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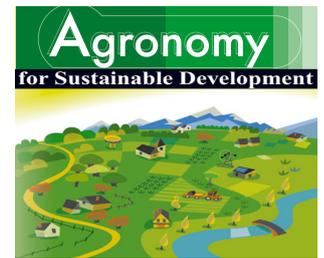
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Research article

High reduction of erosion and nutrient losses by decreasing harvest intensity of lavender grown on slopes

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Abstract – In Mediterranean countries, where rainfall is scarce and irregular, intensive agriculture promotes erosion and nutrient losses from soil, ending eventually in contamination of water bodies. Wild shrubs may protect the soil against the erosivity of raindrops. However, some shrubs such as wild lavender are traditionally harvested by uprooting the entire plant. Thus, we studied here the impact of harvesting only a part of the plant biomass. Cultivating lavender, *Lavandula lanata* L., in erosion plots in Lanjarón, Granada, Spain, we studied the effect of two harvest intensities of 25% and 50% of the plant biomass, on soil erosion, runoff, nutrient loss (NPK) and soil-water dynamics. Our results show that decreasing the harvest intensity from 50% to 25% reduced soil loss by 67%: from 143 to 46 kg soil ha⁻¹ yr⁻¹. Water runoff was also decreased by 59%: from 13 to 5 mm yr⁻¹. These findings demonstrate that the rational harvest of cultivated aromatic plants protected the soil against erosion due to the reduction of soil-particle detachment by raindrop impact, and consequently avoided mechanical soil movement. Further, decreasing the harvest intensity from 50% to 25% reduced N losses by 65%, P losses by 42% and K losses by 64%. Soil-water content at 5, 10 and 20 cm deep was also higher for a harvest intensity of 25% than for a harvest intensity of 50%. In conclusion, this study supports the cultivation of lavender instead of wild harvest, following a rational harvest of biomass for reducing erosion and pollution as well as conserving soil-water content.

soil erosion / runoff / Mediterranean shrub / nutrient loss / soil-water content / SE Spain

1. INTRODUCTION

Soil erosion is a major issue for sustainable agriculture because it leads to the loss of plant nutrients, soil fertility and soil water. To cope with this issue, alternative practices of cultivation and soil conservation have been developed (Bernoux et al., 2006; Shaxon, 2006; Etchevers et al., 2006). Here, we studied soil erosion during cultivation of lavender in Spain. Las Alpujarras is a valley parallel to the crest of the Sierra Nevada Mountains, southeastern Spain, and is situated in a Mediterranean environment, where the scarce vegetation cover or even bare soil, with heavy rainfalls and deficient soil management, have led to soil degradation (López and Romero, 1993; López et al., 1998; Durán et al., 2006). On the other hand, in these mountain areas, wild shrubs reduce erosion and protect soil against degradation (Morgan, 1986; Durán et al., 2004a, 2006). In particular, for the study zone wild aromatic shrubs have been traditionally harvested for many purposes,

e.g. essential oils, beekeeping, cosmetics, and medicinal and culinary uses.

The absence of vegetative covers promotes soil erosion in arid and semiarid areas, where more than 22 million ha, i.e. 43.8% of the land, are affected by topsoil losses higher than 12 Mg ha⁻¹ yr⁻¹, which exceeds the estimated tolerable limits for soil formation, of between 2 and 12 Mg ha⁻¹ yr⁻¹, in Mediterranean environments (Rojo, 1990; López et al., 1998). Moreover, damage to soil surfaces and the plant cover in these areas is difficult to restore (Milton et al., 1994), a problem accentuated by the frequent torrential rains. Strong efforts have been made to curb cropland erosion, primarily by reducing runoff (Martínez et al., 1993, 2001, 2002a, b; Francia et al., 2000; Durán et al., 2004a). Therefore, controlling surface runoff on Mediterranean slopes involves the adequate management of plant covers (Cerdá, 1997; Boix-Fayos et al., 1998; López et al., 1998; Kosmas et al., 1997, 2000; Martínez-Mena et al., 2001; Casermeiro et al., 2004; Durán et al., 2004b), which have been shown to improve the soil quality (García et al., 1995; Bochet et al., 1998).

