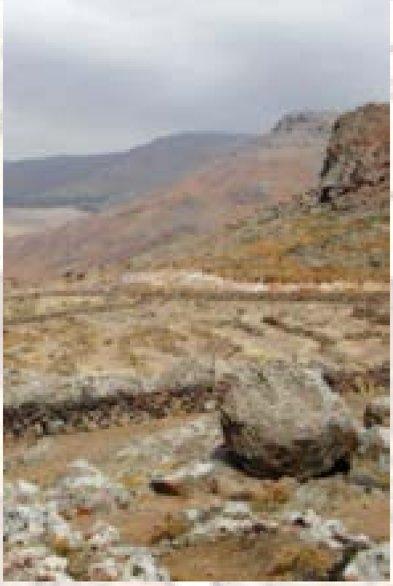
DESIRE REPORT series



Using Indicators for Identifying Best Land Management Practices for Combating Desertification

Compiled by: Agricultural University of Athens

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25th April 2012

Agricultural University of Athens

Report number 94
Series: Scientific reports

Deliverable 2.2.3

This report was written in the context of the Desire project
www.desire-project.eu

WB2: Land degradation indicators

Deliverable: 2.2.3: Using Indicators for Identifying Best Land Management Practices for Combating Desertification

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February 2012

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1. Introduction

Indicators are becoming increasingly important tools for communicating information to decision makers and the public, as well as in assessing the environmental performance and evaluating the progress made by actions applied to combat land degradation. In environmental sciences, a single indicator cannot efficiently describe a complex process such as soil erosion or land desertification. Indicators combined in a composite index allow someone making multiple choices in land management and hence in monitoring of the state of the environment.

As has be pointed out by many authors and various organizations, the fundamental process or causes of land degradation and desertification are degradation of vegetative cover, water erosion, soil salinization, overgrazing, forest fires, water deficiency, etc. All these degradation processes are caused by almost the same mechanisms or driving interrelated forces. Land users or police makers need simple tools to understand the present state of a socio-ecological system and to foresee trends or risks on land degradation caused by the such processes or causes.

The European Environmental Agency has considered that an indicator is a measure, generally quantitative, that can be used to illustrate and communicate complex phenomena simply, including trends and progress over time (EEA, 2005). The Organization for Economic Co-operation and Development (OECD, 2003) has early on established the following criteria for selecting environmental indicators:

- provide a representative picture of environmental conditions, pressures on the environment or society's responses;
- be simple, easy to interpret and able to show trends over time;
- be responsive to changes in the environment and related human activities;
- provide a basis for international comparisons;
- be either national in scope or applicable to regional environmental issues of national significance;
- have a threshold or reference value against which to compare it, so that users can assess the significance of the values associated with it;
- be theoretically well founded in technical and scientific terms;
- be based on international standards and international consensus about its validity;
- allow itself to being linked to economic models, forecasting and information systems.

The necessity of elaborating indicators is one of the priorities identified by the United Nations Convention to Combat Desertification (UNCCD). In National action plans for combating desertification, indicators have been widely used to define areas sensitive to desertification. Based on the research conducted by the EU MEDALUS II project, Environmentally Sensitive Areas (ESAs) to desertification exhibit different sensitivity to desertification for various reasons. Indicators have been used to assess the sensitivity of the land to desertification. For example there are areas presenting high sensitivity to low rainfall and extreme events due to low vegetation cover, low resistance of vegetation to drought, highly erodible parent materials, etc. Four general types of ESAs have been distinguished based on the stage of land degradation (Kosmas *et al.,* 1999):

Critical ESAs: Areas already highly degraded through past misuse, presenting a threat to the environment of the surrounding areas, i.e. badly eroded areas subject to high run-off and sediment loss. This may cause appreciable flooding downstream and reservoir sedimentation.

Fragile ESAs: Areas in which any change in the delicate balance between natural and human activity is likely to bring about desertification. For example, a land use change (a shift towards cereals cultivation) on sensitive soils might produce immediate increase in run-off and erosion, and perhaps pesticide and fertilizer pollution downstream.

Potential ESAs: Areas threatened by desertification under significant climate change, if a particular combination of land use is implemented or where offsite impacts will produce severe problems elsewhere, for example pesticide transfer to downslope or downstream areas under variable land use or socio-economic conditions.

Non Threatened ESAs: Areas with deep to very deep soils, nearly flat, well drained, coarse-textured or finer textured soils, under semi-arid or wetter climatic conditions, independently of vegetation, are considered as being non-threatened by desertification.

The various types of ESAs to desertification are distinguished and mapped by using certain key indicators or parameters for assessing the land capability to withstand further degradation, or the land suitability for supporting specific types of land use. A simple methodology has been developed by Kosmas *et al.* (1999) to identify ESAs to desertification by using 15 simple indicators related to soil, climate, vegetation, and land management characteristics.

The developed methodology on ESAs to desertification describes the stage of land degradation under certain physical environmental characteristics and land management practices. Based on the specific stage of land desertification, another methodology has been developed by the DESIRE project to assess the risk of land degradation and desertification and to identify land management practices for combating desertification. In this project the following five classes of desertification risk have been defined:

Very high desertification risk. Critical areas to desertification very highly degraded subjected to very high erosion rates due to intensive cultivation, overgrazing, frequent fires; or to very high salinization rates due to the presence of shallow groundwater table or irrigation with poor quality of water (Fig. 1).

Fig. 1. Typical examples of critical areas of very high desertification risk due to overgrazing and high soil erosion (left) and due to very high soil salinization caused by the shallow groundwater table with very poor quality of water

<u>High desertification risk</u>. Critical areas to desertification highly degraded subjected to moderate or slight erosion rates or fragile areas to desertification moderately degraded subjected to very high erosion rates due to intensive cultivation, overgrazing, frequent fires; or to high salinization rates due to the presence of moderately shallow groundwater table or irrigation with poor quality of water (Fig. 2).

Fig. 2. Typical examples of fragile area intensively cultivated under very high erosion rates (left) or critical area subjected to frequent forest fires with moderate erosion (right) characterized both by high desertification risk

<u>Moderate desertification risk</u>. Fragile areas to desertification moderately degraded subjected to high or moderate erosion rates or potential areas to desertification subjected to very high or high erosion rates due to intensive cultivation, overgrazing, frequent fires; or to moderate salinization rates due to the presence of moderately deep groundwater table or irrigation with moderate quality of water (Fig. 3).

Fig. 3. Typical examples of fragile area intensively cultivated under high erosion rates (left) or potential area to desertification subjected to low salinization rate due to moderately deep groundwater table of moderate quality (right) characterized both by moderate desertification risk

<u>Low desertification risk</u>. Fragile areas to desertification moderately degraded subjected to low erosion rates or potential areas to desertification slightly degraded subjected to moderate erosion rates due to intensive cultivation, overgrazing, frequent fires; or to low salinization rates due to the presence of relatively deep groundwater table or irrigation with moderately good quality of water (Fig. 4).

Fig. 4. Typical examples of fragile area intensively cultivated under high erosion rates (left) or potential area to desertification subjected to low salinization rate due to moderately deep groundwater table of moderate quality (right) characterized both by moderate desertification risk

<u>No desertification risk</u>. Potential or non-threatened areas to desertification slightly or no degraded subjected to very low or no erosion; or fragile, potential, non-threatened areas to desertification subjected to no salinization risk due to the presence of very deep ground water table or irrigation with good quality of water (Fig. 5).

Fig. 5. Typical examples of non-threatened areas with very deep well-drained soils vey well protected from soil erosion and salinization subjected to no desertification risk

2. The work carried out in DESIRE project

DESIRE was a five years integrated research project funded by the European Commission and initiated in 2007. The main objective of the project was to establish promising alternative land use and management conservation strategies in areas affected by land degradation and desertification based on a close participation of scientists with stakeholder groups in affected areas around the world. Based on this main objective, an effort has been made to analyze a large number of existing indicators related to land degradation and desertification and to derive a minimum number of effective indicators for defining land desertification risk and assessing various land management practices for combating desertification.

Defining candidate indicators

After selection of 17 study sites located in various places around the word, the most important processes or causes of land degradation have been identified by the participating experts in each site. The following processes or causes have been identified: (a) soil erosion including water, tillage and wind erosion, (b) soil salinization, (c) water stress, (d) forest fires, and (e) overgrazing. The next step was to select related indicators to the defined processes or causes. The list of indicators has been formulated by: (a) reviewing literature, (b) consulting stakeholders, and various groups of the EU-research project DESIRE, and (c) using previous research carried out in desertification projects such as MEDALUS III (ENV4-CT95- 0119), MEDRAP (EVK2-CT-2000-20 008), DESERTLINKS (EVK2-CT-2001-00109) etc. Furthermore, focus group meetings have been organized in which participants have been asked to provide their opinion about environmental security and the use of indicators for protection against desertification. Furthermore, taking into consideration the main criteria for selecting indicators such as adequately documented, easily available, sensitive to stressors, cost effective and interpretable; a series of 72 candidate indicators related to the physical environment, social, economic, and land management characteristics were selected for analysis.

Based on existing classification systems, classes have been designated for each indicator and presented in a tabulated form. Weighing indices have been assigned to each class based on existing research or empirically assessing the importance to land degradation and desertification. A series of related indicators were assigned in each degradation process or cause and separately questionnaires have been formulated. Then data were collected in each study site using the compiled manual for this project "Describing Land Degradation Indicators" (http://www.desire-project.eu).

In order to have more accurate and uniform data basis on the studied indicators in the various study sites, an event was organized, including representatives from all study sites, in which a presentation was carried out on how to fill the defined questionnaires. As study field site has been considered a farm belonging to a certain farmer with an area usually ranging from 0.5 to 20 ha and having uniform soil, topographic, land use, and land management characteristics (Fig. 1). A minimum number of 30 field sites were studied for each process and land use in each study site.

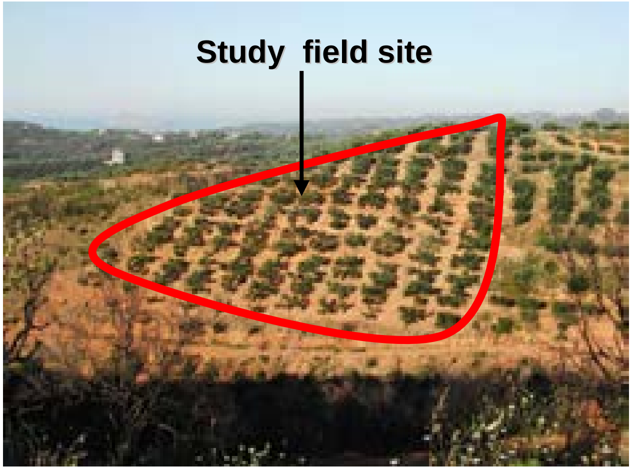

Fig. 1. Example of study field site with certain soil, topography, land use, and land management characteristics belonging to a certain farmer

Data have been collected in 1672 field sites located in 17 Mediterranean and eastern Europe, Latin America, Africa, and Asia study sites. Specifically, data were collected from the following study sites (Fig. 2): (1) Rendina Basin Basilicata-Italy, (2) Nestos Basin Maggana-Greece, (3) Crete-Greece, (4) Mação- Portugal, (5) Gois–Portugal, (6) Guadalentin Basin Murcia-Spain, (7) Konya Karapinar plain-Turkey, (8) Eskisehir Plain-Turkey, (9) Novij Saratov-Russia, (10) Djanybek-Russia, (11) Zeuss Koutine-Tunisia, (12) Boteti Area-Botswana, (13) Santiago Island-Cape Verde, (14) Mamora Sehoul-Morocco, (15) Loess Plateau-China, (16) Secano Interior-Chile, and (17) Cointzio catchment-Mexico.

Fig. 2. Distribution of study sites for collecting data for indicators related to land degradation and desertification

In all study sites, survey research was conducted in different land use types such as olive groves, vineyards, cereals, almonds, cotton, pastures, oak forests, pine forests etc., representative of Mediterranean environmental conditions. The obtained data on indicators were introduced in a harmonized database and were statistically analysed to define a limited number of effective indicators affecting desertification risk under various land degradation processes or causes.

Analysis of data

All collected data were classified according to land degradation processes or causes and land uses. The number of candidate indicators used for the analysis in each process or cause ranged from 16 t o 49. The data base has been improved for missing values for some indicators following the appropriate statistical methodology (Steel, *et al.*, 1997)

An empirical approach was adapted to define desertification risk based on the type of environmentally sensitive area (ESA) to desertification (Kosmas *et al*., 1999) and on the main process or cause of degradation identified for each site such as: (a) degree of soil erosion, (b) soil electrical conductivity for the process of soil salinization. The type of ESA has been used to characterize the present stage of land degradation, in combination with the degree of soil erosion or water stress, etc., the risk of land desertification has been assessed. For example, an area characterized as fragile to desertification will be subjected to high desertification risk under very severe erosion or low risk under slight erosion. The degree of soil erosion has been mainly considered for hilly areas, while soil electrical conductivity has been used mainly in plain areas where the main process of desertification is soil salinization. Soil water storage capacity has been considered for hilly or plain areas where water stress has been defined as the major process of land degradation and desertification. Desertification risk, in areas where overgrazing or forest fires have been identified as major causes of land degradation, has been assessed based on the degree of soil erosion.

After creating the appropriate data basis, the obtained data were analyzed in order to define: (a) the interrelationships between various indicators, and (b) the effectiveness of each indicator to evaluate the sensitivity to desertification. A forward stepwise statistical analysis was conducted for all indicators corresponding to each process or cause of land degradation and the sensitivity of each indicator to desertification risk was identified. The analysis was conducted with dependent variable the desertification risk and independent variables all the indicators assigned for each process or cause using the following linear model (Steel, *et al.*, 1997):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots\cdots + \beta_\kappa X_\kappa$$

Where: Y is the dependent variable of desertification risk, β_0 is the Y intercept, β_1, β_2, etc. are slopes of the regression plane, and X1, X2, etc. are the independent variables of the indicators used. In each pair of indictors which was proved to have high correlation, one of them was usually excluded from the analysis of variance. As an example of the derived algorithms for assessing desertification risk index (DRI) in areas where the main process of land degradation is water stress follows:

DRI = 0.316xRS + 0.194xGE + 0.194xSG - 0.110xDA - 0.107xIS - 0.139xFR = 0.194xSEC - 0.442xRLA + 0.028xWS + 0.313xTC + 0.108xPD + 1.096xPI.

