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SOIL MOISTURE CHANGES AFTER LAND ABANDONMENT IN THE CENTRAL SPANISH PYRENEES

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ABSTRACT: The European mountainous areas, such as the Pyrenees, have suffered important land use changes since the beginning of the XX century. These changes affect the plant cover recovery process and then the runoff and sediment production. Soil moisture can be a key factor in the evolution of the abandoned land. It determines the vegetation recovery, runoff generation, sediment detachment and soil development through runoff and infiltration processes.

This paper aims to study the influence of land-use and seasonality on soil moisture. Measurements were carried out weekly during 1997 and 1998 by means of the Time Domain Reflectrometry method. The selected land-uses were: Cereal (fertilised and with artica management), Fallow, Meadow, Abandoned (after fertilised cereal and artica management), Burnt (two plots under different post-fire recovery conditions), and the Control plot, which is a dense Scrubland.

The results show that land-use is a key factor in the seasonal and spatial variability of soil moisture. The scrubland, meadow and fallow plots showed always a higher water content (> 30 % of soil moisture mean annual value), meanwhile the abandoned land stored less water (23 %). Burnt, artica and cereal plots had intermediate values. Seasonally, summer used to be the driest period as year 1998 confirmed. Nevertheless the year 1997 was extremely wet during summer due to the high rainfall values. Soil moisture was always higher than 10 %, even during the driest periods. Previous weekly rainfall and antecedent soil moisture explain 80 % of the variability. No relationship was found between the soil moisture changes and the variability amongst plots throughout the studied period.

RESUMEN: Las montañas europeas, como los Pirineos, han experimentado importantes cambios de uso del suelo desde principios del siglo XX. Tales cambios afectan a los procesos de colonización vegetal y, por lo tanto, a la escorrentía y la producción de sedimento. La humedad del suelo *es un factor clave en la evolución de las tierras abandonadas, pues determina la cubierta vegetal, la generación de escorrentía, el arranque de partículas y la evolución del suelo a través de los procesos de escorrentía e infiltración.*

Este trabajo estudia la influencia del uso del suelo y la estacionalidad sobre la humedad del suelo. Se tomaron medidas semanalmente durante 1997 y 1998 con el método TDR. Los usos del suelo seleccionados fueron: Cereal (fertilizado y en agricultura nómada), Barbecho, Prado, Abandonado (después de cereal fertilizado y de agricultura nómada). Matorral quemado (dos parcelas con diferente cubierta vegetal posterior al incendio) y Parcela Control, con una densa cubierta de matorral.

Los resultados muestran que el uso del suelo es un factor clave en la variabilidad estacional y espacial de la humedad del suelo. Las parcelas de matorral, prado y barbecho tuvieron siempre un mayor contenido en agua (>30% de humedad del suelo como valor medio anual), mientras que la parcela abandonada almacenaba menos agua (23%). La parcela quemada, la agricultura nómada y el cereal tuvieron valores intermedios. Estacionalmente, el verano fue el periodo más seco durante 1998, mientras que el año 1997 fue extremadamente húmedo en verano. La humedad del suelo fue siempre superior al 10% incluso durante los periodos más secos. La lluvia de la semana precedente y la humedad antecedente del suelo explican el 80% de la variabilidad. No se han encontrado relaciones entre los cambios en la humedad del suelo y la variabilidad entre parcelas durante el periodo de estudio.

Palabras clave: Humedad del suelo, Usos del suelo, Abandono de tierras, Prados, Agricultura nómada, Matorral, Pirineo Central español.

Key-words: Soil humidity, Land-uses, Farmland abandonment, Meadows, Shifting agriculture, Shrubland, Central Spanish Pyrenees.