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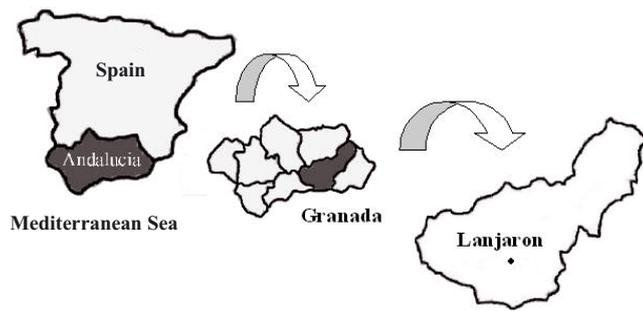


Figure 1. Location of the experimental site of Lanjaron in southeastern Spain.

Since ancient times, aromatic and medicinal plants have had many applications. These plants continue to be used fresh, frozen or dry, as well as transformed into oils, extracts and essences (Weiss, 1997; Lange, 1998; Gresta et al., 2008). They have multiple purposes such as medicinal (pharmaceutical and phytotherapy), food, cosmetic, honey production, and dry-plant decoration. In this context, the cultivated area of aromatic and medicinal plants in Spain is roughly 7000 ha, of which some 4000 ha are devoted to lavender production. In addition, Spain is one of the largest producers of aromatic herbs and essential-oil yield in the EU (Verlet, 1992). The ecological production area, on the increase, is currently about 2300 ha, of which 1700 ha is located in Andalusia. Concretely, in the study area, lavender (*Lavandula lanata* L.) is harvested for many purposes, its essential oils being attributed with medicinal properties (Grieve, 1931; Gatteffosse, 1937; Holmes et al., 2002; Dob et al., 2005). This plant, being drought-tolerant, is advantageous in semiarid areas, where water is the main limiting factor, and it could offer a major economic income for farmers. Furthermore, in these areas, it is becoming progressively more necessary to maximize rainfall infiltration by minimizing the runoff and reducing evaporation from the soil. The objective of this experiment was to assess the effectiveness of lavender groundcover as soil protection, comparing two different harvest intensities (25% and 50%) of the plants and monitoring soil loss, runoff, nutrient losses and soil-water dynamics.

2. MATERIALS AND METHODS

2.1. The study area

The study site is located in Las Alpujarras, a deep valley at 1300 m a.s.l. running parallel to and south of the crest of the Sierra Nevada Mountains in the province of Granada (SE Spain); Universal Transversal Mercator (UTM) X: 456003.08; Y: 4088972.45 (Fig. 1).

The climate is Mediterranean with irregular rainfall concentrated in autumn and winter, the average rainfall, temperature and evapotranspiration being 442.0 mm, 12.4 °C and 750 mm yr⁻¹, respectively (García, 1989). The rainfall pattern is characterized by scarcity and extreme variability in space and time, between years and within the year (Fig. 2).

The soils of the zone are Typical Xerorthent (Soil Survey Staff, 1999) with a sandy-loamy texture and 73% sand, 19% silt, 8% clay, 2.9% of organic matter, 0.13% of total N, 222.3 mg kg⁻¹ available P and 41.2 mg kg⁻¹ available K. Fertilizer was applied to the treatment plots in the form of 15-15-15 NPK at a nominal rate of 850 kg ha⁻¹ and 450 kg ha⁻¹ of ammonium nitrosulfate.