Where: RS is the rain seasonality, GE is the rate of ground water exploitation, SG is the slope gradient (%), DA is the rate of deforested area (% per year), IS is the rate of impervious surface area (ha per 10 km^2 of territorial surface per 10 years), FR is the fire frequency (years), SEC is the soil erosion control (area protected per total area, %), RLA is the rate of land abandonment (ha per 10 years per 10 km^2) , WS is the water scarcity (water available supply per capita / water consumption per capita during the last 10 years), TC is the tourism change (number of overnight stays in a specific destination over one year / average overnight stays in the last 10 years, %), PD is the population density (people per km^2), PI is the policy implementation of existing regulations for environmental protection.

3. Applicability of the developed methodology

The derived methodology on assessing land desertification risk using indicators can be applied in the following land uses: (a) cropland, (b) grazing land, and (c) forested areas. In these land uses, the following land degradation processes or causes have been considered in the proposed methodology:

- Soil erosion by water or tillage
- Soil salinization
- Water stress
- Overgrazing
- Forest fires.

The user of the methodology has to select first land use and second the most important land degradation processes or causes. It is more convenient to apply the methodology separately for each land degradation process or cause.

Table 1 shows, the most important indicators for each land use, land degradation process or cause. The number of indicators affecting desertification risk in areas where soil erosion is the most important degradation process was reduced from 49 to 17, 15, and 11 indicators in cropland, pastures, and forests, respectively. The number of candidate indicators assigned in areas affected by tillage erosion was 16, reduced to 10. The impact of soil salinization on land degradation and desertification can be assess by using 9 indicators from 27 analyzed. The greatest number of candidate indicators described was for water stress, which was reduced from 50 to 12 effective indicators (Table 1). The candidate indicators identified for the causes overgrazing and forest fires were substantially reduced from 44 and 29 to 16 and 8, respectively.

Table 1. Number of candidate indicators used for the analysis and number of effective indicators for each process or cause of land degradation and desertification

a/a	Degradation process	Major land use	Number of candidate indicators	Number of effective indicators
1	Soil erosion by water runoff	Agriculture	49	17
		Pastures and shrubland	49	15
		Forests	49	11
2	Tillage erosion	Agriculture	16	10
3	Soil salinization	Agriculture, natural vegetation	27	9
4	Water stress	Agriculture, natural vegetation	50	12
5	Overgrazing	Natural vegetation, agriculture	44	16
6	Forest fires	Natural vegetation	29	8

Table 2. shows the list of important indicators defined for each land degradation process or cause. Among the most important indicators identified as affecting land degradation and desertification risk are rain seasonality, plant cover, rate of land abandonment, land use intensity, and policy implementation.

Table 2. Important indicators affecting the various processes or causes of land degradation and desertification (symbol ♦ means important indicator)

A/A	Indicators	Land degradation process or cause							
		Water erosion			Tillage erosion	Soil salinization	Water stress	Over-grazing	Forest fires
		Cropland	Pasture	Forests					
		Indicators related to physical environment							
1	Annual rainfall	♦							
2	Potential evapotranspiration					♦			
3	Aridity index			♦				♦	
4	Rainfall seasonality	♦	♦	♦			♦	♦	♦
5	Rainfall erosivity							♦	
6	Water quality					♦			
7	Water scarcity						♦		
8	Flooding frequency					♦			
9	Soil drainage					♦		♦	
10	Parent material				♦				
11	Slope aspect	♦							
12	Slope gradient	♦			♦		♦		
13	Soil texture		♦						
14	Soil depth	♦	♦	♦					
15	Organic matter surface horizon	♦			♦				
16	Exposure of rock outcrops							♦	
17	Fire risk			♦					
18	Distance from seashore					♦			
		Indicators related to socio-economics							
19	Farm size							♦	
20	Farm ownership					♦			
21	Land fragmentation							♦	♦
22	Population density			♦		♦	♦		
23	Old age index								♦
24	Population growth rate								♦
25	Tourism intensity		♦						
26	Tourism change						♦		
27	Parallel employment	♦							
28	Farm subsidies	♦	♦						
		Indicators related to land management							
29	Major land use				♦				♦

30	Vegetation cover type	♦		♦					
31	Plant cover	♦	♦	♦				♦	
32	Land use period		♦					♦	
33	Land use intensity	♦	♦		♦				♦
34	Mechanization index				♦				
35	Tillage operations	♦			♦				
36	Tillage direction		♦						
37	Tillage depth		♦		♦				
38	Grazing control		♦					♦	♦
39	Grazing intensity			♦				♦	
40	Deforested area						♦		
41	Fire frequency						♦	♦	
42	Burned area		♦	♦				♦	
43	Fire protection			♦				♦	♦
44	Sustainable farming	♦							
45	Soil erosion control						♦	♦	
46	Soil water conservation		♦						
47	% irrigation of arable land					♦			
48	Groundwater exploitation					♦	♦		
49	Runoff water storage	♦	♦						
50	Terracing	♦			♦				
51	Land abandonment	♦		♦			♦	♦	
52	Policy implementation	♦	♦		♦		♦		
53	Impervious surface area						♦		

In order to apply the derived methodology, it is important to have data for all the assigned indicators for each process or cause of land degradation. In case that data are missed for some indicators, then average values of the corresponding indicators are recommended to be selected. A similar methodology for assessing land desertification risk has been developed during the execution of the EU research project DESERTLINKS. This methodology has limited applications since the collected data for the various indicators were drawn only from one area (Greece) with no significant variations especially in the indictors related to socio-economic characteristics. The present DESIRE methodology has developed using data from a wide range of physical environment and socio-economic characteristics.

4. Description of important indicators affecting land desertification risk

In the following discussion, the various indicators are classified as following: (a) indicators related to physical environment, (b) indicators related to socio-economics, and (c) indicators related to land management. For each indicator the following characteristics are given: (a) a simple definition, (b) the importance on land degradation and desertification including distribution in the study field sites and relations with other indicators, and (c) sources of data availability or methods used to measure.

4.1 Indicators related to physical environment

Annual rainfall

Definition
Annual rainfall is the mean annual precipitation including rain, snow, hail and sleet.

Importance on land degradation process
Rainfall, amount and distribution, is the major factor affecting biomass production, and also soil erosion rates on hilly lands. Arid, semi-arid, and dry sub-humid climatic conditions are characterized by seasonal climate and specific conditions which makes the existing ecosystems vulnerable to land degradation and desertification. The uneven annual and inter-annual distribution of rainfall, and the occurrence of extreme events are the main climatic factors contributing to land degradation. The prevailing weather conditions during the growing period of plants may be so adverse that the soils remain bare, creating favourable conditions for overland flow and erosion.

Studies conducted during the execution of the EU research projects MEDALUS have shown that soil erosion in hilly areas of the Mediterranean region with shrubby vegetation increases as annual rainfall decreases from 650 mm to 300 mm. The increase in soil erosion is attributed to the decreasing biomass production accompanied with lower vegetation cover. The existing trend during the last decades in the study sites of the DESIRE project is a decrease in annual rainfall and an increase of number of stormy events. Also, predictions using models shows a climate warming is accompanied by lower amounts rainfall and higher rates of evapotranspiration. Under such conditions soil moisture content available for plant growth will decrease significantly, causing lower biomass production, decrease in soil organic matter content, deterioration of soil aggregate stability, decrease in soil infiltration rates, and increase in soil erosion rates and in desertification risk (Fig. 1).

Fig. 1. Examples of sloping areas with semi-arid climatic conditions subjected to severe soil erosion and land degradation (left photo Crete-Greece, right photo Rabat-Morocco)

The analysis of 1582 study field sites from 17 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America have shown that annual rainfall is statistically important related to land degradation and desertification in cropland. Desertification risk becomes higher as annual rainfall decreases, especially in annual rainfall values lower than 650 mm.

The transport and distribution of salts within a landscape and in a soil profile are affected by the prevailing water balance conditions, and the depth of the ground water. A general decrease in precipitation and/or an increase in evapotranspiration will cause an increase of the areas affected by soil salinization, especially of the lowlands around the Mediterranean region. Soil salinity is considered as another important process of land degradation and desertification affecting mainly plain areas. Soil salinization problems will be most severe in areas receiving annual rainfall ranging from 300-600 mm. Areas with high amounts of annual rainfall are subjected to low water scarcity, low salinization, and desertification risk. On the contrary, in field sites located in areas with high aridity indices accompanied with high evapotranspiration rates and long rain seasonality, water scarcity has been mainly characterized as high with subsequent high effects on soil salinization risk. Furthermore, areas with high annual rainfall (greater than 600 mm) have usually good quality of ground water.

Annual rainfall and rain seasonality greatly affects the rate of burned area in pastures. As rainfall decreases, the rate of burned area increases. Low amounts of rainfall combined with high rainfall seasonality favours extensive fires in the above mentioned study field sites. The study field sites which are mainly located in semi-arid climatic conditions have adequate annual biomass production derived during spring period which is getting dry during the summer period favouring forest fires. Also, annual rainfall affects grazing intensity especially in forested areas. Under such conditions the understory vegetation growth is restricted, reducing grazing intensity.

Annual rainfall affects rate of burned area in overgrazed lands. The rate of burned area is mainly characterized as moderate to high in field sites located in areas with high evapotranspiration rates and low annual rainfall. The occurrence of forest fires under such climatic conditions is expected to be high in grazing lands. Furthermore, fire protection is mainly characterized as low in areas characterized by high annual air temperature and low annual rainfall. Such climate conditions favour the production of dry biomass of high flammability and combustion promoting ignition of forest fires during the dry period. Finally, areas with moderate annual rainfall are mainly subjected to high rates of land abandonment.

Measuring the indicator

Data for this indicator can been provided form the National and Local Meteorological Survives and for meteorological stations located in or nearby to the study area. Mean annual rainfall of a period of at least 30 years is required for assessing land desertification risk. The following classes of annual rainfall have been distinguished based on experimental data on soil erosion obtained in research projects on desertification: (a) low annual rainfall <280 mm, (b) moderate annual rainfall 280-650 mm, (c) high annual rainfall 650-1000 mm, and (d) very high annual rainfall >1000 mm.

Potential evapotranspiration

Definition

Potential evapotranspiration is the amount water evaporating if a sufficient water source is available. Potential evapotranspiration (ETo) includes both the potential evaporation from the soil surface and the transpiration by plants. The rate of ETo depends on the existing climatic conditions including radiation energy of the sun, wind speed, air temperature, vapor deficit of the air, and air temperature. ETo values are obtained when the soil water available for this process is non-limiting. In case that soil water availability is limited then the actual evapotranspiration (ETa) occurs receiving values lower than ETo.

Importance on land degradation process

The ratio of actual versus potential evapotranspiration (ETa/ETo) can be used as an important indicator for assessing aridity of an area. Another important climate index of the average water available in the soil is the ratio between mean annual precipitation (P) and mean annual evapotranspiration (ETo). These are critical environmental factors affecting the evolution of natural vegetation. Rainfall and soil water availability in comparison with ETo values can be used as determinant factors for assessing desertification vulnerability of an area.

The analysis of data collected from 1399 field sites in 15 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America has shown that this indicator is especially important for assessing desertification risk in areas affected by soil salinization. Areas under high evapotranspiration rates (ETo>1200 mm per year) are more vulnerable to salinization and desertification. In addition, high evapotranspiration rates accompanied with high aridity indices affects water scarcity with subsequent high effects on soil salinization risk.

The analysis of the obtained data shows that tillage operations are affected by ETo in agricultural areas. Field sites characterized by high evapotranspiration rates remain mainly uncultivated under dry climatic conditions since soils conditions are not favourable for growing crops. In addition, policy implementation is characterized mainly as low in field sites with high annual evapotranspiration rates. Agricultural areas under high evapotranspiration rates are usually less developed and more remote in which policy implementation is usually low.

Annual evapotranspiration rate affects grazing control in pastures. As ETo increases land productivity is reduced accompanied by lack of measures for soil erosion control. Furthermore, grazing intensity is mainly characterized as low in areas with high annual potential evapotranspiration in forested areas (ETo>1200 mm). Policy implementation is usually characterized as moderate to low in field sites located in areas of high annual evapotranspiration rates. Furthermore, the rate of burned area in overgrazed areas is mainly defined as moderate to high in field sites located in areas characterized with high evapotranspiration rates and low annual rainfall. The occurrence of forest fires under such climatic conditions is expected to be high.

Measuring the indicator

The potential evapotranspiration rate can be estimated by various methods. The Penman-Monteith method as modified by Allen (1986) has been used in this research project. The following meteorological data are required for a period of at least 20 years: air temperature, relative humidity, wind speed, and solar radiation. Data for assessing this indicator can been provided form the National and Local Meteorological Survives and for meteorological stations located in or nearby to the field site for analysis (Fig. 2). The following classes of potential evapotranspiration have been considered in this study: (a) very low, ETo<500 mm, (b) low, ETo ranging from 500-800 mm, (c) moderate, ETo ranging from 800-1200 mm, (d) high, ETo ranging from 1200-1500 mm, and (e) very high, ETo>1500 mm.

Fig.2. Automatic meteorological stations for collecting meteorological data for calculating evapotranspiration

Aridity index

Definition

Aridity index classifies the type of climate in relation to water availability. It is an index of the average water available in the soil, defined as the ratio between mean annual precipitation and mean annual evapotranspiration .

Importance on land degradation process

The atmospheric conditions that characterize a desert climate are those that create large water deficits, that is, potential evapotranspiration is much greater than the precipitation. The higher the aridity index of a region the greater the water resources variability and scarcity in time, the more vulnerable the area to desertification (Fig. 3). Soil loss and drought indices can be used to assess the soil and water resources vulnerability and consequently to formulation of strategies compatible with the resources available in a given area.

Data on aridity index for the DESIRE project were collected from 1399 study field sites in 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America (Fig. 3). The most important class of aridity index is high (BGI= 25-150), covering 26.7% of the study field sites. The next important class is the driest (BGI>150), covering 23.3% of the study field sites. The wetter climatic conditions with BGI<50, and 50-75 have been defined in 23.2%, and 11.9% of the study field sites, respectively. Intermediate conditions of aridity index (BGI = 75-100, BGI =100-125) have been found in 6.9% and 8.2% of the study field sites, respectively.

