately rough surface that reduced but did not hamper sediment transfer along microplots. In Lo_D1, surface ground is affected only locally, near plantation holes. There was no limitation to sediment export from microplots due to surface roughness in Max_D treatment, as it was tilled downhill, thus justifying the lowest roughness indexes value of all treatments tested.

In spite of these results, the negative correlation found between run-off and soil loss with random roughness was not significant ($r < 0.539$, in absolute values, computed for each one of the four semesters; Table 4). Therefore, factors other than this one should play a more imposing role in explaining plot erosional response, and they are explored hereafter.

Surface rock fragments

Rock fragments are an evident feature in experimental plots, varying from slightly less than 90% cover in treatments top ranked in disturbance intensity (Max_D and Hi_D2) to less than 20% in No_D (the original condition), the remainder treatments showing about 60% (Table 3). In spite of the generally high rock fragment content in NE Portugal topsoils (Figueiredo 2001), in the experimental area, the original condition corresponded to a moderate rock surface cover. The sharply higher rock fragment cover in all treatments but No_D was, therefore, induced by site preparation operations, rising to very high proportions where soil disturbance was highest.

Rock fragments cover proportion correlated positively with run-off and with soil loss, although not significantly in all four semesters of the erosion monitoring period (Table 4).

Vegetation

Vegetation in this paper refers to adventitious herbaceous vegetation that covers experimental plots, the actual and most effective plant cover at this stage of forest stand development. Site preparation strongly affected vegetation cover, as No_D, the original condition at the start of erosion monitoring period had a good cover (79%), while it represented about 10% in Max_D and in Hi_D2 (treatments with highest disturbance intensity), the remainder showing around 30% cover (Table 3).

Besides soil disturbance, tillage operations also contribute to vegetation clearance and the period of low cover should be short to limit erosion risk during forest stand early development. As shown in Fig. 7, for all treatments except Max_D (potential erosion), vegetation rapidly colonized plots area, reaching 70% cover or more in early May 2002, 3 months after the first assessment. Treatments with more intense soil disturbance took longer to reach the reference cover depicted by No_D (original condition) at the start of experiment, while moderate and slight intensity treatments overcame reference cover in 3 months. Max_D had a much slower vegetation recovery and, together with Mo_D1, did not reach reference value within the 2 years. No_D also rapidly increased vegetation cover that never fell below 97% during the erosion monitoring period.

Run-off and soil loss are negatively correlated with vegetation cover proportion, significantly in most of the four semesters (Table 4). The decline in the correlation coefficient between the variables mentioned in the fourth semester (Table 4) is interpreted as the result of the dense cover provided by vegetation above a certain threshold, for which soil protection is not significantly increased with vegetation cover increase.

Discussion

Run-off and soil loss rates and factors

As mentioned in the previous Section, run-off and soil loss annual rates globally average about 20 mm and 1 t ha^{-1}, respectively, and these values are not comparable with what is reported in literature for forest areas, normally addressing to fully developed stands where soil and water losses drop to very low annual rates (Morgan 2005). Soil loss was sharply higher on treatment Max_D, tilled downhill and equivalent to 2.3 t ha^{-1} year^{-1}. This value is very slightly above the reference tolerable loss in shallow soils (Arnoldus 1977), even though Verheijen et al. (2009) indicate a lower reference value (1.4 t ha^{-1} year^{-1}), in any case meaning that local conditions globally present a severe, but not very severe, potential risk of erosion by water.

In one of a set of rainfall erosive events, labelled as the critical period (Fig. 5), peak soil loss rates exceeded by 10 times in average the annual means computed for the whole experiment. In the critical period, losses were also equivalent to annual rates higher than soil loss tolerance, estimated with Verheijen et al. (2009) reference value (1.4 t ha^{-1} year^{-1}) and annual long-term rainfall amount in the area (656 mm). In this period, severe erosional impacts occurred in soils of all plots but those with No_D treatment (original condition), and in Max_D, peak rate reached an equivalent to 15.4 t ha^{-1} year^{-1}, a value above tolerance even for the deep soils, 11.2 t ha^{-1}, according to Arnoldus (1977).

As depicted in Fig. 4, seasonal distribution of soil loss does not match that of precipitation, and this was also found by de Figueiredo and Ferreira (1993) and Figueiredo (2001), when studying long-term soil loss records in Douro valley vineyards (NE Portugal). Figueiredo et al. (1998) showed this very much depended on the timing of highly erosive events along the recorded series, which accounted in their study for 23 and 45% of total recorded, respectively, in the most and in the two most erosive events. However, much lower concentration was found in this experiment (16 and 28% in average for all treatments but No_D).