In the study area the prevalent natural vegetation includes: *Adenocarpus decorticans*, *Cystus scoparius*, *Retama sphaerocarpa*, *Lavandula pedunculata*, *Ulex parviflorus*, *Halimium viscosum*, *Genista umbellata*, *Thymus vulgaris*, *Salvia lavandulifolia*, *Rosmarinus officinalis*, *Psoralea bituminosa*, *Carlina vulgaris*, *Dittrichia viscosa* and *Artemisia campestris*. Also, there are some forests of *Quercus rotundifolia*, *Juniperus oxicedrus*, *Ruscus aculeatus* and herbaceous plants: *Festuca granatensis*, *Agrostis castellana*, *Dactylis* sp. and *Bromus* sp. (Rivas, 1961; Cuadros and Francia, 1991). Most of the wild aromatic shrubs in the area have widespread applications in the pharmaceutical and cosmetic industries. Therefore, it is necessary to maintain and protect these plants against indiscriminate uprooting (Blanco et al., 1996, 1998). Furthermore, these plants are important in this semiarid environment for erosion control, decreasing runoff, reducing soil-particle detachment by raindrop impact (Bingner et al., 1992), and consequently reducing mechanical soil movement (Lal, 1995). In addition, the plant cover percentage also influences the dynamics of soil moisture, the primary limiting resource in semiarid environments.

2.2. Field and laboratory measurements

Four erosion plots, 4 × 24 m (96 m²), were laid out on a hillside with a 20% slope. The total length of the hillside was about 35 m, with a straight slope. Each erosion plot had a galvanized enclosure, drawer collector, and sediment and runoff tank, which were emptied after each rainfall event. The plots were planted with lavender (*Lavandula lanata* L.) on a planting grid of 75 × 75 cm. The plants grew for one year before applying the treatments. Two different treatments of harvest intensities (replicated twice) were applied: 25% and 50%, respectively (hereafter harvest intensity-25% and harvest intensity-50%), of the total biomass were removed by clipping. For the monitoring period, the runoff and soil erosion from the plots were collected and measured after each erosive event. The rainfall data were collected from a local meteorological station (<100 m from the plots). For each of the events, the average intensity [$I = (\text{Total rain}/\text{total time})$ (mm/h)], maximum intensity at 30 min (I_{30}) and kinetic energy were calculated ($KE = 210 + 89 \log_{10} I$) (Wischmeier and Smith, 1978; Brandt, 1990). In addition, each runoff sample was analyzed for nitrate (NO₃), ammonium (NH₄), phosphate (PO₄) and potassium (K) concentration in accordance with standard methods for the examination of soils (MAPA, 1971) and waters (APHA, AWWA, WPCF, 1995).

The soil-water content (θ_v) was determined using the Frequency Domain Reflectometry (FDR) system, at 5, 10, 20, 30, 40 and 50 cm deep. The FDR used was the commercial device

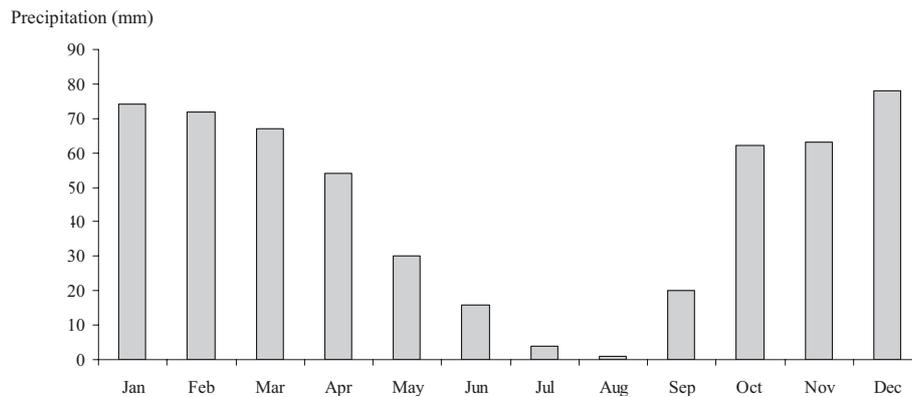


Figure 2. Average monthly rainfall in the study area.