Fig. 3: Area subjected to extremely high aridity indices affecting grazing land in Crete-Greece (left) and in south Portugal (left)

The obtained data have shown that this indicator is especially important for assessing desertification risk in forested and overgrazed areas. Field sites located in areas of high aridity index (BG aridity index>120) are usually subjected to moderate or high desertification risk.

Aridity index is related to water scarcity in an area. Field sites located in areas with high aridity indices accompanied with high evapotranspiration rates and long rain seasonality, water scarcity are mainly characterized as high with subsequent high effects on soil salinization risk. Water quality has been found in the study sites of the DESIRE project negatively related with aridity index. This is something exceptional, but it can be probably explained if other social and land management characteristics of the study sites are considered. Furthermore, in areas with high aridity indices and high rain seasonality, land use intensity is mainly characterized as moderate or low reducing desertification risk.

Under high aridity indices and high rain seasonality, soil erosion control measures are mainly characterized as moderate to adequate. In such adverse climatic conditions plant growth is highly restricted and grazing of the land is not so profitable discouraging farmers to use it.

Measuring the indicator

Aridity index can be defined as the ratio between mean annual precipitation (P) and mean annual evapotranspiration (ETo) by the Bagnouls-Gaussen index (BGI) using the following equation:

$$BGI = \sum_{i=1}^{n} (2ti - Pi)*k$$

Where: ti is the mean air temperature for month i in 0°C, Pi is the total precipitation for month i in mm; and k represents the proportion of month during which 2ti - Pi >0. Data for assessing this indicator can been provided form the National and Local Meteorological Survives and for meteorological stations located in or nearby to the study site. The following classes are distinguished for this indicator: (a) very low aridity, BGI<50, (b) low aridity, BGI ranging from 50-75, (c) moderate aridity, BGI ranging from 75-100, (d) high aridity, BGI ranging from 100-125, (e) very high aridity, BGI ranging from 125=150, and (f) extremely dry aridity, BGI>150.

Rainfall seasonality

Definition

Rainfall seasonality is related to the distribution of rainfall during a normal year.

Importance on land degradation process

An irregular distribution of rainfall means that most of the rainfall occurs in the period from October to May in area with semi-arid climatic conditions. Rainfall seasonality affects soil erosion, plant species composition and growth rate. Very high inter-annual rainfall variability causes periods of particularly long drought and sudden and high-intensity rainfall. Under long rainfall seasonality, rainfed vegetation growing in relatively dry badlands provides poorly plant cover inadequately protecting soil from erosion, leading to desertification (Fig. 4). Reduced biomass production, in turn, directly affects the organic matter content of the soil and the aggregation and stability of the surface horizon against erosion. In addition reduced vegetation growth is followed by a net decrease in carbon dioxide assimilation by the plants, and thus it greatly contributes to climate change at local and regional scale, and to desertification in a broad sense. However, the existing vegetation under arid and semi-arid climatic conditions presents a great capacity of adaptation and resistance to dry conditions, and many species can survive many months through prolonged droughts with soil moisture content below the theoretical wilting point protecting extensive areas from desertification.

Data for this indicator were calculated for 1399 field sites of the DESIRE project, corresponding to 17 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Based on the existing data, the prevailing climatic conditions are characterized as marked seasonal with long dry season, covering 37.9% of the study field sites. The following important class of rainfall seasonality is the rather seasonal with a short drier season measured, covering 29.1% of the study field sites. Climatic conditions with precipitation spread throughout the year but with a definite wetter season has been found in 16.4% of the study field sites. Areas characterized as seasonal with respect to rainfall distribution have been defined in 15.8% of the study field sites.

 

Fig. 4. Typical examples of areas with rather seasonal precipitation and short drier season (Eskisehir Plain-Turkey, left), and extreme rainfall seasonality with most precipitation occurring in a period less than 3 months (Santiago Island-Cape Verde, right)

Among the most important climate indicators analyzed in the DESIRE project is rain seasonality, affecting the processes of water erosion in all major land uses, water stress, and the causes of overgrazing, and forest fires. Rain seasonality does not show the same trend in all the processes and causes. The conducted study in the above areas has shown that field sites located in agricultural areas with long dry season (rain seasonality index >0.80), the assessed desertification risk due to soil erosion is moderate to low. In the opposite, field sites located in pastures and forests desertification risk is moderate to high under long rain seasonality. Under long rain seasonality climate characteristics, farmers used to restrict cultivation of the land leaving crop residues on the soil surface restricting soil erosion. In the opposite, under long rain seasonality field sites in pastures or forested areas usually subjected to overgrazing or are more vulnerable to forest fires supporting lower plant cover and generating higher erosion rates. In addition, field sites located in areas where the main causes are overgrazing, water stress, and forest fires are more vulnerable to land degradation and desertification under long rain seasonality.

Rain seasonality is related to tillage operations in cropland. Tillage operations in the study field sites are negatively affected by rain seasonality. Field sites were mainly uncultivated under long rain seasonality values since farmers avoid to cultivate the land under adverse climatic conditions.

Rain seasonality is related to grazing control, rate of burned area, and soil erosion control measures in pastures. Under long periods of drought, grazing control is not easily achieved since the produced palatable biomass is not adequate to feed even a medium number of grazing animals. F urthermore, low amounts of rainfall combined with long rain seasonality favours extensive fires. The conducted study in this project was in field sites mainly located in semi-arid climatic conditions, where adequate annual biomass production is produced during the spring period favouring fires during the dry period. In addition, under long rain seasonality, soil erosion control measures are mainly characterized as moderate to adequate. Under such adverse climatic conditions, plant growth is highly restricted and grazing of the land is not profitable discouraging farmers to use it.

Important land management indicators in forested areas affected by rain seasonality are grazing intensity, runoff water storage, and policy implementation. Grazing intensity is mainly characterized as high under high rainfall seasonality index. Furthermore, forested areas with moderate to high rain seasonality indices (SIi.>0.60) are subjected to moderate or adequate runoff water storage actions. In addition, policy implementation is mainly characterized as moderate to adequate under long rain seasonality indices.

Fire protection measures in areas where the main cause of land degradation is forest fires are usually inadequate under long rain seasonality. Also, in these areas under long rain seasonality land abandonment rates are mainly low. These trends of rate of land abandonment may be attributed both to high rates of land abandonment in previous decades resulting in low rates in the last decades in the study areas.

Measuring the indicator

The rainfall seasonality can be estimated by the Seasonality Index (SIi) (derived by Walsh and Lawler (1981). The following equation is used for calculating the SI:

$$SIi = \frac{1}{Ri} \sum_{n=1}^{n=12} \left| Xin - \frac{Ri}{12} \right|$$

Where Ri is the total annual precipitation for the particular year under study and Xin is the actual monthly precipitation for month n**.** The season rainfall/total rainfall (%) index takes values from 0 to 100%. The statistical theoretic "normal" value for each season is 25%. The monthly rainfall/total rainfall (%) index has an equal distribution approximately 8% per each month. The bigger the difference from this value, the highest the rain seasonality. The precipitation regime then has been characterized using the classes of SIi in the following Table.

SIi	Precipitation regime
<0.19	Precipitation spread throughout the year
0.20-0.39	Precipitation spread throughout the year, but with a definite wetter season
0.40-0.59	Rather seasonal with a short drier season
0.60-0.79	Seasonal
0.80-0.99	Marked seasonal with a long dry season
1.00-1.19	Most precipitation in <3 months

Data for assessing this indicator can been provided form the National and Local Meteorological Survives and for meteorological stations located in or nearby to the study area.

Rainfall erosivity

Definition

Rainfall erosivity is a climatic factor which can be determined from local rainfall data.

Importance on land degradation process

Rainfall erosivity is highly related to soil loss. High rain erosivity indicates greater erosive capacity of the overland water flow. Soil erosion by running water occurs where the intensity and duration of rainstorms exceeds the capacity of the soil to infiltrate the rain. Where rainfalls are intense, it is particularly urgent to adopt conservation and management techniques to protect the soil during the rainy season. Rainfall erosivity depends primarily on rainfall intensity and amount.

Data on rain erosivity for the DESIRE project have been collected in 948 study field sites, corresponding to 12 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of rain erosivity in the majority of the study field sites is very low to low, covering 47.0%, and 28.3%, respectively, of the study field sites. High or very high rainfall erosivity values have been estimated in 8.5%, and 15.3% of the study field sites.

Rain erosivity is defined as important indicator only for field sites located in areas subjected to overgrazing. Furthermore, rain erosivity affects tillage operations in cropland by reducing them. Also soil erosion control measures are affected by rain erosivity in pastures. Under high rain erosivity values, soil erosion control in pastures have been mainly characterized as low to moderate.

Measuring the indicator

Rain erosivity can be calculated by the modified version of the Fournier index (FI) with the following equation:

$$FI = \sum_{i=1}^{12} Pi^2 / p$$

Where Pi is the precipitation total in month i, and p is the mean annual precipitation. The Fournier index can been classified as in the following Table. Data for assessing this indicator can been provided form the National and Local Meteorological Survives and for meteorological stations located in or nearby to the study site.

Class description	Fournier index (FI) range
Very low	< 60
Low	60–90
Moderate	91-120
High	121-160
Very high	>160

Water quality

Definition

Water quality is related to the concentration of soluble salts such as NaCl, KCl, heavy metals, fertilizers or pesticides , etc.

Importance on land degradation process

In the last four decades, favourable soil and climatic conditions, new technologies of farming, the increasing demands for foods and the availability of ground or surface water has resulted in intensive farming of the lowlands as well as hilly lands. Furthermore, the development of fast transportation means and the availability of cheap holiday-offers have encouraged the expansion of domestic and international mass tourism over the last 30 years. Under such conditions water quality is under high risk of deterioration.

Water resources are under severe physical, social, economical and environmental stresses, compounding to the water uses. The need for intensification of agriculture to meet the high cost of production, the use of poor quality of water (sea water intrusion), the lack of drainage system are in many cases responsible for soil degradation resulting from water logging, salinization, alkalinization, and soil erosion. Soil salinization resulting from poor quality of water is one of the key processes that could lead to desertification especially the plain areas along the coast. It is a growing problem all over the world and affects million of hectares in Europe. Agriculture plays a major role in by causing high water consumption and water chemical degradation but at the same time the economic sector is facing the strongest impacts.

The criteria for good water quality for irrigation in agriculture are: low salinity, and low ratio of Na^+ to Ca^{2+} Mg^{2+}. The index usually used to characterize the quality of irrigation water with respect to its influence on the exchangeable sodium percentage (soil sodification) is the sodium adsorption ratio (SAR) which is defined as follows:

$$\mathbf{SAR = [Na^+] / \{([Ca^{2+}] + [Mg^{2+}])/2^{**} (1/2).}$$

This is the ratio of the sodium ion (Na^+) concentration to the square root of the average concentration of the divalent calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions.

One main reason of increasing amounts of salts in aquifers is sea-water intrusion due to over-exploitation resulting from increasing water demands for multiple uses. The use of poor quality of water for irrigation and under certain soil and climatic conditions soil salinization occurs (Fig. 5). Increasing salt levels in the top soil layers can affect plant growth and productivity. High concentrations of various salts (e.g., sodium chloride, magnesium and calcium sulphates and bicarbonates) affect plants growth both directly by their toxicity and indirectly by increasing osmotic potential and lowering root water uptake. In dry climates continuous salt accumulation could lead to desertification, while in humid or sub-humid climates moderate or severe salinization may occur periodically.

Water quality characteristics used for irrigation have been collected in 361 field sites, corresponding to 5 study sites located in Mediterranean Europe, eastern Europe, and Africa. High quality of irrigation water (electrical conductivity <400 μS) has been found in 46.8% of the study field sites. Low to very low quality of irrigation water (800-1500, >1500 μS) has been recorded in 25.8% and 18.3% of the study field sites, respectively. Moderate quality of irrigation water (electrical conductivity 400-800 μS) has been found in 9.1% of the study field sites.

Fig. 5. Salt affected areas due to poor quality of ground water causing soil salinization resulting from high rates of evaporation in Botswana (left) and Greece (right)

Water quality is an important indicator for areas in which the main process of land degradation is soil salinization. As it is expected, ground or surface water of low quality used for irrigation especially under semi-arid climatic conditions favours salt concentration in soils and soil salinization. Furthermore, areas characterized by low quantities of available water, accompanied by low water quality, are subjected to high water scarcity and high soil salinization risk. Furthermore, water quality is associated with plant cover. The availability of water resources of good quality contribute to sufficient vegetation growth promoting higher plant cover percentages.

Water quality and water scarcity are usually two co-existing indicators highly affecting soil salinization. The analysis of the data collected in the study field sites have shown that water quality has been affected by indicators related to climate, soil, vegetation, water, water use, tourism, institutional, and social characteristics (Fig. 6). The most important climate indicators affecting water quality were annual rainfall, aridity index, and rain seasonality. Water quality is positively related to annual rainfall. Areas with high annual rainfall had good quality of ground water. Water quality is negatively related with aridity index. This is something exceptional, but it can be probably explained if other social and land management characteristics of the study sites are considered. Water quality is negatively related to rain seasonality. Field sites located in areas with high rain seasonality have mainly poor quality of water.

Important indicators related to water and water use affecting water quality in the study field sites are water quantity, water consumption/water demands, and water scarcity. Field sites located in areas with low quantities of available water resources have generally poor quality of water. In addition, areas with high ratio of water consumption/water demands have low quality of water. Furthermore, field sites located in areas of high water scarcity have generally moderate to poor water quality. Of course, under the conditions of policy implementation of existing regulations on water resources protection, water quality is mainly characterized as moderate to high.

Even though soil indicators are of local importance, as they characterize mainly the study field sites, the analysis of the data have shown that areas with medium to moderately fine-textured soils of high water storage capacity have high water quality.