1. Introduction

The European mountainous areas have suffered important land use changes since the beginning of the XX century. In the Pyrenees, the land abandonment has lead to a landscape characterised by a mosaic of different land-uses. These changes affect the vegetation recovery process and then the runoff and sediment production (García-Ruiz, 1996; García-Ruiz *et al.,* 1996). During the second half of the XX century most of ploughed land was abandoned, and the pastoral land use increased. In the Borau valley, Pyrenees, Lasanta et al., (2000) found an increase in the forest surface (54 %) and a reduction from 42 to 5 % of the cultivated land. Similar data can be found throughout the mountain areas of the Mediterranean. These active changes in the land use modify the water and sediment supply. Studies carried out in the Pyrenees showed the highest water and sediment losses on fallow land; meanwhile the shrub-covered surfaces supplied very little sediment and runoff (García-Ruiz, 1997). Arnáez & Ortigosa (1997) found that scrub covered surfaces were also the less eroded areas in La Rioja, Spain. These changes in a land use, vegetation cover and for this in sediment and water dynamics lead to an alteration of the channel equilibrium. In fact, Valero-Garcés *et al.,* (1999) indicated that most of the changes in the siltation of the mountain reservoirs in the Pyrenees were caused by channel erosion processes. Likely, the reduction of the erosion rates due to the recovery of vegetation triggered the erosion of the channel banks. At smaller catchments scales, the research of Llorens *et al.,* (1997a) indicated that the abandonment of drainage ditches increase water storage, but if the elementary stream network rearrange the old fields the land will be gullied, and then runoff and sediment production will be much higher. The studies of the runoff and erosion processes have been completed by the research done on the interception by the vegetation (Llorens, 1997b).

Although, soil moisture plays an important role in the hydrological cycle, very little is know about its behaviour in a changing environment like the Pyrenees. Soil moisture regulates the runoff and infiltration processes and for this the sediment detachment. Moreover, soil moisture also determines the vegetation recovery and soil development after abandonment. The knowledge of the seasonal and spatial changes of soil moisture will give information about the erosion process dynamics, the interaction between vegetation and soil moisture, and the water sustainability in an area such as the Pyrenees affected by active environmental changes.

This paper aims to study the influence of land-use and seasonality on the soil moisture. Measurements were carried out weekly during 1997 and 1998 by means of the Time Domain Reflectrometry method, with no measurements during the very cold winter season, when soil is very wet. We focussed the research on the driest periods of the year, when the changes of soil water are more dynamic.

2. Materials and Methods

The study area is located in the municipality of Aisa, in the Central Spanish Pyrenees (Figure 1). The upper part of the Aisa valley is composed of Mesozoic limestone and sandstones, the central and southern part of the valley the lithology is dominated by flysh. This bedrock where the plots are located, is composed by alternate thin layers of calcareous sandstones and marls.

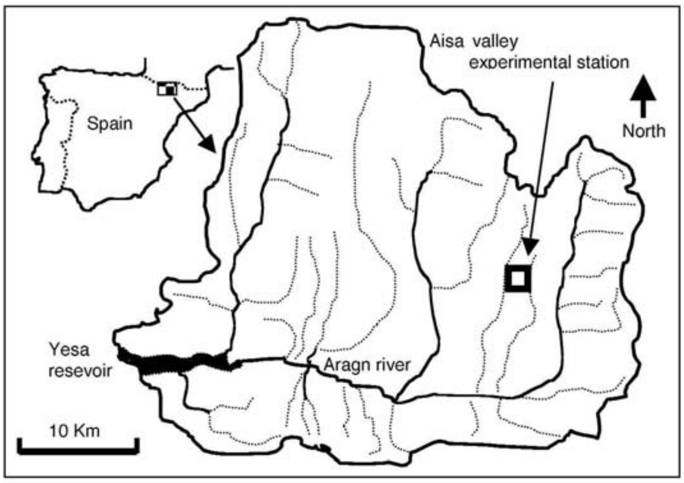

Figure 1. Location of the study area.