Results at event level confirm one of the basic assumptions of the experiment, which was that the first stages of stand development are those most critical as far as erosional losses are concerned. As expected, soil disturbance and vegetation clearance by tillage and machinery operation affect soil structural condition, increasing potential for erosion losses (Morgan 2005). It should be noted, however, that ground vegetation cover was already high in most plots (over 70% in early May) when 3rd and most erosive rainfall event occurred (mid-May 2002). Plots responded according to disturbance intensity for either run-off or soil loss, although much more expressively in the latter case. Changes in erosion rates, or related soil properties, with time since tillage induced disturbance are reported in literature for many environments, soil use types and management systems, including forests on marginal land (Dissmeyer and Foster 1984; van Wesemael et al. 1996; Bresson et al. 2006). It seems that structural rearrangements following tillage, as affected by rains falling onto the ground had a much faster consequence to soil particles removal than to run-off generation and development. The decline of surface storage with cumulative precipitation may help explaining the persistence through time of run-off rates relatively steadier than those of soil loss (Guzha 2004).

Correlations between erosivity indexes and soil and run-off water losses are also in line with the above interpretation on processes acting in microplots (Table 2). In fact, besides changes during experiment time span, in all treatments except No_D (original abandoned field), erosivity indexes best correlated with run-off and soil loss are rainfall intensity based, while in No_D, precipitation amount is a better performing index. Seemingly, in processes prevailing in sediment export out of microplots with disturbed surface, detachment plays a major control role, which is also expectable from studies at this scale (Le Bissonnais et al. 1998; Cerdan et al. 2004).

Surface roughness is responsible for enhancing the above-mentioned run-off surface detention, therefore increasing infiltration, reducing run-off amount and delaying its generation; as well, it reduces sediment transport along the slope (Morgan et al. 1998b; Takken et al. 2001). Roughness ratio (RFR) values assembled in Morgan et al. (1998b), for soils tilled with different implements, are much higher than the ones computed with microplot data and presented earlier ($RFR > 13\%$, Table 3). However, according to Auzet et al. (1990) criteria, based on random roughness (RR), microplot surface ground is not qualified as smooth ($RR < 1.2$ cm), being very rough in treatments Lo_D2 and in Hi_D2 ($RR > 3$ cm).

Together with and adding to surface roughness, the high rock fragment content in top soil at the experimental is an evident consequence of tillage operations. As noted and modelled by Govers et al. (2006), besides water erosion (as the dominant natural mechanism, negligible in the present study due to the longer time span the process requires), distribution of surface rock fragments on cultivated hill-slopes is also very much dependent on tillage effects, either segregation or displacement by farm machinery and implements.

Relationships of rock fragment cover with run-off and soil loss were extensively studied by Poesen and Ingelmo-Sanchez (1992), Poesen and Lavee (1991), Poesen and Lavee (1994) and Poesen et al. (1994) who demonstrated that a poor soil structural status may promote the sealing of interfaces of embedded rock fragments with fine earth, thus leading to a change of the more common negative relationship (Wischmeier and Smith 1978; de Figueiredo and Poesen 1998; Cerdan et al. 2010), to a positive or a non-monotonic one. Correlation coefficients are consistently positive between rock fragments cover and run-off and soil loss in the four experimental semesters (Table 4), and the stated explanation for these findings seemingly applies in the present study as both conditions are met in soils of the experimental area: weak aggregation of a recently disturbed soil and surface rock fragments mostly embedded.

Ground adventitious vegetation cover, the relevant for soil protection in the earliest stages of forest stand development, had an important effect on plot erosional response in this experiment, as shown by the relative magnitude of the negative correlation coefficients between that variable and either run-off or soil loss (Table 4). The vastly reported negative exponential relationship (Wischmeier and Smith 1978; López-Bermúdez et al. 1998; Basic et al. 2001; Descroix et al. 2001; Casermeiro et al. 2004; Zhang et al. 2004) was not the best fit in the present study, but, instead, a negative log function (Fonseca 2005).

At the beginning of the experiment, plots cover evolution by adventitious vegetation followed the favourable spring growth conditions, but the first summer drought limited progress in plots colonization rates, a typically Mediterranean plant response pattern to environmental conditions (Ruiz-Sinoga et al. 2010; Ouyang et al. 2010; Nunes et al. 2011). In most treatments (the ones with less disturbing site preparation), small changes occurred in vegetation cover during the subsequent semesters of the two-year experiment, and this caused the decline of the correlation coefficients between vegetation cover and run-off and soil loss, besides ensuring an effective protection of surface soil (Fig. 7, Table 4). As an indication confirmed by this experiment, the threshold value for effective cover by vegetation is about 65% (Snelder and Bryan 1995; Fonseca 2005; Le Bissonnais et al. 2005; Ruiz-Sinoga et al. 2010). The threshold value was not reached but merely approached after 2 years only in one treatment (Max_D, potential erosion), where vegetation clearance by tillage operations was most effective.