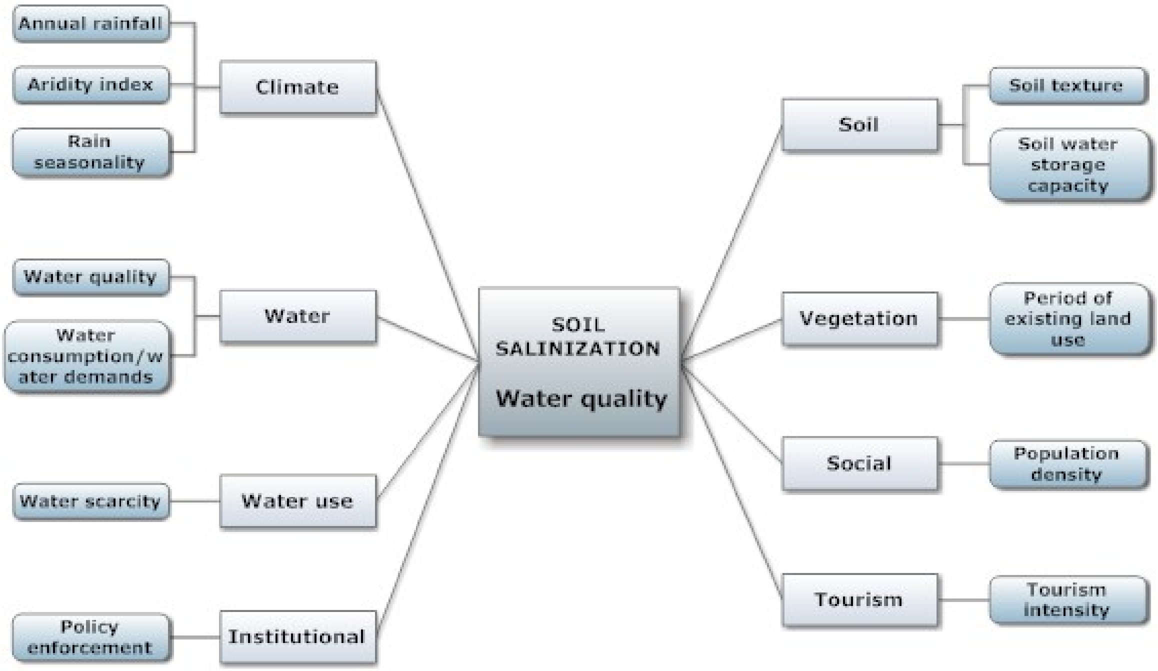

Fig. 6. Important indicators related to water quality in field sites where soil salinization was a dominant process of land desertification

Concerning vegetation characteristics, only the period of existing land use is related to water quality. Areas in which land use has changed frequently are mainly characterized by poor quality of water. This can be explained in relation to land use intensity. Land use change occurs frequently in areas intensively cultivated which means high amounts of water are used for irrigation aggravating water quality.

Water quality is significantly related to tourism intensity and population density of the broader areas in which the study field sites are located. Areas with high population density or high tourism intensity have good to moderate quality of water. This can be explained for the study field sites by various factors such as: (a) presence of rivers carrying high quantities of good quality water accompanied with adequate enrichment of ground water, (b) expansion of necessary infrastructure for providing adequate quantities of good quality of remote water to satisfy the needs of local population including tourists during the summer period.

Measuring the indicator

Water quality can be assessed by measuring electrical conductivity of the water using an electrical conductivity meter. The following classes of electrical conductivity (EC) in μS can be used: (a) good quality, EC<400 μS, (b) moderate quality, EC = 400-800 μS, (c) low quality, EC = 800-1500 μS, and (d) very low quality, EC >1500 μS.

Water scarcity

Definition

This indicator assesses the change in the difference between the water availability per capita and the water consumption per capita during a certain period.

Importance on land degradation process

The change in water scarcity can be affected both by the increased consumption and/or decrease in supply. Scarcity, by definition means diminishing resources (for example due to climate change) and/or a pressure on the supply of available resources from an increasing demand (Fig. 7). The water consumption per capita includes the total demands for drinking water, process water, irrigation water and cooling water by all economic sectors, expressed in cubic meters per year per capita. The World Health Organization uses the level of 1,000-2,000 cubic meters per person per year to identify risk on water scarcity. When these values drop below 1,000 cubic meters per person per year, then areas are considered as experiencing water scarcity.

Fig. 7. Water resources used for human consumption (left) but under dry climatic conditions water scarcity (right) becomes a major issue

Data for water scarcity have been collected in 656 study field sites, corresponding to 10 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Water scarcity has been characterized as high in the majority of the cases, covering 54.3% of the study sites. The next important class of water scarcity is low, covering 19.5% of the study field sites. Moderate water scarcity class has been defined in 13.6% of the study field sites. No water scarcity has been defined only in 9.5% of the study sites.

Water scarcity is especially important indicator for assessing desertification risk in areas where the main cause of land degradation is water stress and soil salinization. Areas under high water scarcity are subjected to higher desertification risk.

The analysis of the data have shown that water scarcity is negatively related to soil erosion control. Field sites located in areas characterized by high water scarcity are usually overgrazed without any measures for soil erosion control.

Water scarcity is related to rate of burned area in pastures overgrazed. Areas under high water scarcity are usually subjected to low rates of burned area. Probably people living in such areas are more aware of the importance of environmental protection fighting against forest fires which greatly affects water availability.

An important water use indicator affecting land abandonment is water scarcity. Areas characterized by low water scarcity are predominately subjected to high rates of land abandonment.

Water scarcity is related to various indicators in areas affected by salinization. Such indicators are related to climate, water, water runoff, and tourism characteristics (Fig. 8). Among the most important climate indicators affecting water scarcity are annual rainfall, aridity index, annual potential evapotranspiration and rain seasonality. Areas with high amounts of annual rainfall are mainly characterized as subjected to low water scarcity, low salinization and desertification risk. On the contrary, areas with high aridity indices accompanied with high evapotranspiration rates and long rain seasonality are subjected to high water scarcity with subsequent high impacts on soil salinization risk.

Important water indicators affecting water scarcity in areas affected by soil salinization are water quality, water quantity, and water consumption/water demands. Areas characterized by low quantities of available water, accompanied by low water quality, are mainly subjected to high water scarcity and high soil salinization risk. Water scarcity is aggravated in areas where the ratio of water consumption/water demands is high. Also areas associated with watersheds of high drainage density are mainly characterized by high water scarcity.

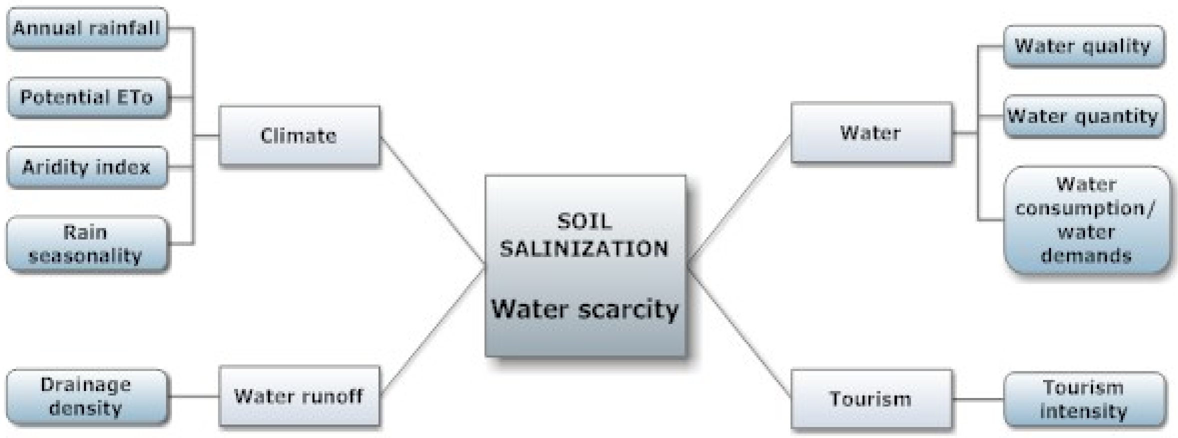

Fig. 8. Important indicators related to water scarcity in areas where important process of land desertification is soil salinization

Tourism intensity is affecting water scarcity in an area. Areas with high tourism intensity require high quantities of water per capita inducing water scarcity in the broad area. Under such conditions, water is allocated for consumption accompanied with low priority for the amount and the quality of water allocated for irrigation, enhancing problems of soil salinization in irrigated land. Furthermore, areas under high water scarcity have generally moderate to poor water quality.

Measuring the indicator

This indicator can be assessed by contacting the local water resources management authorities. Water scarcity (WS) is defined for this project as the ratio of water availability per capita (WAC) divided by the water consumption per capita (WCC) per year for the period of the past ten years. The following 5 classes are identified: (a) no water scarcity, WS>2; (b) low, WS = 1.5-2; (c) moderate, WS = 1.5-1.0; (d) high, WS = 0.5-1.0, and (e) very high WS<0.5.

Flooding frequency

Definition

Flood frequency is the probability of occurrence of damaging floods in a piece of land during the year.

Importance on land degradation process

Floods are a function of climate variability (especially rainfall patterns), basin hydrology (including river bed shape), and intensity of drainage and debit flow as well as soil characteristics, particularly water holding capacity of soils. Flooding can be the impact of extensive deforestation, widespread forest fires, overgrazing, collapse of terraces and soil conservation structures accelerating surface water runoff and flooding intensity on t he lowlands. High amount of water runoff and sediment loss from the upper sloping land represents a serious treat for flooding of low land, siltation of water courses, damages to crops and infrastructures, and filling of valleys and reservoirs (Fig. 9). Coastal zones are particularly prone to such devastating processes. Littoralisation accentuates the process of increased surface water runoff mainly through the artificial infrastructure cover that reduces water infiltration into the soil and disturbs the natural ecosystem.

Fig. 9. Areas with high frequency of flooding causing damage to the growing crops

Data on flooding frequency has been collected in 258 field sites, corresponding to 5 study sites, located in Mediterranean Europe, and eastern Europe. The number of study sites is rather limited since this indicator has been described only in areas in which soil salinization is the main process of land degradation and desertification. The dominant class of flooding frequency is very rare or never known in this sites, covering 45.0% of the study field sites. The next important class is frequent flooding (once every 1-2 years), covering 21.7% of the study field sites. Very rare flooding frequency (once every 10 years) has been recorded in 15.1% of the study field sites. Frequent flooding (once every 1-2 years) is found in 11.2% of the study field sites. Finally, rare frequency of flooding (once every 6-10 years) has been mainly recorded in 6.6% of the total field sites.

As it was mentioned above, flooding frequency is an important indicator for assessing desertification risk in areas affected by soil salinization. This indicator is negatively related to soil salinization. Areas subjected to frequent or infrequent flooding are subjected to lower salinization risk since water free of salts is percolated into the soil leaching excess of salts. However, areas located in the lower part of an alluvial plain or in a river delta are usually subjected to very frequent flooding, while they are highly affected by salinization. Such field sites are very limited in this study.

Measuring the indicator
Flooding frequency data can be obtained from the local administrations, local farmers or by personal estimation. The following classes of flooding frequency are used for the purpose of this project: (a) never flooding, (b) very rare: once every 10 years, (c) rare: once every 6-10 years, (d) infrequent: once every 3-5 years, and (e) frequent: every 1-2 years.

Soil drainage

Definition
Soil drainage is related to how rapidly excess water leaves the soil by runoff or internal drainage. Internal drainage is referred to downward movement of water into the soil profile and it affects the redistribute of soil water to lower depths of the profile, increasing the water content in the subsoil.

Importance on land degradation process
Soil drainage has been described in 446 field sites, corresponding to 6 study sites located in Mediterranean Europe, eastern Europe, and Africa. Soil drained conditions are related to physiographic and topographic conditions. Soils on slopping areas are usually well drained. In the opposite, soils found in plain areas located at the lower concave physiographic positions close to water bodies or having a ground water table close to the soil surface are usually poorly drained. Based on these data, well drained soils are dominant covering 40.7% of the total study field sites. The next important class identified is very poorly drained soils covering 33.0% of the study field sites. Poorly drained soils cover 16.1% of the study field sites.

Soil drainage is mainly related to desertification risk in areas affected by soil salinization and overgrazing. Field sites located in poorly drained soils are more vulnerable to soil salinization than in well drained soils. In the opposite, field sites located in areas subjected to overgrazing are better protected from desertification since animals can move through the area a certain period of the year when the soils are relatively dry.

Measuring the indicator
Drainage is classified in classes according to the term which generally describes the condition of how long the soil is free of saturation. For example in a well drained soil water is removed very rapidly and no occurrence of internal free water is observed. In the opposite, in a poorly drained, the soil is saturated for a long period resulting in the formation of mottles of iron and manganese in the upper 30 cm of the soil, or grey colors of reducing conditions, with a permanent water table usually at a depth greater than 75 cm. Poor drainage is associated with soil salinization under certain conditions leading to desertification, as well as with the loss of profit from cultivated plants.

Soil drainage conditions for the purpose of the this study can been defined on the basis of the depth of hydromorphic features such as iron or manganese mottles or gray colors, and the depth of the groundwater table. The following drainage classes are distinguished:

Very well to well drained soils

Soils with any Fe or Mn mottles or gray colors at some depth greater than 100 cm from the soil surface. The soil is not wet enough near the soil surface or the soil does not remain wet during the growing period of the plants. Water is removed from the soil rapidly (Fig. 10).

Moderately well to somewhat poorly drained soils

Fe, Mn or grey mottles are present in the soil, at some depth between 30 and 100 cm from the soil surface. The soil is wet enough near the soil surface or the soil remains wet during the early growing period of the plants. Water is removed from the soil slowly.

Poorly drained soils

Mottles of Fe and Mn are present in the upper 30 cm of the soil, or grey colors of reducing conditions are present. A permanent water table usually exists at a depth greater than 75 cm. In some of these soils the ground water may reach to the surface during the wet period of the year. Water is removed from the soil so slowly that the soils are wet at shallow depth for long periods.

Very poorly drained soils

Mottles of Fe and Mn are present in the upper 30 cm of the soil, or grey colors of reducing conditions are present. A permanent water table usually exists at a depth less than 75 cm. In many of these soils the ground water may reach to the surface during the wet period of the year. Water is removed from the soil so slowly that the soils are wet at shallow depth for long periods.


Fig. 10. Example of well drained soil (left) and poorly drained soil (right)

Data on soil drainage can be obtained from various regional, national or international institutions involved in collecting and elaborating soil survey data. Also, soil drainage can be defined by digging a soil profile or making an auger hole and observing hydromorphic features such as mottles or concretions of manganese or iron, grey colors, etc. as described above.

Parent material

Definition

Parent material is considered as a soil-forming factor affecting soil properties, plant growth, soil erosion and ecosystem resilience.

Importance on land degradation process

Residual soils have specific physical and chemical characteristics closely related to the parent material. For example soils formed on limestone are usually moderately fine- to fine-textured, slow permeable, neutral to high pH values, high base saturation and high nutrient status. However, carbonate enriched soils may induce minor element deficiencies to sensitive plants. In the opposite, soils formed on acid igneous are usually medium-textured, highly permeable, low pH values, low base saturation, and low nutrient status.