Climate is characterised by a mean annual temperature of 10 ºC, with a cold winter (3.6 ºC in January) and warm summer (19.7 ºC for August). Mean annual rainfall is 1212 mm with wet winters (329 mm), springs (326 mm) and autumns (373 mm). Summer is drier (184 mm). It should be highlighted that thunderstorms are very usual during summer were rainfall intensities higher than 100 mm h^{-1} are not unusual. Due to the random distribution of the thunderstorms, rainfall distribution of the summer precipitation is very variable amongst years. Data from the experimental station show wet and dry summer seasons, although the dry ones are more usual than the wet ones.

Soils are developed on Eocene flysch, which favours steep slopes, ranging from 30 to 60 % steepness. Soils are clay loam with an organic matter content of about 2 %. Plots of 3 x 10 m were installed in the same slope in order to avoid differences amongst them in soil, vegetation and slope characteristics. Although the *Pinus sylvestris* woods are the dominant vegetation cover on the north-facing slopes, in the south-facing slopes the shrubs (*Genista scorpius*, *Buxus sempervirens*, *Rosa gr. canina*) are dominant. In the Pyrenees, the cultivation took place during centuries on the south-facing slope due to the warmer climatic conditions. This is why the selected experimental station is located in a south-facing slope.

Since 1991 different land uses were applied in different plots: Artica (shifting agriculture), fallow land, cereal plot (chemical fertilization), burnt plot (previously densely covered), meadows and control plot (shrub covered). In 1993 another two plots were installed: a new burnt plot (previously covered by shrubs) and a one new fallow (alternating with barley cultivation). And in 1996, after 5 year shifting agriculture the artica plot was abandoned and a new artica plot installed.

The soil moisture measurements started in 1997, when the nine land uses were not disturbed by other changes. These land uses are representatives of the current land management found in the Pyrenees in areas affected by agriculture. The plot characteristics are the following:

Cultivation period:

Artica: Biomass collected in the field mixed with the soil and burnt as fertilisation strategy.
Cereal: Ploughed and sowed yearly, with chemical fertilisation.
Fallow: Ploughed bare soil.
Meadow: This is a cover of grass managed to feed caws or sheep.

Abandoned period (0-10 years):

Abandoned-1: Sowed with cereal in 1992 and abandoned the year after.
Abandoned-2: Cultivated with artica management (1992-1995) and later abandoned.

Period of disturbation by fire (after abandonment and vegetation recovery):

Burnt-1: Plot burnt July 19^{th}, 1991, with fast vegetation recovery.
Burnt-2: Plot burnt May 3^{rd}, 1993, which also have a dense vegetation cover.

Vegetation recovery (30 years):

Scrubland: This is the control plot with a dense cover of *Genista scorpius*.

Measurements of the soil moisture content were done from June 4th, 1997 to October 28th, 1997. During this period weekly sampling was done with 19 sampling days. During the following year (from March 4th to November 18th) 27 sampling days were completed. Within each plot, one TDR probe was located at 0-20 cm depth (Ferre et al., 1996).

Measurements during winter were avoided due to the very high soil water content. The study was focussed on the soil moisture evolution during summer, when water stress can affect vegetation development. An automatic raingauge was installed in order to know the rainfall characteristics.

Data were analysed with descriptive statistics and by regression with the SPSS program. In addition multiple lineal correlations were done in order to determine the factors of the soil moisture changes. The SPSS program was used to statistical analysis.

3. Results

3.1. Seasonal changes of soil moisture

Soil moisture showed a different evolution during the years 1997 and 1998. From June the 3rd to October 28th of 1997 the average soil moisture content was 28.5 %, meanwhile it reached 34.4 % during the summer season. The seasonal evolution, as shown in figure 2 show that the soil moisture was in summer higher as in spring. Autumn, with values about 20 %, was drier than summer. This was due to the summer thunderstorms which accounted 366,4 mm of rainfall, and the unusual dry autumn, with only 17 mm collected during the studied period (first five weeks of autumn).