Integrated discussion on site preparation technique performance

Treatments, representing in this experiment a set of site preparation techniques, affected plot erosional response, confirming the hypotheses stated for experimental design. Factors identified as relevant for the discussion of results

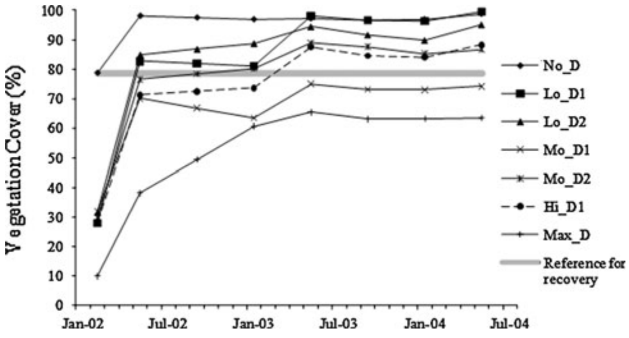

Fig. 7 Treatments average vegetation cover evolution during the erosion monitoring period

were individually addressed to above, but an integrated approach is required in order to better devise the role of these site preparation techniques in erosion control in the initial stage of stand development and, eventually, derive recommendations outcoming from these results.

Erosional loss rates generally followed soil disturbance intensity for both water and sediment export. Disturbance intensity positively affected ground surface microtopography and rock fragment cover (due to implement reshaping of surface configuration and soil particles segregation) and reduced adventitious vegetation cover (removed and or buried), visibly contributing to loosening soil fine earth and negatively affecting aggregate stability (due to disruption of the original soil structure, not quantitatively assessed in the present study).

Even though all features indicated contribute to characterize disturbance intensity, soil and water losses at microplot scale better relate with vegetation. Cover and rate of recovery are crucial for early erosion control (Nunes et al. 2011), especially considering the uncertain weather conditions, typical of the Mediterranean. In fact, Llovet et al. (2009) report that in a 7-year study in NE Spain, where vegetation evolution after wild fire and farmland abandonment was monitored, the highest erosion rate was recorded after 3 years of observations. In permanent crops as vineyards of the Douro valley in NE Portugal, such major event occurred 10 years since start of recording period (Figueiredo et al. 1998). In the present study, the most erosive event occurred 3 months after monitoring period started, when vegetation was recovering from site preparation clearance, responding to spring favourable weather conditions. Slight disturbance intensity treatments (Lo_D1 and Lo_D2) were the best performing to this respect, while the high disturbance intensity (Hi_D1) kept vegetation cover below reference initial No_D condition for a year (Fig. 7).

Actual rock fragment cover is very high in the experimental plots, averaging about 68% in all treatments but No_D, the original condition (Table 3). This feature cannot be neglected when interpreting results obtained even considering the lack of functional relationship with erosional losses recorded, mainly because it helps explaining magnitude of potential erosion measured in Max_D and the general pattern of time evolution of soil loss in all treatments. de Figueiredo and Poesen (1998) and Figueiredo (2001) obtained sigmoid shape erosional response curves similar to those of Fig. 5 on a simulation experiment with a highly erodible soil and variable surface rock fragment cover, and Figueiredo et al. (2008) presented a descriptive model explaining such response curves. They showed that the higher the rock fragment content, the larger the time (cumulative precipitation) necessary to reach the peak in erodibility of the fine earth, which declines thereafter (due to the exhaustion of surface particles available for transport and crust development), and the lower that peak. Furthermore, among all erosion factors considered in the experimental area, the close to tolerance annual potential erosion rate is explainable by the high cover proportion of coarse particles over ground surface in Max_D plots.