Maximum intensity I_{30} (mm h^{-1})

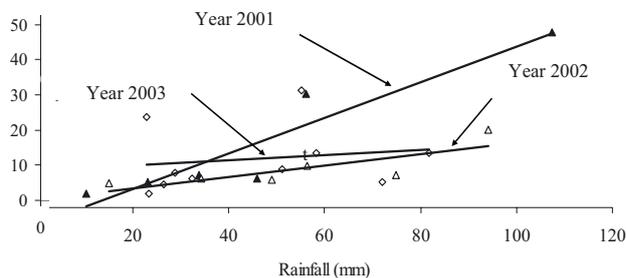


Figure 3. Relationship between total rainfall and maximum intensity at 30 minutes during the study period. 2001: $y = 0.048x - 0.459$ ($r^2 = 0.93$); 2002: $y = 0.0153x + 0.224$ ($r^2 = 0.99$); 2003: $y = 0.0069x + 0.98$ ($r^2 = 0.95$). Note the strong relationship between the two studied variables (high r^2), particularly in 2002.

with a hand-held capacitance probe (Diviner-Sentek Pty Ltd.). This instrument comprises a data display connected by cable to a portable probe rod with one sensor attached. This method includes the soil as part of a capacitor, in which the permanent dipoles of water are aligned by an electric field and become polarized. The dielectric dipoles respond to the frequency of the electric field. The response is a function of molecular inertia, the binding forces, and the frequency of the electric field (Dean et al., 1987; Gardner et al., 1991). We calibrated the device under field conditions and the data points collected in the calibration procedure were curve fit with the equation according to technical specifications (Diviner-Sentek Pty Ltd.). Probes were encased in rigid polyvinyl chloride (PVC) access tubes, which were inserted into holes augered with a portable motorized drill rig. Slurry prepared with finely ground loamy soil and water was applied to the bottom of each hole before inserting the probe access tubes. This procedure was designed to fill the air space between the outer wall of the access tube and the wall of the augered hole, ensuring good contact of the probe sensors with the surrounding soil.

By analysis of variance (ANOVA), the means of different effects at both harvest intensities were compared, and differences between individual means were tested using the Least Significance Difference (LSD) test at $P < 0.05$. Correlation coefficients were calculated between I_{30} and kinetic energy versus rainfall.

2.3. Rainfall intensity and kinetic energy for the study area

The distribution pattern of rainfall during the study period was typical of the Mediterranean climate, being concentrated

in autumn and winter: 88% in 2001, 82% in 2002 and 64% in 2003. There was also marked annual variability in the total rainfall events. The total rainfall for the first, second and third years was 276.5, 323.2 and 452.1 mm, respectively. A comparison of these precipitation data with the historic average annual precipitation designated 2001 and 2002 as years with lower than average rainfall, while 2003 was characteristic of an average year. The last year also registered the highest total annual values for kinetic energy (KE) ($82 \text{ J m}^{-2} \text{ cm}^{-1}$) and maximum intensity at 30 min (I_{30}) (12.9 cm h^{-1}). The minimum values for rainfall and KE were registered in 2001. Correlations between I_{30} and rainfall are shown in Figure 3 for each year. These two variables were strongly correlated, giving r^2 higher than 0.90. A strong relationship was found between rainfall and kinetic energy for the entire study period ($r^2 = 0.94$) (Fig. 4).

3. RESULTS AND DISCUSSION

3.1. Soil loss, runoff and nutrient losses

Table I presents the results of the analysis of variance concerning the effect of the harvest intensities on the average soil loss and runoff. Average soil-loss values were significantly higher in harvest intensity-50% than in harvest intensity-25%: 21.3 and 6.9 Kg ha^{-1} , respectively. Similarly, runoff was significantly greater in harvest intensity-50% (1.9 mm) than in harvest intensity-25% (0.7 mm). The soil loss was statistically higher in the first year of the study period. However, runoff did not significantly differ for the entire study period.