Areas with soils formed on different types of parent materials exhibit various degrees of sensitivity to land degradation and desertification. For example, limestone produces shallow soils with a relatively dry moisture regime characterized by moderate erodibility and slow vegetation recovery (Fig. 11). Many areas with soils formed on limestone have been greatly degraded and decertified. Areas with soils formed on shale are normally characterized by high productivity, may supply appreciable amounts of previously stored water to the stressed plants protecting areas from desertification. On the other hand, soils formed on marl, despite their considerable depth and high productivity in normal and wet years, they are very susceptible to desertification, unable to support any annual vegetation in particularly dry years due to adverse soil physical properties. These soils frequently form a surface crust inhibiting water infiltration and increasing surface water runoff.

Fig. 11. Areas under the same climatic conditions with soils formed on marl (left) and limestone (right) subjected to different degree of desertification

This indicator has been described in 1492 study field sites, corresponding to 15 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing parent materials are sedimentary rocks such as limestone, marl, and conglomerates in 47.5% of the study sites. The next important parent material is unconsolidated deposits consisting mainly of alluvial deposits covering 31.8% of the study field sites. Acid igneous, basic igneous, and metamorphic parent materials are found in few cases with frequency of appearance 8.9%, 5.2% and 5.8%, respectively.

This indicator has been introduced in the algorithm for assessing desertification risk only in field sites where the main process of land degradation is tillage erosion. Parent material, especially in residuals soils, greatly affects soil properties such as soil texture, rock fragment content, etc. Based on the obtained data, soils formed on shale, marl, conglomerate or alluvial deposits are more vulnerable to tillage erosion than soils formed on limestone, acid igneous rocks or sandstones.

Parent material has been found as an important indicator in forested areas in which soil erosion is the main process of land desertification. Grazing intensity in forested areas is characterized as moderate to high in soils formed in conglomerates, shale, and basic igneous rocks. Soils formed in such soil parent materials are usually more productive than soils formed in limestone and acid igneous rocks. Soils formed on limestone and acid igneous rocks are usually dry for long period or highly degraded with low biomass production resulting in low grazing intensity. Also, actions for soil erosion protection such as storage of water runoff has been mainly identified in field sites in which soils have been formed on marl, basic igneous, shale, and alluvial deposits. Furthermore, policy implementation is lower on areas with soils formed in limestone, acid igneous rocks, and sandstone compared with areas with soils formed in marl, basic igneous, shale, schist, and alluvial deposits.

Measuring the indicator

Parent material has been classified in this study based on existing systems of classification. The various types of parent materials prevailing in the study sites have been grouped into the following classes according to their petrology and mineralogical composition:

Major class	Group	Type
Igneous rock	acid igneous	Granite, grano-diorite, quartz-diorite, rhyolite
		Pyroclastics
	basic igneous	Gabbro, basalt, dolerite
	ultrabasic igneous	Peridotite, pyroxenite, ironstone, serpentine
Metamorphic rock	acid metamorphic	Quartzite, gneiss
		Slate, phyllite
	Basic metamorphic	Schist, gneiss rich in ferromagnesian,
		Marble
Sedimentary rock	clastic sediments	Conglomerate,
		Sandstone,
		Siltstone, mudstone, claystone, shale
		Limestone
		Marl
Unconsolidated		Fluvial
		Lacustrine
		Marine
		Colluvial

Parent material is easy to identify in the field or can be defined by using the geological map of the area. Geological maps are available from the National Geological Institutes or other geological services.

Slope aspect

Definition

Slope aspect is defined as the orientation of the land with respect to the sun.

Importance on land degradation process

Slope aspect is considered an important factor for land degradation processes affecting the microclimatic conditions by regulating the angle and the duration in which the sun's rays strike the surface of the soil. Variation in slope aspect and elevation influence the distribution of energy, meteoric water, plant nutrients, and vegetation growth by varying the exposure of the soil to wind and precipitation and the conditions for natural drainage and soil erosion. In Mediterranean climatic conditions slopes with southern and western facing aspects are warmer and have higher evaporation rates than northern and eastern aspects. Therefore, a slower recovery of vegetation is expected on southern and western aspects, and higher erosion rates than on northern and eastern aspects. As a consequence, southern exposed slopes usually are more degraded or are more sensitive to desertification than northern exposed slopes.

This indicator has been described in 1141 field sites, corresponding to 14 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The majority of the cases measured (61.2%) are northern facing slopes or plain areas, while the rest (38.7%) are southern facing slopes. Slope aspect is an indicator especially important for land degradation and desertification in agricultural areas affected by water erosion. South-faced slopes are usually more sensitive to soil erosion due to the lower plant cover under semi-arid climatic conditions and therefore more vulnerable to desertification.

Slope aspect is related to soil erosion measures especially in forested areas studied in the DESIRE project. Actions such as runoff water storage are mainly present in field sites located in north-facing slightly to moderately sloping areas. Steep south-facing slopes are mainly characterized by the absence of runoff water storage actions. Furthermore, policy implementation is mainly characterized as low to moderate in field sites located in steep south-facing slopes. Such field sites have generally low land productivity, discouraging farmers to invest for environmental protection.

Measuring the indicator

Slope aspect can be defined by using a compass or by assessing the relative earth's surface with respect to the magnetic north (Fig. 12). The following classes are defined: (a) north-N, north-west-NW, and north-east-NE, (b) south-S, south-west-SW, and south-east-SE, and (c) plain areas.

Fig. 12. Compass for assessing the relative earth's surface with respect to the magnetic north

Slope gradient

Definition
Slope gradient refers to the angle which any part of the earth's surface makes with an horizontal datum.

Importance on land degradation process
Slope gradient greatly affects amount of surface water run-off and soil sediment loss. Soil erosion rates become acute when slope angle exceeds a c ritical value and then increases logarithmically. Studies conducted in the island of Lesvos (Greece) have shown that soil erosion was moderate or high in slope gradients greater than 12%. Slope gradient can have variable effect in different climatic zones, depending mainly on annual rainfall. Generally speaking, soil sediment loss can be estimated by the product of the amount of surface water run-off times the slope gradient times a constant related to soil surface characteristics. As the slope becomes steeper, the runoff coefficient increases, the kinetic energy and carrying capacity of surface water flow becomes greater, soil stability and slope stability decreases, and soil sediment loss increase. Therefore, slope gradient is undoubtedly considered as one of the most important determinants of soil erosion and desertification in hilly areas, when they loose their protective vegetation.

Data for this indicator were collected in 1239 field sites of the DESIRE project, corresponding to 14 study sites located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The majority of the study field sites (57.1%) have slope gradient less than 12%. Slope gradient between 12-35% has been described in 21.2% of the study sites. Steep (35-60%) to very steep (>60%) slopes were measured in 21.7 of the study field sites.

Among the most important soil indicators affecting land degradation and desertification risk in the study sites is slope gradient. This indicator had significantly contributed with high coefficient values in the algorithms for assessing desertification risk in agricultural areas affected by water erosion and tillage erosion, as well as in agricultural or grazing lands affected by water stress.

Tillage operations in agricultural areas are related to slope gradient and soil depth. As slope gradient increased, or soil depth decreased tillage operations are rather limited in the study field sites. Thus, field sites with shallow soils or steep slopes are rarely cultivated reducing desertification risk.

Slope gradient is an important indicator in pastures and forested areas. The rate of burned area is increased as slope gradient increased since steep slopes favours fast expansion of a fire but only in the upslope direction. Also, soil erosion control measures by enhancing plant cover is positively related to slope gradient in overgrazed lands. Field sites with low slope gradients are subjected to higher grazing intensity without any actions for controlling soil erosion. Furthermore, policy implementation is mainly characterized as low to moderate in field sites located in steep south-facing slopes.

Slope gradient is highly related to land use intensity in areas affected by water stress. Soils in steep slopes are usually less intensively cultivated due to some limitations in mechanization and higher water stress. Furthermore, land use intensity is related to vegetation cover type. Field sites with cereals, annual grasslands are mainly characterized by high land use intensity compared to olive groves.

Measuring the indicator

Slope gradient can be easily measured:(a) by using topographic maps, (b) in the field by using a clysimeter (Fig. 13), (c) by rough estimation. The following classes are used: (a) almost flat, slope gradient (SG) <2%, (b) gently sloping, SG = 2-6%, (c) moderately sloping, SG = 6 -12%, (d) strongly sloping, SG = 12-18%, (e) slightly steep, SG =18-25%, (f) moderately steep, SG = 25-35%, (g) steep, SG = 35-60%, and (i) very steep, SG>60%.

Soil texture

Definition

Soil texture is the relative proportion of sand, silt, and clay in a soil. Sand, silt, and clay are the 2.0 to 0.05 mm, the 0.05 to 0.002 mm and the less than 0.002 mm soil fractions, respectively.

Importance on land degradation process

Soil texture greatly affects soil drainage, water holding capacity, soil temperature, soil erosion, as well as soil fertility, and plant productivity. Clay holds more water available for plant growth than sandy soils and the presence of water considerably modifies the heat requirements of the soil. Clay soils have poor drainage of excess water and may become waterlogged. Soil texture affects soil resistance to erosion. The coarser the soil texture, the smaller the active surface area of the soil particles, and the smaller is the resistance of the soil to erosion (high soil erodibility). Soils containing high amount of silt, such as those formed on marl deposits, are sensitive to crust formation generating high surface water runoff and sediment loss.

Fig. 13. Clysimeter used for measuring slope gradient of a land surface

Soil texture has been determined in 1497 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant textural class is fine, covering 39.0% of the study field sites. The following important textural class is medium, covering 28.7% of the study field sites. Moderately fine textural class is found in 14.2% of the study field. Coarse and very coarse textural classes are found in some cases covering 4.6% and 10.6% of the study field sites, respectively. Very fine textural class is very limited, covering 2.9% of the study field sites.

Even though soil texture is an important indicator affecting soil water storage capacity and soil erodibilty, it has introduced only in the algorithm assessing desertification risk in pastures. One of the main reasons is the low variability, or the co-variance with other soil parameters such as parent material, existing in the study field sites considered in each process or cause of land degradation. In most of the cases, soil texture of the surface horizon in the study field sites was characterized as fine or medium.

Soil texture is related to policy implementation in agricultural areas. Areas with soils characterized as medium-, moderately fine-, and fine-textured with high water storage capacity, police implementation has mainly been characterized as high. Such soils usually support an adequate crop production providing a sufficient farm income with a higher possibility for investment by the farmer on land protection. Furthermore, field sites in pastures with soils of low water storage capacity or coarse-textured have low productivity and grazing control is usually absent.

Soil texture is related to land management practice in forested areas. Areas with coarse-textured soils of low water storage capacity are usually subjected to high grazing intensity since the produced palatable biomass is rather limited. Also, runoff water storage actions are more often described in coarse- to medium-textured soils than in fine- to very fine-textured soils in these areas. Furthermore, policy implementation is mainly characterized as moderate to low in field sites with fine- to moderately fine-textured soils.

Soil texture can greatly affect water stress, plant growth and plant cover under semi-arid or arid climatic conditions. Shallow soils combined with coarse-textural classes have low water storage capacity and plant cover is usually lower than 60% under semi-arid climatic conditions. On the contrary, deep medium to moderately fine-textured soils are characterized with high water storage capacity favouring high plant cover and lower water stress and desertification risk.

Measuring the indicator
Soils can be classified according to their texture in classes, and each textural class has a given range of sand, silt and clay. The following 12 classes are used here: sand (S), loamy sand (LS), sandy loam (SL), loam, (L), silt loam (SiL), silt (Si), clay loam (CL), sandy clay loam (SCL), silty clay loam (SiCL), clay (C), silty clay (SiC), and sandy clay (SC) (Fig.14). Four broad groups of classes are recognized: Sands, Silts, Clays and Loams. Sands contain at least 80% sand particles and 15% or less clay particles by weight. Silts contain at least 80% silt and 12% clay particles, respectively. Clays contain at least 35% of clay particles. Loams are mixtures of sand, silt and clay particles that exhibit the properties of those particles in equal proportions. Loam soils have the best combination of physical and chemical properties in terms of cultivation and crop growth.

Soil texture can be estimated in the field through the feel of a moist soil molded between fingers and thumb. Also soil texture is quantitatively determined in the laboratory using the hydrometer method. The 12 textural classes are further grouped into 6 categories very coarse (S, LS), coarse (SL), medium (L, SiL, and Si), fine (Cl, SCL, and SiCL), fine (C, SiC and SC) and very fine soils having clay content greater than 70%.

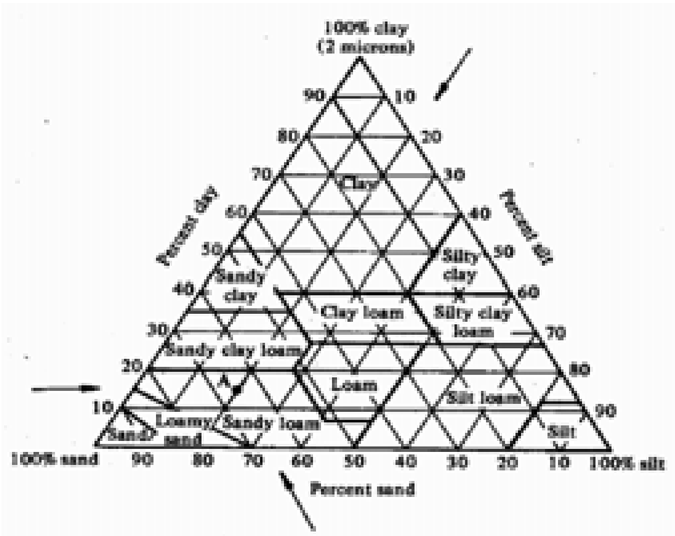

Fig. 14. The USDA textural triangle showing the limits of sand, silt and clay contents of the various textural classes

Soil depth

Definition
Soil depth defines the root space and the volume of soil from where the plants satisfy their water and nutrient demands.