During 1998, from March the 4th to November 18th, soil moisture evolution shows the expected yearly trends. Summer was the driest season; meanwhile spring and autumn

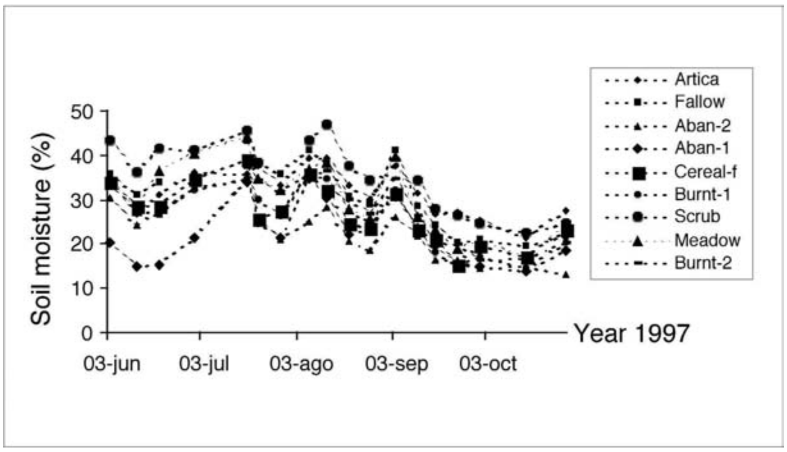

Figure 2. Soil moisture changes during the measured period of 1997.

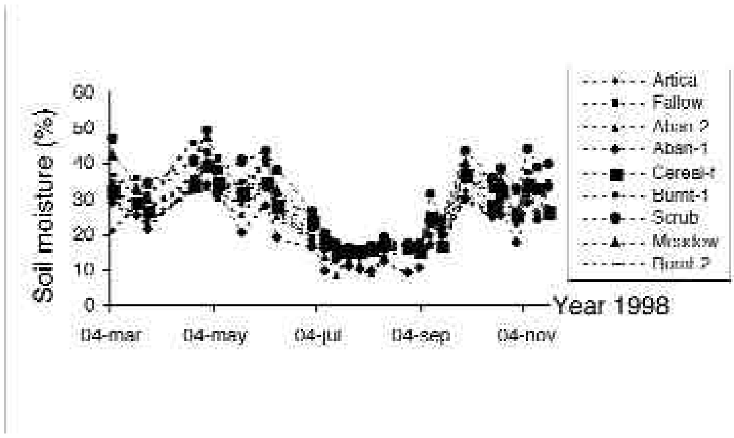

Figure 3. Soil moisture changes during the measured period of 1998.

were wetter (Figure 3). The mean annual soil water content was 32.6 % meanwhile during the summer sampling period the soil moisture was only 17.1 %.

Table 1 shows the measurements carried out during the summer of 1997 and 1998 and it can be seen that in average values the 1997 summer soil moisture was 2.5 times the measured soil moisture content during 1998. During the summer 1998 the total amount of rainfall was 147.6 mm, slightly less than the average summer rainfall (182 mm). Differences amongst the summers of 1997 and 1998 affect the nine different land uses. The wettest soils in 1997 were also the wettest ones in 1998 as figure 4 show.

The differences between land uses along the year can be due to wetting and drying periods. During the wetting periods, spatial differences between land-uses are reduced and homogeneity of soil moisture increases. On the contrary, drying periods result in an increase of the differences between land uses due to the influence of land use on soil water content. However, this control of the soil moisture spatial variability by the wetting and drying processes was not clear enough in the Central Spanish Pyrenees during the studied period as it is shown by figures 5 and 6. The increase or decrease in the soil moisture did not influence the variation coefficient and thus, it seems that soil moisture spatial variability is not controlled by rainfall.

Table 1. Average soil moisture for summer 1997 and 1998 at each of the plots and for all plots.