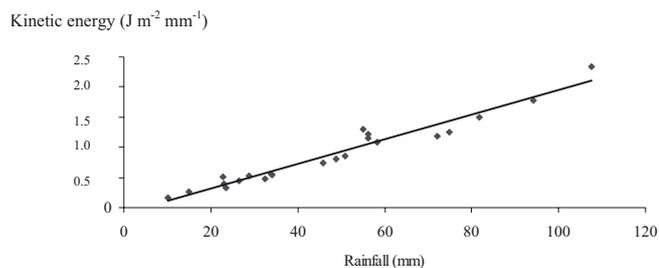


Figure 4. Relationship between rainfall and kinetic energy for the study period ($y = 0.204x - 0.919$; $r^2 = 0.94$); each point represents the kinetic energy associated with each recorded rainfall event. Note the high relationship between both variables due to the high r^2 obtained.

Table I. Average soil loss and runoff.

Treatment	Soil loss (kg ha ⁻¹)	Runoff (mm)
HI-25	6.9 a	0.7 a
HI-50	21.3 b	1.9 b
Year		
2001	27.3 a	1.8 a
2002	7.9 b	1.5 a
2003	7.2 b	0.7 a
ANOVA		
Treatment	*	*
Year	*	ns
Interaction	ns	ns

Values with different letters within the column are statistically different at the level 0.05 (LSD); HI-25, harvest intensity-25%; HI-50, harvest intensity-50%; * significant at $P < 0.05$; ns, not significant.

The average annual soil loss for harvest intensity-25% and harvest intensity-50% was 46.5 kg ha⁻¹ yr⁻¹ and 142.5 kg ha⁻¹ yr⁻¹, respectively, and therefore harvest intensity-25% reduced soil loss by 67% with respect to harvest intensity-50%. Harvest intensity-25% also reduced total runoff with respect to harvest intensity-50% by 60% (5.3 and 13.0 mm, respectively). In the study area, soil erosion and runoff with similar field conditions were measured for bare soil (Durán et al., 2004a, 2006), the values being 6140 kg ha⁻¹ and 182 mm, respectively. Thus, the harvest intensity-25% and harvest intensity-50% treatments with respect to bare soil reduced soil erosion by 99% and 97%, respectively, and runoff by 97% and 92%, respectively. In this context, since the harvest of wild aromatic shrubs is one of the economic activities for local farmers, and agro-environmental conservation is urgent, thus, the benefits of a rational harvest of 50% of the aerial biomass are clear. With this measure the erosion is controlled, protecting soil from nutrient losses, and increasing the organic matter (Durán et al., 2006). Therefore, the cultivation of aromatic plants with aromatic, medicinal, culinary and melliferous uses reconciles sustainable agriculture with environmental protection.

The cumulative soil loss and runoff confirmed the difference between the two treatments (Fig. 5). Clearly, harvest intensity-25% decreased soil loss and runoff due to the greater