Importance on land degradation process
Soil depth can be considered as an important soil indicator affecting land desertification. Percentage vegetation cover of a soil surface under semi-arid climatic conditions is largely

controlled by soil water storage capacity and therefore soil depth. Soil depth decrease due to soil erosion is a serious threat to the soil quality and productivity in hilly areas (Fig. 15). The effects of soil erosion on its productivity depend largely on the thickness and quality of the topsoil and on the nature of the subsoil. Many hilly soils are shallow or have some undesirable properties in the subsoil such as petrocalcic horizon, or bedrock (Fig. 15) that adversely affects yields. In either case, productivity will decrease as the topsoil gets thinner by erosion and undesirable subsoil is mixed into the topsoil by tillage.

Soil depth has been measured in 1577 field sites, corresponding to 17 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Many of the study fields have very deep soils (depth>150 cm), covering over 22.6% of the total sites. The next important class of soil depth is slightly deep (depth 30-60 cm), covering 21.8% of the field sites. Moderately deep (depth 60-100 cm) and deep soils (100-150 cm) cover 12.7% and 15.7% of the study field sites, respectively. Very shallow (depth <15 cm) to shallow (15-30 cm) soils have been found in several cases covering 11.2% and 16.0%, respectively.

Soil depth is an important indicator for assessing desertification risk in all land uses affected by surface water runoff soil erosion. The rate of soil erosion largely depends on the thickness and quality of the topsoil and on the nature of the subsoil. Shallow soils have lower water storage capacity and therefore, surface water runoff is generating shortly after a moderate rainfall event. The contribution of soil depth in assessing land degradation and desertification risk is higher in forested areas (higher regression coefficient) followed by pastures and agricultural areas.

Fig. 15. Deep soil formed on marl deposits (left) and shallow soil formed on limestone (right)

Soil depth is related to tillage operations in agricultural areas affected by soil erosion. As soil depth decreases, tillage operations are rather limited since land productivity is highly reduced. Areas with shallow soils combined with steep slopes are rarely cultivated.

Grazing control in pastures is highly related to soil depth. Grazing control in areas with shallow soils is almost absent since biomass production is highly limited to satisfy the basic needs of the grazing animals. Highly degraded areas with shallow soils are usually considered as badlands by the farmers avoiding any actions against soil erosion through grazing control.

Soil depth and soil texture greatly affects soil water storage capacity and therefore plant growth and plant cover under semi-arid or arid climatic conditions. Shallow soils combined with coarse-textural classes have low water storage capacity and plant cover is usually lower than 60%. On the contrary, deep medium to moderately fine-textured soils are characterized with high water storage capacity favouring high plant cover and lower water stress and desertification risk.

Fire protection in forested areas, where the main cause is forest fires, is related to soil depth. Fire protection is negatively related to soil depth. Fire protection in areas with deep soils is mainly characterized as moderate to low. Areas with deep soils generally produce high amounts of biomass, and fires that occur there can not be easily controlled.

Soil depth is a major determinant factor in land abandonment. Soil depth greatly affects water storage capacity and water available for plant growth. Areas with shallow soils are usually abandoned with higher rates than areas with deep soils since crop production becomes unprofitable in areas with shallow soils.

Measuring the indicator

Soil depth can be measured using an auger or in existing cuts. The following classes are distinguished: (a) very shallow, soil depth (SD) <10; (b) shallow, SD = 10-30 cm; (c) slightly deep, SD = 30-60 cm; (d) moderately deep, SD = 60-100 cm; (e) deep, SD = 100-150 cm; and (f) very deep, SD>150 cm.

Organic matter

Definition

Organic matter of the soil represents the accumulation of partially decayed and partially synthesized plant and animal residues. The organic matter of the soil constitutes a small percentage about 2-4 percent in the soil surface in inorganic soils.

Importance on land degradation process

Soil organic matter represents a key indicator for soil quality, both for agricultural functions (i.e. production and economy) and for environmental functions (e.g., carbon sequestration and air quality). Soil organic carbon is a major indicator influencing physical, chemical and biological soil parameters. Aggregation and stability of soil structure increase with organic matter content. These in turn increase infiltration rate and water storage capacity of the soil, as well as resistance against erosion by water and wind. The development of agriculture has caused a large loss of soil organic matter (Fig. 16). Global climatic change may have a similar effect.

Apart from climatic factors (mainly drought and increase in air temperature), the main processes causing losses in soil C are cultivation of undisturbed land, soil erosion, mineralization of organic matter, leaching of dissolved organic and inorganic substances. Soil erosion by water or wind, represents the most important soil organic matter decline process. There are several land management practices for soil carbon conservation, such as reduced or zero tillage, application of bio-solids (manure, crop residues, and compost), cover and deep-rooting crops, conservation of grassland and woodland, improved rotations, fertilization and irrigation.

Data for the organic matter content in the soil surface horizon have been collected in 1136 field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The majority of the study soils had low (2.0-1.1%) to very low (<1%) organic matter content, covering 40.0% and 34.9% of the study field sites. Moderate (2.1-6.0%) amounts of organic matter was found in 22.2% of the study sites. High amounts of organic matter in surface horizon have been measured in very few field sites in forested land.

Soil organic matter content has a great contribution in assessing desertification risk in agricultural areas affected by tillage erosion. Soils of low organic matter content usually are subjected to higher rates of tillage erosion since non-structured or weekly structured soils are easily dispersed and displaced by tillage implements. Furthermore, low amounts of soil organic matter content in agricultural areas affected by water erosion are more vulnerable to degradation and desertification.

Soil organic matter content has been affected in pastures by grazing intensity, and rate of burned area. Soil in areas subjected to high grazing intensities usually contain low amount of organic matter content since high soil erosion rates are expected in such cases. Also areas with soil of low organic matter content in the soil surface have usually low rates of burned area since the amount of organic matter is usually low under limited amounts of biomass production, which favours ignition and propagation of a fire. Of course, soil organic matter content can been affected by other factors such as climate, type of vegetation, other soil characteristics, etc. Finally, soil organic matter content is positively related to the effectiveness of soil erosion control measures applied in pastures.

Fig. 16. Agricultural soil of low (left) and forest soil of medium (right) organic matter content in the soil surface

Organic matter content is also related to water runoff storage actions in forested areas. Areas with soils of low organic matter content are usually subjected to low runoff water storage actions.

Measuring the indicator

Soil organic matter can be determined by chemical analysis of soil samples of fine earth (materials pass through a 2 mm sieve) or by dry combustion. The chemical method consists of oxidation of soil organic carbon by gently boiling for 2 hours with an acid dichromate solution using the modified Walkey-Black wet oxidation procedure (Nelson and Sommers, 1996). The excess of dichromate is determined by titration with ferrous sulphate. The dry combination method consists of heating in 500 ^{o}C an oven-dry in 105 ^{o}C soil sample. Both methods are recommended, depending on the laboratory available facilities. The following classes can been distinguished: (a) high organic matter content (OM>6%, (b) medium, OM = 2.1-6.0%, (c) low, OM = 2.0-1.1%, and (d) very low, OM =<1.0%.

Exposure of rock outcrops

Definition

Exposure of rock outcrops refers to a miscellaneous area which consists of spots of exposures of bedrock and soil. A type of land having little or no soil supported vegetation.

Importance on land degradation process

Areas characterized by exposed rock outcrops usually are greatly degraded due to soil erosion and they are mainly characterized as critical areas to desertification. Such conditions are very common in soils formed on consolidated parent materials such as limestone, sandstone, lava, etc. (Fig. 17).

Fig. 17. Shallow highly degraded soils, with the bedrock exposed in patches on the soil surface (rock outcrops), formed on acid igneous rock (left) and limestone (right)

Data for rock outcrops have been defined in 1056 field sites, corresponding to 12 field sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Field sites free of rock outcrops have been defined in 57.8% of the cases. The following important class is rock outcrops exposed in an area of 1-10% of the study field, covering 27.5% of the study field sites. The classes of rock outcrops 10-30%, 30-60%, and >60% are found in few cases.

Percentage of rock outcrops is related to the stage of land degradation. Soils with high percentage of rock outcrops have usually lost their ability to support adequate vegetation for protecting soil from erosion and providing adequate biomass to grazing animals. Such landscapes are very sensitive to overgraze and degradation since animals are seeking their food in patches of soils with low amount of palatable biomass. Desertification risk is higher as the percentage of rock outcrops increases in areas subjected to overgraze. Furthermore, as exposure of rock outcrops increases, soil erosion is usually reduced under certain conditions.

This mainly corresponds to field sites where limestone is the soil parent material. Limestone usually is associated with deep cracks or faults favouring deep water percolation, thus reducing surface water runoff and soil erosion rates.

Percentage of rock outcrops greatly affects water stress in the growing plants. Areas with high percentage of rock outcrops have limited soil water storage capacity, resulting in high water stress, low plant cover, and high land desertification risk.

Measuring the indicator

Exposure of rock outcrops can be estimated in the field by choosing a representative area of at least 500 m^2 and assessing the percentage of the surface in which the underline rock is exposed. The following four classes have been defined for the purpose of the DESIRE project: (a) free of rock outcrops, (b) low, rock outcrops = 1-10%, (c) moderate, rock outcrops = 10-30%, (d) high, rock outcrops = 30-60%, and (e) very high, rock outcrops>60%.

Fire risk

Definition

Fire risk is determined by the particular composition of vegetation and therefore both by its flammability and combustion capacity and its capacity to recover after fire.

Importance on land degradation process

Mediterranean natural vegetation is highly flammable and combustible due to the existence of species with high content of resins or essential oils such as pine forests (Fig. 18). In the opposite, perennial agricultural crops, such as olives, vines, etc. are usually characterized as low fire risk. Even though agricultural crops are low fire risk, several times are destroyed by forest fires if they are located nearby a forested land.

This indicator has been described in a rather limited number of field sites (295 field sites) in 7 study sites, located in Mediterranean Europe, Africa, Asia, and Latin America. Based on the obtained data, the dominant class of fire risk is low, covering 72.9% of the total field. The next important class of fire risk is very high covering 17.3% of the total field sites Moderate and high fire risk has been recorded in 4.4% and 5.5% 0f the study field sites, respectively.

Fig. 18. Examples of areas with low fire risk (olive grove, left) and very high fire risk (pine forest, right)

The analysis of the obtained data have shown that as fire risk of the existing vegetation increases desertification risk decreases in forested areas. This is an unexpected trend for forested areas. One explanation may be the following, such areas are mainly covered with coniferous plant species or Mediterranean Macchia easily regenerated growing in relatively deep soils of moderate sensitivity to land degradation.

Fire risk is related to rate of burned area in pastures overgrazed. Areas covered with vegetation of high fire risk are usually subjected to high fire frequency and therefore the rate of burned area is highly enhancing desertification risk in the overgrazed land.

The indicators fire risk is related to rate of land abandonment. Areas covered with vegetation of high fire risk have been subjected to higher rates of land abandonment. Fires in such areas are frequent, causing high soil erosion rates and land degradation followed by abandonment. In addition, the rate of land abandonment is positively related to the rate of burned area. Areas characterized by high rates of burned area are usually combined with high rates of land abandonment.

Measuring the indicator

Fire risk can be estimated on the basis of the structure and the dominant vegetation species present in each site. The following categories of fire risk have been used in the DESIRE project: (a) low, including perennial crops, annual crops such as maize, tobacco, sunflower, etc.; (b) moderate, including annual crops such as cereals or meadows, deciduous oaks, mixed deciduous and evergreen oaks, mixed Mediterranean Macchia and evergreen forests; (c) high, including Mediterranean Macchia; and (d) very high, including coniferous forests.

Distance from the sea shore

Definition

This indicator defines the distance of a piece of land from the seashore.

Importance on land degradation process

This indicator is mainly used to assess the effect of water quality on soil salinization risk. The shorter the distance of a site from the nearby seashore, the greater the risk of soil salinization is expected. Soil texture and hydromorphic conditions are greatly related to the distance from the seashore and of course the location in relation to riverbed. Soils located short distance and far from the riverbed are usually fine-textured and poorly drained with a permanent ground water table fluctuating between 30-150 cm from the soil surfaces. Such soils under semi-arid and arid climatic conditions are vulnerable to salinization and desertification. In the opposite, soils located far from the coast and from the riverbed are usually well drained or some what poorly drained of medium to moderately fine texture. Such soils are lees vulnerable too salinization and desertification under the same climatic conditions (Fig. 19).

Fig. 19. Examples of soils located in the same alluvial plain but in different distance from the seashore (left photo-very poorly, fine-textured with high amounts of salts, located 750 m from the seashore; right photo-well drained, moderately fine textured soil, free of salts, located 4200 m from the seashore

Data for this indicator have been collected in 258 study field sites, corresponding to 5 study sites, located in Mediterranean Europe, eastern Europe, and Africa. The dominant class of distance from the seashore is greater than 15 km, covering 45% of the study field sites. The next important class of distance from the seashore was 2-5 km, covering 15.5% of the study field. The other classes of distance from the seashore shows an almost uniform distribution with frequency of appearance less than 10%, covering all the distances form the seashore.

Measuring the indicator

The distance form the shortest seashore of a field can be measured by using topographic maps, ortho-photomaps, any distance measurement instrument. The following classes of distance from seashore (D) have been distinguished in this project: (a) D<0.25 km, (b) D=0.25-1 km, (c) D=1-2 km, (d) D=2-5 km, (e) D=5-8 km, (f) D=8-15 km, and (g) D>15 km.

4.2 Indicators related to socio-economics

Farm size

Definition

The indicator defines physical size of a farm and not the economical size of the farm.

Importance on land degradation process

Farm size generally speaking affects land management practices and organization of farm activities. Large farm size can have an impact on the shape of the farm such as uniform fields with less boundary features and isolated trees, as well as on the degree of intensification of operations as capital replaces labor, which enables farmers to produce higher output from the land. The tendency toward greater concentration in production usually leads farmers to the replacement of mixed farming by more specific and uniform production such as livestock or arable based farms, etc. Studies conducted in the island of Lesvos (Greece) have shown that land use change has been affected by farm size. Land use change has occurred when farm size is greater than 10 hectares. In smaller farm sizes changes in land use are not so often.

Mismanagement of the land is closely related to social and economic changes in the rural areas. Low prices of dry farming products and competition from other countries resulted in low farmer's income. Then, farmers had to adopt different cultivation methods to get public subsidies, or change to more profitable crops, or to expand agriculture in marginal areas, or to abandon the land and migrate in urban areas. These processes have favoured land fragmentation with parcels to become smaller and smaller.