	Artica	**Fallow**	**Abando-2**	**Abando-1**	**Cereal fer.**	**Burnt-1**	**Scrubland**	**Meadow**	**Burnt-2**	**Average**
Summer1997										
Average	34,2	34,0	24,1	25,3	28,0	28,1	37,7	32,5	30,5	34,4
Std	4,2	7,3	5,6	5,8	6,6	6,4	6,6	7,5	6,0	4,5
Vc (%)	12,4	21,4	23,4	22,8	23,5	22,6	17,6	23,1	19,6	13,0
Summer1998										
Average	17,3	17,4	13,9	12,7	18,1	17,8	20,3	18,5	18,0	17,1
Std	2,5	2,3	3,1	3,2	3,3	2,9	5,1	3,8	3,3	2,9
Vc (%)	14,7	13,4	22,3	24,9	18,1	16,5	25,3	20,6	18,5	17,2

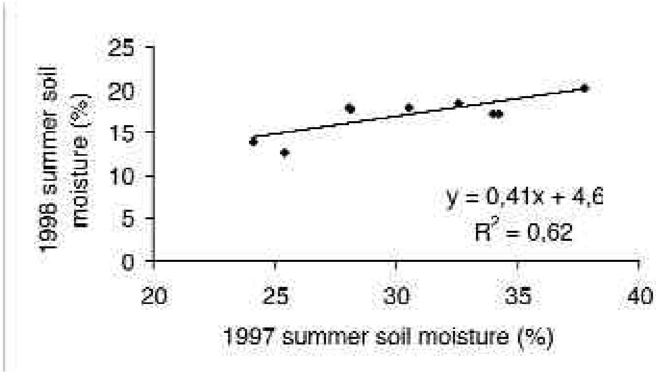

Figure 4. Relationship between 1997 and 1998 summer soil moisture for the nine studied land uses.

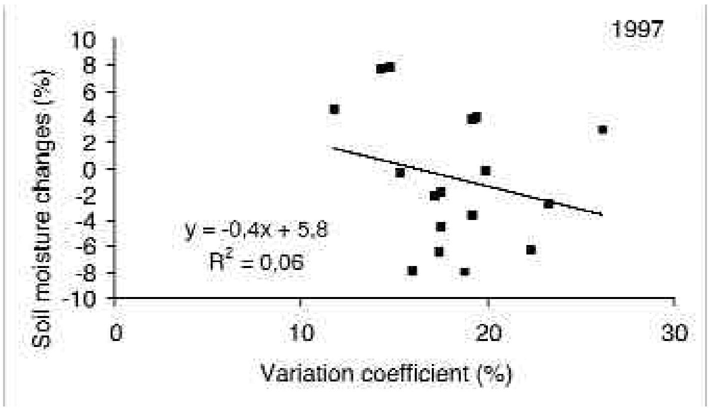

Figure 5. Relationship between the increase in soil moisture and the variation coefficient during the measured period of 1997.

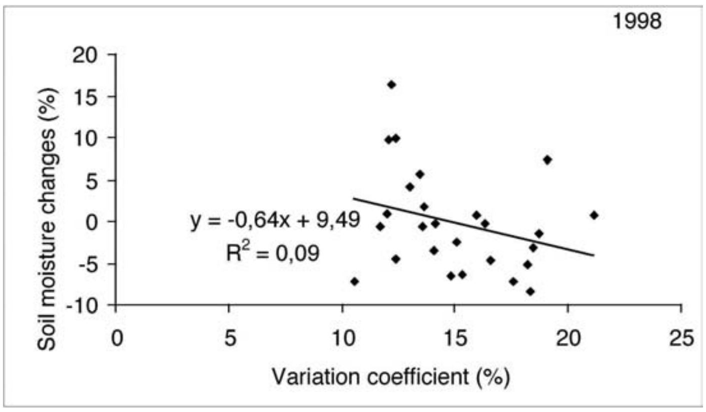

Figure 6. Relationship between the increase in soil moisture and the variation coefficient during the measured period of 1998.