Erosional response curves as those depicted in Fig. 5 help confirming once more the early stages of stand development as the most critical, in what concerns quantitative erosional impacts. The effectiveness in erosion control of the different site preparation techniques tested has to be assessed not only for the annual average reference condition but also, and decisively, for the shorter term concerning the first rainfalls after stand installation. Therefore, as Max_D represents local potential erosion, Fig. 8 depicts the relative ability of tested treatments, with slight (Lo_D), moderate (Mo_D) and intensive disturbance (Hi_D), to mitigate erosional impact, either in terms of magnitude or in terms of duration of this impact, based on

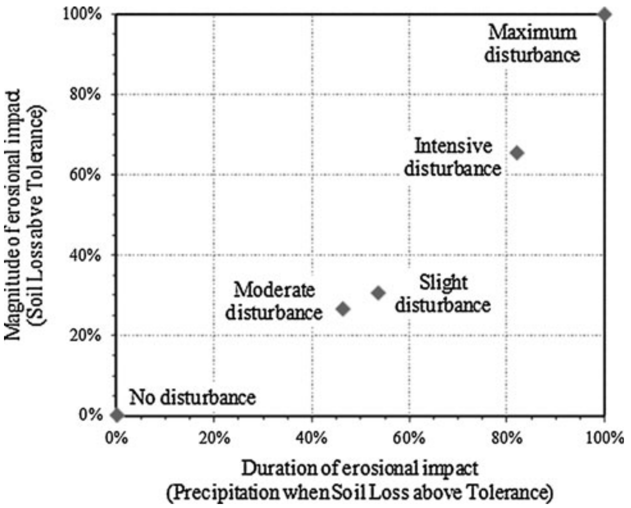

Fig. 8 Erosional impact mitigation by site preparation techniques according to soil disturbance intensity: relative average magnitude and duration, expressed as indicated (100% equals 172-mm precipitation and 342 g m^{-2} soil loss)

soil loss above tolerance and the associated cumulative precipitation, respectively. Moderate and slight site preparation techniques may reduce impact to about 30% and shorten duration in 50% of those occurring under potential erosion conditions. The intensive disturbance treatment tested (Hi_D1) is clearly less effective in mitigating this impact on young forest stands. It should be added that treatments performance in erosion impact mitigation in the critical period is higher in what concerns magnitude than duration (Fig. 8), and this reflects a generally observed low contribution of the very erosive events to total rainfall amount recorded in the experimental period (as cumulative precipitation is the erosive time scale adopted).

Finally, it is important to stress that on the whole, forest stand scale sediment export is virtually not possible with moderate and highly intensive site preparation techniques (all those with contour bunds, Mo_D1, Mo_D2 and Hi_D1, together with Hi_D2 as already discussed above). Nevertheless, it may occur when ditches drain to the divisional network set in stand area, as dirt roads or fire control lanes. The situation was observed once during the experimental period, in the experimental area but not in the experimental plots, when heavy downpours filled in some ditch edges, unable to infiltrate fast the excess rainfall.

The above remark drives attention for soil disturbance characterizing features, in one hand, and scale of soil and run-off water losses assessment, in the other hand. In fact, there are conflicting trends in the effects of such features in the erosional response as, for instance, in the case of surface roughness versus vegetation cover: the latter decreasing with increasing soil disturbance, while contributing to increase erosion rates; the former increasing with increasing soil disturbance, while contributing to decrease erosion rates. A combined assessment, as that performed with the experiment presented, is required to enable finding the balance between effects of factors directly and inversely related to plot erosional response and, by this, finding the trend of this response to soil disturbance induced by site preparation techniques. However, the erosional response depends on scale of observation, and, as noted above, the trend may be reversed when passing from within the planted plot to the whole forest stand.

Conclusions

In the first 2 years of a mixed forest stand development, installed under Mediterranean climatic conditions with different site preparation techniques, soil loss rates globally averaged in the experimental area the equivalent to around 1 t ha^{-1} year^{-1}, and run-off to around 20 mm year^{-1} (2% run-off coefficient), figures that fall within the tolerance range of soil and water losses and mean that techniques tested showed erosion control effectiveness.

Soil loss and run-off rates tend to increase with soil disturbance intensity associated with site preparation mechanical operations. Slight and moderate intensity techniques were best performing in erosion control reducing annual rate to 40 and 60% of the potential erosion condition, for soil loss and run-off, respectively.

The first 6 months of stand development were the most critical in what concerns erosional impacts of site preparation operations, when event soil loss exceeded tolerance in all disturbed plots, but rates of soil and water losses sharply decline afterwards.

The low vegetation cover and the very high surface rock fragment cover left after site preparation operations, as well as the following vegetation recovery rate in this early phase, combined with very erosive rainfalls at the end of spring, conditioned plots erosional response observed. Again, site preparation techniques with slight and moderate intensity of soil disturbance were the best performing in controlling erosion in the most critical events, halving the vulnerable period and reducing soil loss rates to about 30% of the potential, as vegetation rapidly reached more than 80% cover.

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