The indicator farm size has been defined in 972 study field sites, corresponding to 12 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant classes of farm size identified in the study field sites are less than 2 hectares and 10-30 hectares (Fig. 20), covering 22.7% and 22.3% of the total fields, respectively. The next important classes of farm size are 2-5 and 30-50 ha, covering 20.7% and 15.9% of the total field sites, respectively. Farm size classes of 50-100 ha and >100 ha have been found in 1.7% and 13.3% of the study field sites, respectively. Farm sizes of 5-10 ha have been found in few cases (4.0% of the study field sites).

Farm size is defined as an important indicator affecting desertification risk in pastures subjected to overgrazing. Large farm sizes (greater than 30 ha) have a negative impact on land degradation and desertification in areas overgrazed. A uniform large farm is better organized with the tendency of uniform production such as livestock. In small farm sizes, animal density is usually high in order to provide an adequate income to the farmer resulting in overgrazing and land degradation.

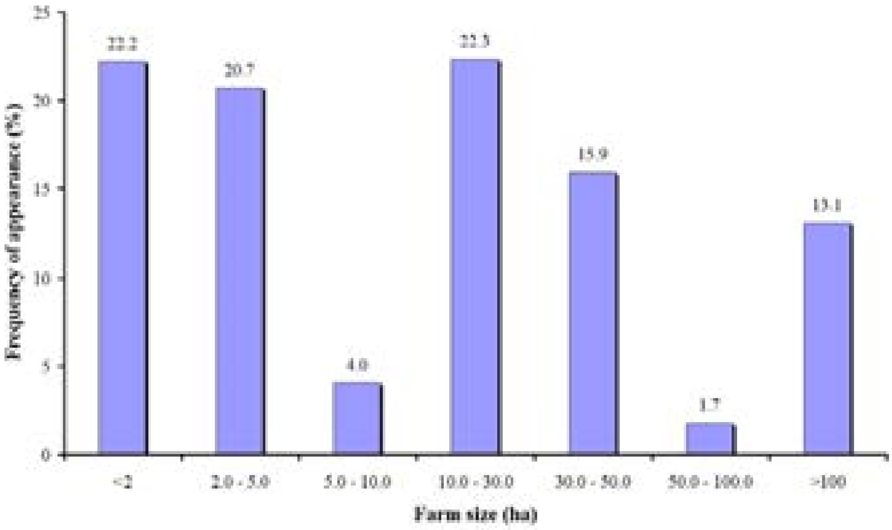

Fig. 20. Distribution of farm sizes classes defined in 972 field sites

Man actions such as tillage operations and policy implementation in agricultural areas are affected by farm size. As farm size decreased tillage operations usually decreased since farmers are not usually organized on a professional basis. Furthermore, policy implementation is mainly characterized as low in large farm sizes (greater than 30 ha). Farmers having large farm sizes used to organize crop production on more professional basis, systematically cultivating the land for maximum production without applying measures for land protection.

Farm size is related to soil erosion control measures in pastures overgrazed. Field sites located in farms of small size have been mainly characterized by adequate soil erosion control measures. Such actions are probably related with small numbers of animals kept by the local farmers avoiding overgrazing.

Measuring the indicator

The farm size is defined after contacting the land user. This indicator contributes to the definition of the agricultural structure of the area affected by desertification. The following classes have been used in this project: less than 2 ha, 2-5 ha, 5-10 ha, 10-20 ha, 20-30 ha, 30-50 ha, 50-100 ha, and >100 ha.

Farm ownership

Definition

Farm ownership defines the type of tenure of a farm, for example owner-farmed, tenant–farmed, share-farmed, etc.

Importance on land degradation process

Farm ownership can affect land management practices. Usually farmers do not apply measures for land protection from degradation, since they seek temporally only maximum profit. Farmers without a steady perspective in the property of the land are not encouraged to invest in soil conservation measures or make long-term investments. UNCCD has emphasized the importance of improvement of the institutional and regulatory framework of natural resource management to provide security of land tenure for local populations. Farm ownership represents a fundamental factor for decision-makers for addressing political measures to individual farmers or to more effective public level.

Land ownership has been identified in 1291 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Land owner-farmed has been identified in 59.9% of the field sites (Fig. 21). The following important class of land ownership is shared-farmed in which the land is in partnership by the landlord and the sharecrop farmed under a written or oral share-farming contract, covering 14.6% of the study field sites. State-farmed has been defined in 14.5% of the study field sites. Tenant-farmed has been identified in 6.0% of the study field sites.

Farm ownership has been defined as an important indicator affecting desertification risk in area affected mainly from soil salinization. Farmers having a tenant or shared-farm usually do not apply measures for land protection from degradation since they seek temporally only maximum profit.

Farm ownership is related to land use intensity in agricultural areas. Land use intensity is mainly characterized as low to moderate in areas characterized as owner-farmed. High land use intensity is mainly identified in areas characterized as tenant- or state-farmed. Under such conditions, farmers try to gain as much as they can, intensively cultivating the land.

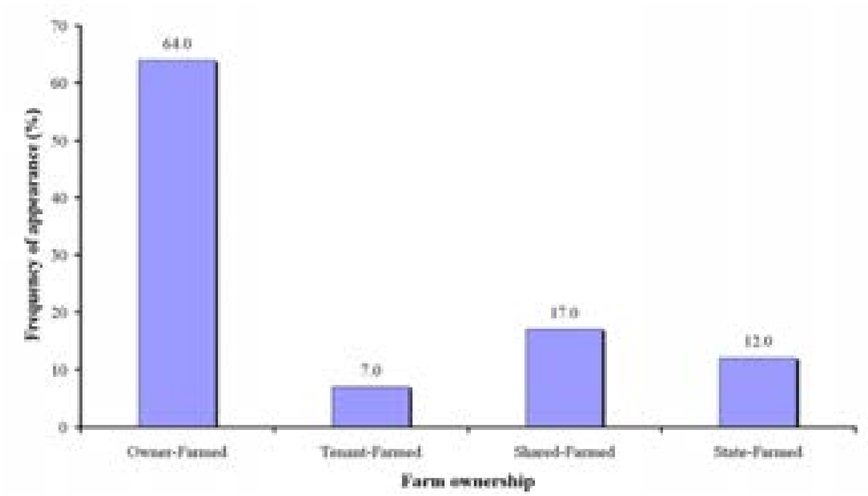

Fig. 21. Distribution of farm ownership categories identified in 1291 study sites

Similar trends are mainly identified in pastures. As farm ownership changes from owner- farmed to shared-farmed, state-farmed, tenant-farmed, measures for soil erosion control are diminished. Farmers keeping a grazing land under tenant-farmed conditions usually do not care about measures for land protection.

Forested areas used for grazing and characterized as state- and tenant-farms are usually subjected to high grazing intensity. On the contrary, field sites characterized as owner- or shared-farms are better managed, subjected to medium or low grazing intensity

Farm ownership is related to the rate of burned area in overgrazed land. Tenant- or state-farmed field sites are usually subjected to higher rates of burned area than owner- or shared-farmed field sites. Farmers used to put fire in grazing land to simulate the growth of palatable biomass production for the grazing animals, aggravating the problem of desertification in these areas.

Measuring the indicator

Farm ownership is defined in this project as the percentage of rented agricultural land in the owner-farmed agricultural area. In a field site, ownership status is identified by contacting the land user. Agricultural land is the sum of arable land, kitchen gardens (horticulture), permanent pastures and meadows and permanent crop. According to the EUROSTAT CODE the utilized agricultural area is classified as following: (a) owner–farmed, agricultural land being farmed by the holding which is the property of the holder or farmed by him or inheritable long-term lease holder or under some other equivalent type of tenure; (b) tenant–farmed, land rented by the holding in return for a fixed rent agreed in advance (in cash, kind or otherwise), and for which there is a (written or oral) tenancy agreement; (c) shared-farmed, land (which may constitute a complete holding) farmed in partnership by the landlord and the sharecropper under a written or oral share-farming contract, the output (either economic or physical) of the share cropped area is shared between two parties on an agreed basis; (d) state farm, and (e) other modes.

Land fragmentation

Definition

Land fragmentation defines the number of parcels per holdings.

Importance on land degradation process

Land fragmentation can affect land management practices and decision-making related to the structure of the farm. A highly fragmented land is not easily to mechanized and cultivate in a direction in which soil erosion is not restricted (Fig. 22). If the fields belonging to a farm are located in various locations, then economic performance of various activities becomes less profitable and can lead to abandonment of the farm, worsening the quality of the environment. In extreme situation, marginal lands located at long distance from the farm centre can be progressively abandoned. Moreover, long distance located parcels can not be easily controlled the protection and maintenance of the landscape. Farm fragmentation in combination with adverse soil, topographic and climatic conditions affects land use change decision-making. Studies conducted in the island of Lesvos have shown that as the number of parcels in each farm increased, land use remained often unchanged. When a farm was divided in several parcels distributed in various locations, farmer used to allocate land uses according to the land productivity keeping such distribution usually unchanged for long periods.

Fig. 22. Land characterized as highly fragmented (left) and low fragmented (right) in which fields are uniform

Land fragmentation has been defined on 918 f ield sites, corresponding to 12 s tudy sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of land fragmentation in the study field sites is 1-3 parcels per holding, covering 36.8% of the study field sites. The following important class of land fragmentation is 7-9 parcels, covering 30.2% of the total fields. Parcels 13-15 per holding have been found in 14.7% of the study field sites. The next important class of land fragmentation is 4-6 parcels per holding, covering 12.9% of the study sites. Finally, very high land fragmentation (>19 parcels per holding) has been defined only in 4.5% of the study field sites.

The obtained data have shown that land fragmentation highly affects land degradation and desertification especially in areas overgrazed. The estimated coefficient of linear regression is one of the highest among the various indicators considered in this study. A highly fragmented land is not easily organized on a professional basis. If the fields belonging to a farmer are located in various locations, then the grazing animals are concentrated in small fields overgrazing them, generating high erosion rates, increasing desertification risk.

Grazing control in pastures is related to land fragmentation. Grazing control is mainly absent as land fragmentation increased. Farmers used to keep the animals for longer period in highly fragmented land, or the available biomass for even medium number of animals is rather limited, overgrazing it. Furthermore, land fragmentation is usually positively related to soil erosion control in areas subjected to overgrazing. Field sites belonging to farms with low land fragmentation are subjected to overgrazing since animals use to remain in the same area for a long period.

Measuring the indicator

Data on land fragmentation can be collected by contacting the land user. The following classes have been defined for this project: (a) 1-3 parcels, (b) 4-6 parcels, (c) 7-9 parcels, (d) 10-12 parcels, (e) 13-15 parcels, (f) 16-19 parcels, and (g) >19 parcels.

Population density

Definition

Population density is defined as the ratio between (total) population and surface (land) area in which this population exists.

Importance on land degradation process

Population density is an indicator closely related with the level of human pressure to natural resources and with the sensitivity of an area to land degradation and desertification. Over the last decades the Mediterranean countries have experienced a t remendous increase of population. In 2000 the whole 22 riparian countries had 428 million people compared to 285 million in 1970. T he population density is quite different between northern and southern countries with the latest having an annual growth rate of 2.35% per year or an increase of 3.9 million people per year for all the countries from Morocco to Turkey. These numbers are five times higher than the northern Mediterranean countries.

Data for this indicator have been defined in 1408 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Low population density (PD<50 people /km^2) is the prevailing class, covering 61.4% of the study field sites (Fig. 23). Moderate population density (PD=50-100 people /km^2) has been defined in 32.5% of the study field sites, High population density (PD=100-300 people /km^2) has been described in 6.1% of the study field sites, corresponding to the study site of Santiago Island-Cape Verde.

Population density is an important indicator especially for forested affected by water erosion, agricultural areas affected by salinization, as well as for areas affected by water stress. Areas affected by soil erosion or water stress are more vulnerable to land degradation and desertification under high population densities (higher than 100 p eople km^{-2}). Opposite trends are found for agricultural areas affected by soil salinization. Since population density is a regional indicator, there must be an error in the calculation of this indicator. Many times people prefer to live far from low lands affected by salinization, therefore, this indicator must include broader areas for calculation of population density.

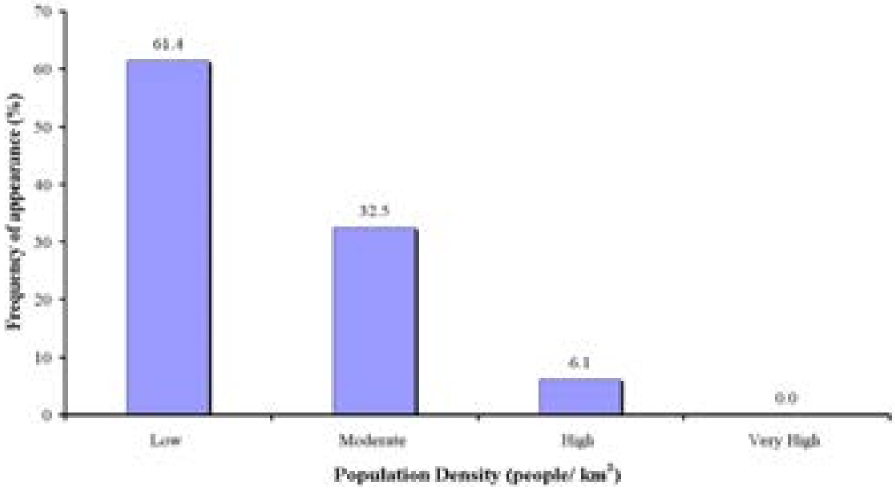

Fig. 23. Distribution of population density classes defined in 1408 field sites

Population density is an indicator closely related to tillage operations in agricultural areas. In the study areas with high population densities, tillage operations are mainly identified as low. This is an opposite trends than someone expects. Perhaps people leaving in areas of high population densities are more likely to have off-farm income. It seems that some other social and economic conditions prevailing in the study areas are also influencing the cultivation of the land such as the ratio of rural/urban population, net farm income, etc.

Population density is related to grazing control in pastures affected by soil erosion. Grazing control is usually was more effective in areas with low population density.

Actions for runoff water storage are related to population density in forested areas affected by water erosion. Areas with low population densities, or high population growth rates are mainly characterized by the absence of runoff water storage actions. Furthermore, policy implementation is related to population density as well as other social characteristics. Areas with high old age index, low population density, and high population growth rate, policy implementation is mainly characterized as low. Since the social characteristics used here cover broad areas and the urban/rural distribution of the local population is not known, the conclusions on how such indicators are affecting policy implementation needs further investigation.