3.2. The effect of land use on soil moisture

Soil moisture data has been analysed for the years 1997 and 1998. For the year 1997 mean values reached 30.5 % for the nine land uses. The abandoned fields reached the lowest values (24-25 %); on the other hand, the scrubland reached 37 % of soil water content. The year 1998, showed values of about 21 % in the abandoned fields. Scrubland was found to have the wettest soil (Table 2). Soil moisture was reduced from 1997 to 1998 an average of 4.2 %. It ranged from a 10 % reduction in Artica to a 1.4 % reduction in the abandoned field (Abando-2). The average values for the whole data set confirm that the abandoned field has the lowest soil moisture contents (23 %). Scrubland is the wettest soil (35 %), the Meadow and the Fallow (31 %) have wet soils, meanwhile the Artica management, burnt soils and the fertilised cereal have intermediate values (see table 2).

Table 2. Average soil moisture content for 1997 and 1998, reduction from 1997 to 1998 and average for the two years (1997 and 1998). Average, standard deviation and variation coefficient for the nine land uses studied.

Land-use	Year 1997	Year 1998	Reduction 1998-1997	Average 1997-1998
Abando-1	25,34	20,94	4,40	23,14
Abando-2	24,09	22,66	1,43	23,38
Burnt-1	28,07	26,13	1,94	27,10
Cereal fer.	28,04	26,29	1,75	27,17
Burnt-2	30,51	27,49	3,02	29,00
Artica	34,19	24,15	10,04	29,17
Meadow	32,54	28,84	3,70	30,69
Fallow	33,95	28,17	5,78	31,06
Scrubland	37,69	31,98	5,71	34,83
Average	30,49	26,29	4,20	28,39
Std	4,49	3,36	2,72	3,72
Vc (%)	14,71	12,77	64,89	13,10

3.3. Factors of soil moisture changes

Multiple linear correlations were done for season and yearly data of soil moisture. Table 3 shows the correlation coefficient between the soil moisture with the previous soil moisture content and the previous weekly rainfall at each of the studied land uses. For the whole data sets and for the summer (> 50 % of the measurements) the influence of previous rainfall and soil moisture explain 80 % of the soil moisture variability. The type of rainfall, the amount of runoff, the transpiration, the evaporation rate, and the time from the last rainfall likely will explain the 20 % of the non-explained variation.

4. Discussion

Abandoned fields are characterised by a dynamic recovery of vegetation and changes in soil. These changes are due to natural vegetation succession and human activity, which

Table 3. Correlation coefficient between the soil moisture and the antecedent soil moisture con - tent and the previous weekly rainfall for each of the nine land uses during the years 1997 and 1998 and at each season studied: spring, summer and autumn. Two samples were collected during winter, and 3 measurements were rejected due to lack in data.

Plots	**Year (n = 46)**	**Summer (n = 24)**	**Autumn (n = 8)**	**Spring (n = 9)**
Artica	0.762	0.826	0.675	0.060
Fallow	0.861	0.838	0.760	0.762
Abandon-2	0.834	0.779	0.822	0.535
Cereal fer.	0.801	0.804	0.703	0.836
Abandon-1	0.739	0.713	0.580	0.328
Burnt-1	0.764	0.773	0.503	0.395
Scrubland	0.821	0.808	0.747	0.368
Meadow	0.792	0.805	0.747	0.368
Burnt-2	0.831	0.815	0.830	0.392
Average	0,801	0,796	0,707	0,498
Std	0,040	0,037	0,108	0,196
Vc (%)	4,997	4,665	15,253	39,426

also affect the soil moisture dynamics. Following Molinillo et al., (1997) the abandoned fields of the central Pyrenees pass through four stages: (i) invasion by herbaceous plants, with some woody shrubs after 10-15 years, (ii) spreading and generalized covering by woody shrubs between 10 to 35 years, (iii) retraction of shrubs and invasion of herbaceous plants (60 years), and finally (iv) entry of young trees in fields of more than 60 years of abandonment. The research at the Aisa experimental station during 10 years is focussed in the first two stages. There, the different land uses found during the last 30 years were replicated. The results presented show that land-use is a key factor of the soil moisture dynamics in the mountainous areas such as the Pyrenees.