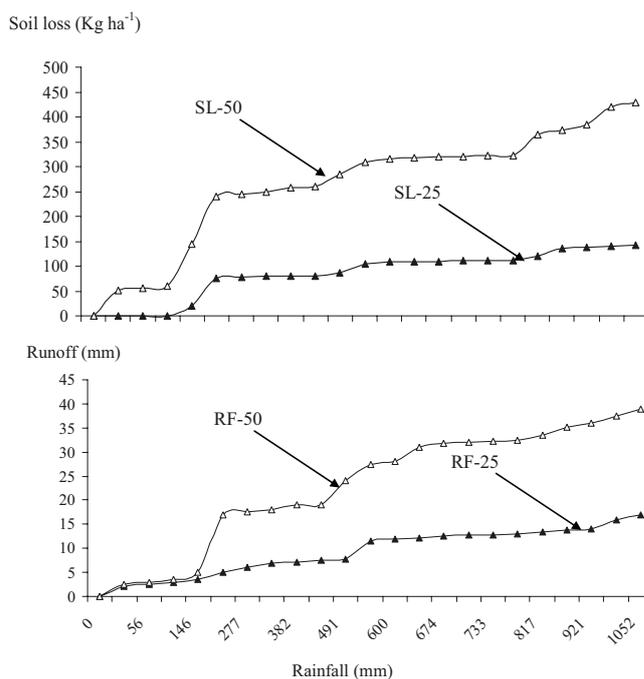


Figure 5. Cumulative soil loss and runoff for the study period. SL: soil loss. RF: runoff. 25 refers to 25% harvest intensity. 50 refers to 50% harvest intensity.

remaining biomass, which protected the soil surface. In this sense, the capacity of shrubs to intercept raindrops is the determining factor for avoiding the development of impermeable soil crusts which exacerbate runoff, a fact pointed out by many authors (Wiersum, 1983; Francis and Thormes, 1990; Martínez et al., 1995; Casermeiro et al., 2002; Durán et al., 2006).

These results show the mechanical protection of plant cover of lavender, decreasing the kinetic energy of raindrops on the soil surface and thereby diminishing runoff and soil loss, i.e. erosion. In the Alpujarras valley in the study area, farmers by tradition indiscriminately uproot wild aromatic and medicinal plants during what would be the harvest period for a crop of the same species. These plants are not frequently cultivated but rather gleaned in the wild by uprooting. This is a serious environmental problem, because the area is sloped and, when aromatic plants are harvested in this way, the soil is left bare, increasing the risk of sudden erosion and soil loss during torrential rains, which are very common in the area.

The average nutrient losses by surface runoff per area for P-PO₄ and K were significantly ($P < 0.05$) higher with harvest intensity-50% (0.17 and 4.0 mg m⁻², respectively) than with harvest intensity-25% (0.06 and 1.40 mg m⁻², respectively) (data not shown). Particularly, average losses for both P-PO₄ and K were 2.8 times higher in harvest intensity-50% than in harvest intensity-25%. By contrast, no significant differences ($P < 0.05$) were found for NO₃ or NH₄. In general, total N, P and K losses for the study period were 36.6, 1.5 and 22.8 mg m⁻², respectively, for harvest intensity-25%, and 104.2, 2.6 and 63.9 mg m⁻² for harvest intensity-50%. That is, the total losses of N, P and K in harvest intensity-25% with

Table II. Average yearly concentrations of nutrients in runoff per treatment.

	HI-25				HI-50			
	N-NO ₃	N-NH ₄	P-PO ₄	K	N-NO ₃	N-NH ₄	P-PO ₄	K
2001								
Average	6.4	2.6	0.3	2.4	4.2	3.3	0.3	3.2
SD.	2.0	1.7	0.3	3.4	3.2	3.0	0.2	3.7
Max.	9.6	4.5	0.8	8.6	10.5	6.5	0.5	8.6
Min.	3.4	0.8	0.1	0.1	2.1	0.3	0.1	0.0
2002								
Average	1.8	1.3	0.1	4.6	1.2	1.1	0.1	5.2
SD	0.5	0.5	0.1	4.3	0.5	0.5	0.1	5.1
Max.	2.4	1.6	0.2	12.8	1.7	1.8	0.4	15.4
Min.	1.1	0.5	0.0	0.3	0.8	0.7	0.0	1.9
2003								
Average	1.9	1.8	0.1	5.0	1.6	1.3	0.1	9.1
SD	0.5	0.6	0.0	2.5	0.1	0.3	0.0	5.7
Max.	2.4	2.5	0.1	8.1	1.6	1.6	0.2	16.3
Min.	1.5	1.3	0.1	2.0	1.4	1.1	0.1	2.8

HI-25, harvest intensity-25%; HI-50, harvest intensity-50%; SD, standard deviation.

respect to harvest intensity-50% were reduced by 65, 42 and 64%, respectively.