Before the land was abandoned, land use in the Pyrenees was characterised by three main managements on the cultivated areas: cereal with fertilization, artica (shifting agriculture with burning) and fallow. During the experimental period, the fallow plot shows greater soil moisture content (31 %) than the cereal (27 %). Probably, this is due to the greater transpiration of the barley, and also due to the crust developed on the fallow land during the dry period, which induces a reduction in the evaporation rates from the soil. Moreover, the interception of rainfall by the cereal reduces the effective rainfall, meanwhile in the fallow the whole rainfall reaches the soil, which explains his greater soil moisture. Artica has an intermediate value (29 %) of soil moisture. It moves from 34 % the first year (1997) to 24 % soil water content the year 1998. This is the highest interannual change found (Table 2), and can be explained by the ash loss and the compactation of the soil after the first year.

After abandoment, a meadow is developed on the fields, covering during years the soil. The meadows are also man-made, and this is why we mow the grass two times per year in order to favour the development of herbs. These conditions result in a mean soil water content of 31 % for the studied period, which is similar to the values of the fallow land, and higher than the cultivated cereal and artica. The higher soil moisture in meadow land use should be related to his higher infiltration rates. For the studied plots, Lasanta and García-Ruiz (1998) found low runoff rates for the meadow. The cereal plot had a runoff discharge of 8.4 % during the year 1997; meanwhile the meadow runoff was 6.9 %. These differences supposes 20 mm of runoff loss from the cereal plot in comparison to the meadow during 1997. In 1996 the differences were even greater, 50 mm more runoff on the cereal plot than in the meadow. More runoff means less infiltration and a lower soil moisture content.

After 30 years the meadows are colonised by shrubs. Comparison of means between scrubland and abandoned land (after artica and cereal) shows an increase of soil moisture in 12 %, from 23 to 35 %. These differences should be highlighted. The water retention capacity of soils is improved by land abandonment after vegetation recovery. This changes is related to the organic matter increase and the macro and microporosity developed by the fauna and flora, which allows higher infiltration rates (Cerdà et al., 1994; Cerdà et al., 1995). A recovery of soil organic matter was found in the Pyrenees (Lasanta, 1989; Ruiz-Flaño, 1993) and in other mountainous areas (Rodríguez et al., 1991: Martínez Fernández et al., 1994) after abandonment.

The positive evolution of the soil moisture content after abandonment can be modified if forest fire takes place. Wildfires are common on abandoned fields and forested areas. Sometimes, shepherds burnt the shrubs to increase the meadows, so the burned abandoned field is quite common. Fire reduces the soil moisture content in the abandoned fields from 34 to 28 %, due to the effect of fire on soil: crusting, soil water repellency, etc. Many studies demonstrated that during the year following the fires higher runoff and sediment yields are collected (Marqués & Mora, 1992; Sala, 1996, Gimeno et al., 2000). However, the recovery of vegetation is very fast after fires, and then erosion rates have similar values 3-4 years after the fire than before (Cerdá, 1998).

The burnt soils (28 % of mean soil moisture content) have a greater water retention capacity than the recently abandoned ones, which reached around 23 % of soil moisture. This is probably due to the ashes. Abandonment takes place during the driest years, without fertilisation and after exploitation of nutrients by the crops. After abandonment, the macroporosity of the ploughed soil is reduced, crust is developed and then, soil and water is partially lost. Recovery of vegetation is more difficult under these conditions. However, after forest fire microporosity of the scrubland soils, developed by roots, animals, binding agents such as organic matter, calcium carbonates, are damaged but not destroyed, and the ashes favour the infiltration of water. In the Aisa experimental plots, Lasanta & García Ruiz (1998), found in 1996 that for the plot burnt in 1991 runoff was 4.1 % (3.9 % for the scrubland) and 5.9 % (5.8 % for the scrubland) in 1997. The plot burnt in 1993 showed slightly greater runoff values: 5.5 and 8.6 % for the years 1996 and 1997.

As concerning seasonality of soil water content, it was expected to find the lowest soil moisture contents during summer, like it was found in 1998. However, during summer

1997 the soil moisture content was two times higher than during summer 1998. Moreover, summer 1997 was as wet as spring 1997 and wetter than autumn 1997. The Pyrenees'summers can be extremely wet, although normally it is the dry season.

Previous research carried out in the central Spanish Pyrenees demonstrated that during the maximum demographic pressure of the XIX century the erosion processes were very active. The shifting agriculture (artica) and ploughing leads to huge amounts of sediment eroded from the slopes (García-Ruiz et al., 1995). In filled reservoirs, changes in the fluvial systems, high stone cover in the slopes are some of the main features (García Ruiz & Valero, 1998). After the 50's abandonment the geomorphologic activity of the land was reduced by the recovery of vegetation, and now the plant colonization is the main factor of the erosion processes. This paper confirms that these changes of the dynamics also affected the soil moisture content. A decrease of soil water content was found during the first stages of abandonment, but after shrub colonisation the soil moisture content reached the highest values. Fire leads to a reduction of soil water content, at least during the five years after the fire.

Data on soil moisture available under Mediterranean environments is very short. Most of the data is coming from very degraded environments such as badlands. Cerdà (1996) in South-eastern Spain (300 mm y^{-1}) found than during the dry periods the soil moisture at 0-20 cm depth did not surpass 10 % for vegetated areas and was even lower than 5 % in the bare ones. During the wet periods values of soil moisture were always below 20 % in the vegetated north-facing slopes and were always lower than 15 % in the bare ones. During summer the values at 0-5 cm depth were around 2 %. Ceballos and Schnabel (1998) found in the Dehesa areas of Extremadura a strong seasonal contrast in the soil moisture content. Mean soil moisture values found during summer were around 2 %; meanwhile during an extremely wet winter the values reached values around 25 %. González-Hidalgo et al., (1996-1997) found also extremely dry soils during summer in the south of the Huesca province, where annual rainfall is around 450 mm.

5. Conclusions

The Aisa experimental station, a representative area of the Pyrenees environments, shows that the soil moisture is extremely high in comparison to other Mediterranean environments. Values found in Aisa were never lower than 10 %, even during the summer.

Seasonal evolution of soil moisture is determined by rainfall and previous soil moisture content. Under wet but variable precipitation, as in the Pyrenees, dry or wet soils were found at different seasons. Summer is normally the driest season but during rainy summers the soil can be wetter as spring or autumn. Soil moisture is normally high and even extremely high during the rainy seasons.

Land use and land management determine the soil moisture content. We know that farmland abandonment has positive effects for runoff control and soil conservation. Land abandonment also results after some decades in soils with greater organic matter content, lower bulk density and higher water retention capacity. However, from the abandonment to the complete recovery of shrubs (around 30 years) many changes in soil water content can be found due to the dynamic evolution of the abandoned land and the human interferences. Recently abandoned land has the lowest soil water content, but the recovery of vegetation and the improvement of the soil result in higher values after 30 years, higher even than during cultivation. However, fire can reduce the soil moisture, but the soil water content will never be as low as during the first stages after abandonment.

Plant cover favours greater soil moisture content as it was found on the scrubland plot or in the meadow. This is related to greater infiltration rates, which avoid runoff. However, ploughing also favours the increase of porosity of the soil, which enhance infiltration and avoid evaporation. Moreover, the negligible vegetation cover results in low transpiration losses.

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