Table II presents the average yearly nutrient-concentration values for both treatments in runoff during the study period. The highest average N-NO₃ concentration in runoff for harvest intensity-25% and harvest intensity-50% was registered in the first year of the study period (6.4 and 4.2 mg L⁻¹, respectively). However, the maximum for this year was in harvest intensity-50% (10.5 mg L⁻¹). This concentration exceeded the upper limit of 10 mg L⁻¹ recommended for drinking water by the U.S. EPA (1976).

Regarding N-NH₄, the highest concentrations were found in harvest intensity-50%, but in both treatments exceeded 0.5 mg L⁻¹, the standard limit for public water supplies. There were several runoff events from all plots where the N-NH₄ concentration even exceeded 2 mg L⁻¹, a level considered toxic to fish. The highest maximum values of P-PO₄ concentrations were registered in 2001 (0.8 and 0.5 mg L⁻¹ for harvest intensity-25% and harvest intensity-50%, respectively), exceeding established limits usually associated with eutrophication of surface waters: from 0.01 mg P L⁻¹ (Vollenweider, 1968; Vollenweider and Kerekes, 1980) to 0.05 mg L⁻¹ (U.S. EPA, 1976), or 0.05–0.1 mg L⁻¹ total P for the protection of fresh water (ANZECC, 1992).

The highest average K concentrations were registered in 2003: averaging 5.0 and 9.1 mg L⁻¹ for harvest intensity-25% and harvest intensity-50%, respectively. Furthermore, the maximum concentrations were consistently found in harvest intensity-50% (8.6, 15.4 and 16.3 mg L⁻¹ for 2001, 2002 and 2003, respectively), exceeding 12 mg L⁻¹, the upper limit recommended for drinking water (U.S. EPA, 1976). It is evident from the results that the presence of nutrients in runoff was associated with yearly fertilizer applications. Therefore, the NPK loss in agricultural runoff may be reduced by source- and transport-control strategies, such as moderate intensities of harvesting plants in areas susceptible to erosion. Thus, se-

Table III. Average soil-water content at different depths.

Soil depth (cm)	Treatment	
	HI-25	HI-50
	(%)	
5	8.6 a	6.7 b
10	10.3 a	8.5 b
20	12.7 a	11.0 b
30	12.9 a	12.6 a
40	12.5 a	13.0 a
50	13.6 a	13.2 a

Values with different letters between columns are statistically different at the level 0.05 (LSD). HI-25, harvest intensity-25%; HI-50, harvest intensity-50%.

vere harvest intensities of wild aromatic plants in mountainous areas promote heavy leaching of nutrients by runoff, which can cause eventual losses in soil fertility and a high risk of contamination of freshwaters or eutrophication of natural ecosystems.

3.2. Soil-moisture dynamics

Table III shows the average soil-water content at different depths. For both treatments, soil moisture increased in depth during the study period, due to the high hydraulic conductivity of sandy-loamy soil. Moreover, lavender plants protected the soil against direct radiation, reducing evaporation from the soil surface. At 5, 10 and 20 cm deep, soil-water content at harvest intensity-25% was significantly higher than at harvest intensity-50%, in contrast to 30, 40 and 50 cm deep, where no statistical differences were found.

With respect to the entire soil profile, the average θ_v in 2001 for harvest intensity-25% and harvest intensity-50% was 11.4 and 10.7%, respectively; in 2002, values were similar for both treatments (11.2 %); and in 2003, 12.4 and 11.0%,

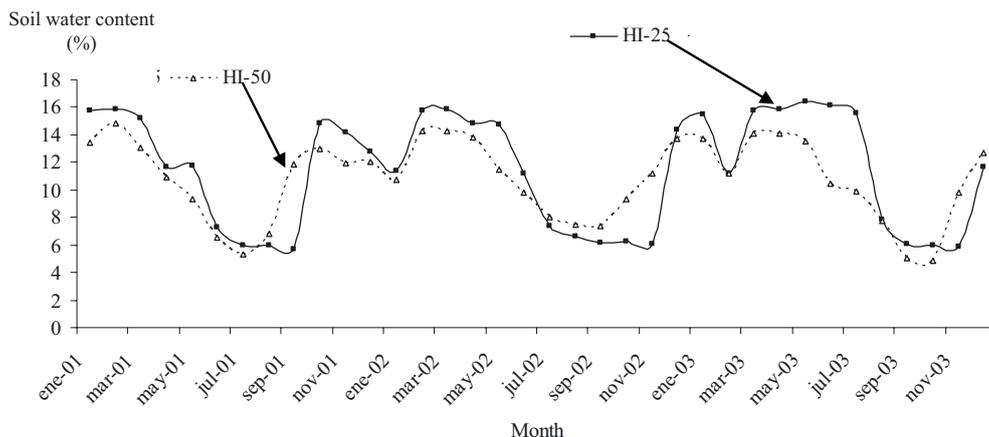


Figure 6. Soil moisture dynamics for each treatment during the study period. HI-50, harvest intensity-50%; HI-25, harvest intensity-25%.

respectively. Thus, over the whole study period, for the entire soil profile, harvest intensity-25% promoted higher soil water content with respect to harvest intensity-50%. This was because of greater soil water under denser vegetation cover due to the lower evapotranspiration losses, as pointed out by Schuster (1986). However, the relationship between plant cover and soil moisture in semiarid environments is a debated issue. In fact, Breshears et al. (1997) reported lower soil-moisture content for canopy locations than for intercanopy locations in a semiarid woodland. This agrees with our findings for the driest seasons of 2001 and 2002, when soil-water content was higher for harvest intensity-50% (Fig. 6): this is probably due to the higher evapotranspiration in harvest intensity-25% plots. During summer, in arid regions such as the study area, evapotranspiration exceeds precipitation and thus soil-water content falls to minimum values. In autumn and winter months, the soil is again recharged. The maximum θ_v was registered in March of 2003 for harvest intensity-25% (16.3%), and the minimum θ_v in August of 2003 for harvest intensity-50% (4.8%).

In semiarid areas, vegetation plays a vital role in water conservation, especially on hillsides, where slopes augment the risk of runoff and therefore water losses. However, sustainable cultivation of aromatic plants can enhance infiltration, percolation and retention of water in deeper soil layers, as demonstrated in the study area.

4. CONCLUSION

The results from the present study show that the harvest intensity-25% treatment reduced erosion and runoff rates by 67 and 60%, respectively, more than harvest intensity-50% did. The greater percentage of remaining vegetation cover (75%) in harvest intensity-25% intercepted raindrops more effectively, reducing their kinetic energy. Part of the rainwater (stemflow and throughfall) infiltrated into the soil matrix, accumulating at low depths. The nutrient losses by runoff were considerably higher in harvest intensity-50% than in harvest intensity-25%. That is, the total losses of N, P and K in harvest intensity-25% with respect to harvest intensity-50% were reduced by 65, 42 and 64%, respectively. Therefore, the proper

protection of soil from erosion and nutrient losses was found by harvesting 25% lavender biomass on semiarid slopes. In arid and sloped areas of southeastern Spain, vegetative cover plays a crucial role in protecting soil against erosion. Unfortunately, farmers usually uproot aromatic plants indiscriminately at harvest, leaving soil bare. The cultivation of these plants, such as lavender, with harvest of 50% of aboveground biomass, under rainfed conditions could diminish the risk of erosion and provide an extra economic income for farmers, maintaining the equilibrium between economic interests and eco-friendly measures.

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