Water quality in areas affected by soil salinization is significantly related to population density. Areas with high population density have mainly good to moderate quality of water. This can be attributed for the study areas by various factors such as: (a) presence of rivers carrying high quantities of good quality water accompanied with adequate enrichment of ground water, (b) expansion of necessary infrastructure for providing adequate quantities of good quality of remote water to satisfy the needs of local population including tourists during the summer period.

Population density is also an important indicator in areas affected by water stress. Areas with high population density have supported low plant cover due to overexploitation of natural resources promoting high desertification risk.

Rate of burned area is related to population density in areas affected by water stress. Areas with high population density are usually subjected to high rates of burned area. Such actions are very common in many areas with high population density due to imposing high pressure on the natural resources.

Rate of land abandonment is related to population density. Areas with high human poverty indices have been mainly characterized by high rates of land abandonment. Also, areas with low population density are mainly characterized with high rates of land abandonment. This can be explained with the migration or rural population to urban areas or working parallel in other economical sectors such as tourism or industry.

Measuring the indicator

Population density can be calculated by data provided by the National Statistical Service. The following equation is used for calculation of population density (PD) (source: http://en.wikipedia.org/wiki/Population_density):

$$\text{Population Density} = \frac{\text{No of individuals}}{\text{Area of the region in which they live}} = \frac{\text{People}}{\text{km}^2}$$

The following classes are used in this project: (a) low- PD<50 people /km^2, (b) moderate-PD=50-100 people/km^2, (c) high-PD=100-300 people /km^2, and (d) very high-PD>300 people / km^2.

Old age index

Definition

The old age index measures the relationship between the populations over the age of 65 divided by the total population.

Importance on land degradation process

The purpose of the indicator is to emphasize the strong imbalance that exists between the large numbers of elderly people in relations to the total population. This index is related to the applied land management practices and to the introduction of new technologies. Elder people used to remain under the traditional land management practices, while younger farmers are relatively easily convinced to introduce new technologies and land management practices, considering sustainability of land resources. Furthermore, elder people in dry lands are not usually replaced in farming by their sons and the land is often abandoned or land management practice or land use changes leading later to abandonment after possible further degradation.

Changes in the social structure of an area can be both a driving force and an impact on land degradation and desertification. Changes in the social structure can occur if the local socio-economic conditions has become incapable for satisfying the population's needs. This may be the result of land degradation caused in the landscape in the previous time resulting in decreasing land productivity and farmers' income. Under such conditions, land is abandoned and population migrates to other more promising areas. The concentration of people in certain areas results in large pressure on the land resources and especially on water resources due to continuously increasing demands for food and water consumption. The increasing demands for food and water results on intensive use of natural resources and a new cycle of land degradation and desertification is initiated in the areas of high population density.

Data for this indicator have been defined in 1056 study field sites, corresponding to 10 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Old age index is mainly characterized as high, covering 42.9% of the study field sites (Fig. 24). Moderate old age index is the next important class, covering 25.2% of the study field sites. Low old age index has been defined in 23.4% of the study field sites. Finally, very high old age index has been identified in 8.5% of the study field sites.

This indicator is significantly important for forested areas in which the main cause of land degradation is forest fires. Areas under high old age index (greater than 1.7) are more vulnerable to forest fires and to desertification risk. This can be associated with the removal of animals from forests allowing high flammable biomass growth favouring wild forest fires.

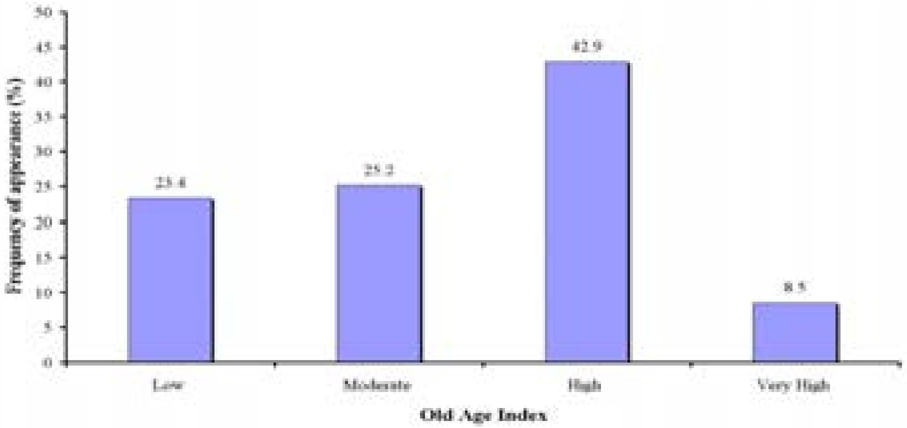

Fig. 24. Distribution of old age index classes defined in 1056 field sites

Soil erosion control measures in pastures are related to human old age index. Soil erosion control measures are negatively related to old age index. Old aged people do not care so much for applying measures for soil erosion control. In the opposite, high population growth rates lead to overexploitation of the land. It seems that the optimal social conditions related to these indicators are somewhere in the middle, that means moderate population growth rate and moderate old age indices. In addition, areas with population of high old age index usually do not keep large numbers of animals, therefore, land is extensively grazed leaving high amounts of dry biomass in the land favouring ignition of fires.

Old age index is related to grazing intensity in forested areas. Such areas with low population old age indices are subjected to high grazing intensity. Such social conditions favour the establishment of professional farms with large numbers of animals overgrazing the land. Furthermore, areas with high old age indices are usually characterized by the absence of runoff water storage actions in forested areas. Also, in areas with high old age index, low population density, and high population growth rate, policy implementation is mainly characterized as low. Since the social characteristics used here cover broad areas and the urban/rural distribution of the local population is not clear, the conclusions on how such indicators are affecting policy implementation for environmental sustainability are not satisfactory.

Old age index is related to plant cover in areas affected by water stress. Areas with high old age indices are mainly characterized as supporting adequate plant cover subjected to lower desertification risk.

Measuring the indicator
Old age index can be calculated by data provided from the National Statistical Service. This old age index (R) is calculated by the following equation (source: http://en.wikipedia.org/wiki/Population_density):

$$\text{Old Age Index} = \frac{\text{Population 65 years old and older}}{\text{Total Population}} \times 100$$

The following classes of old age index are used for this project: (a) low- old age index R<5, (b) moderate- R=5-10, (c) high- R=10-20, and (d) very high- R>20.

Population growth rate

Definition
Population growth rate is a measure of change of population of a certain area.

Importance on land degradation process
The rate of population growth is identified by Agenda 21 of the United Nations as one of the crucial factors affecting long-term sustainability of natural resources. Rapid population growth can impose limitations on a country's capacity for handling a wide range of economic, social, and environmental issues, particularly when rapid population growth occurs in connection with poverty and lack of access to natural resources.

Data for this indicator have been defined in 1065 field sites, corresponding to 10 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of population growth rate is low (growth rate <0.2% per year), covering 46.0% of the study field sites (Fig. 25). Moderate population growth rate has been defined in 29.1% of the study field sites. The next important class of growth rate is high (0.4-0.6% per year), covering 16.0% of the study field sites. Very high population growth rate has been defined in 8.9% of the study field sites, corresponding to some cases of the study sites of Boteti Area-Botswana, Secano Interior-Chile, and Santiago Island-Cape Verde.

Population growth rate is especially important for forested areas affected by fires in assessing desertification risk. Rapid population growth rate can be connected with poverty and high pressure to natural resources. The analysis of the obtained data have shown that areas with low population growth rate is positively related to land degradation. This finding is in agreement with population old age index. Low population growth rates accompanied with high old age index leads to decreasing animal population grazing the forested land and increasing forest fires due to higher remaining flammable biomass.

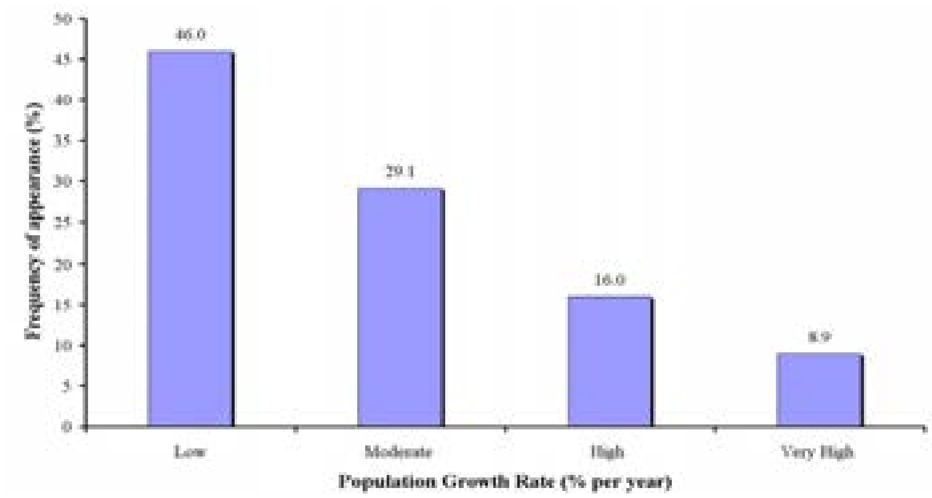

Fig. 25. Distribution of population growth rate classes defined in 1065 field sites

Population growth rate is closely related to tillage operations in agricultural areas. In areas with high population densities and high rates of population growth, tillage operations are m ainly identified as low. These are opposite trends than someone expects. Perhaps people under such social conditions are more likely to have off-farm income. Furthermore, policy implementation is also significantly affected by population growth rate in agricultural areas. Under high population growth rates policy implementation is mainly characterized as low.

Grazing control is related to population growth rate in pastures. Grazing control is more effective mainly in areas of low population density. In addition, soil erosion control measures are related to population growth rate in pastures. Soil erosion control measures are negatively related to population growth rate. High population growth rates lead to overexploitation of the land without applying measures for protection. Also, population growth rate is related to rate of burned area in pastures. In areas with high population growth rate, farmers intensively grazed the land with large number of animals. Under such conditions, farmers use to put fires for promotion of palatable grass growth for feeding the high number of animals.

Population growth rate is related to grazing intensity in forested areas in which the main process of land degradation is soil erosion. Areas with low population growth rates have been mainly characterized as subjected to high grazing intensity. Such social conditions favour the establishment of professional farms with large numbers of animals overgrazing the land. In addition, actions such as runoff water storage in forested areas is related to population growth rate. Areas of high population growth rates have been mainly characterized by the absence of runoff water storage actions. Furthermore, policy implementation for environmental protection is related to population growth rate. In areas with high population growth rate, policy implementation is mainly characterized as low.

Population growth rate is also related to plant cover in areas affected by water stress. Areas characterized by high population growth rates are mainly characterized as supporting low vegetation cover enhancing water runoff and land degradation. In addition, such conditions of plant cover prevail in areas of high poverty index. Land use intensity is also related to population growth rate. Data from the study areas have shown that high population growth rates are usually associated with low land use intensity. This trend needs further analysis since other socio-economic factors may be associated with land use intensity.

Population growth rate is related to rate of burned areas in pastures where the main cause of land degradation is overgrazing. Areas with high population growth rate are subjected to high rates of burned area. Such actions are very common in many areas with high population density due to imposing high pressure on the natural resources.

Measuring the indicator

Data for calculating population growth rate (PGR) can be obtained from the National Statistical Service. PGR is calculated as the increase in population during a period of time, usually one year, expressed as a percentage of the population at the beginning of the period. It corresponds to the number of births and deaths during the certain period and the number of people migrating to (immigration) and from (emigration) a country. (Source: http://www.worldbank.org/depweb/english/modules/social/pgr). The following equation is used for calculation of PGR:

$$\text{Population Growth Rate} = \frac{(\text{Birth Rate} + \text{Immigration}) - (\text{Mortality Rate} + \text{Emigration})}{\text{Population Size}}$$

The following classes are defined for this indicator: (a) low population growth rate- PGR <0.2% per year, (b) moderate- PGR = 0.2-0.4% per year, (c) high- PGR = 0.4-0.6% per year, and (d) very high-PGR>0.6% per year.

Tourism intensity

Definition

Tourism intensity shows the average distribution of tourists over a certain area, providing a general indication of pressures on natural resources, with regard to a reference period (year) or during a peak season.

Importance on land degradation process

The Mediterranean region is the third most preferred international tourist destination and the first for European tourists, accommodating around 218 million visitors every year. According to the World Tourism Organization tourists' movement in the Mediterranean would increase in the near future. It is estimated than by the year 2025 the region would receive 396 million international and 273 million domestic tourists.

Tourism industry plays an important role in the Mediterranean economy. However, tourism has created a number of environmental problems ranging from loss of agriculture lands, water pollution, coastal erosion, increasing water consumption, decreasing recharge of aquifers, flooding of lowland, soil salinization, etc. The increasing tourism exerts a significant impact on the land-use patterns and the allocation of water resources. The most immediate changes in land-use is: (a) the shift in crop production to meet the high tourist requirements, (b) the replacing several of the traditional crops, and (c) the abandonment of lands of low quality. The high demands for water consumption or other economic activities have increased the price of water and forcing the cost of agricultural production, while in many cases, water of low quality is used for irrigation causing soil salinization problems. Coastlines are being sealed over by harbours and marinas, roads, houses, other facilities to accommodate the expansion of tourist industry, removing fertile soils from production and the interrupting functions with the environment.

Tourism intensity is defined as the number of overnights stays by tourists per 10 square kilometres per annum and in peak season. It is a regional indicator covering broad areas.

Data for this indicator have been collected for 1342 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing tourist intensity is low, covering 80.8% of the study field site (Fig. 26). The next important class of tourism intensity is moderate, covering 14.2% of the study field sites. High tourism intensity has been identified in 4.9% of the study sites, corresponding mainly to Crete-Greece study site.

Based on t he obtained data, tourism intensity is especially important indicator for assessing desertification risk in pastures. The higher the tourism intensity the higher the land degradation and desertification risk in this land. In order to meet the high tourist demands, crop production and infrastructures have led to expansion of agriculture in pastures overgrazing the remaining grazing land, putting fires for expanding tourism installations into physical areas, therefore, imposing high land degradation and desertification risk.

Policy implementation is significantly affected by tourism intensity in agricultural areas. Areas under hi gh tourism intensity are mainly characterized with moderate or high policy implementation. Under such conditions, local people consider agriculture as a secondary branch of their economy usually accompanied by under-exploitation of natural resources.

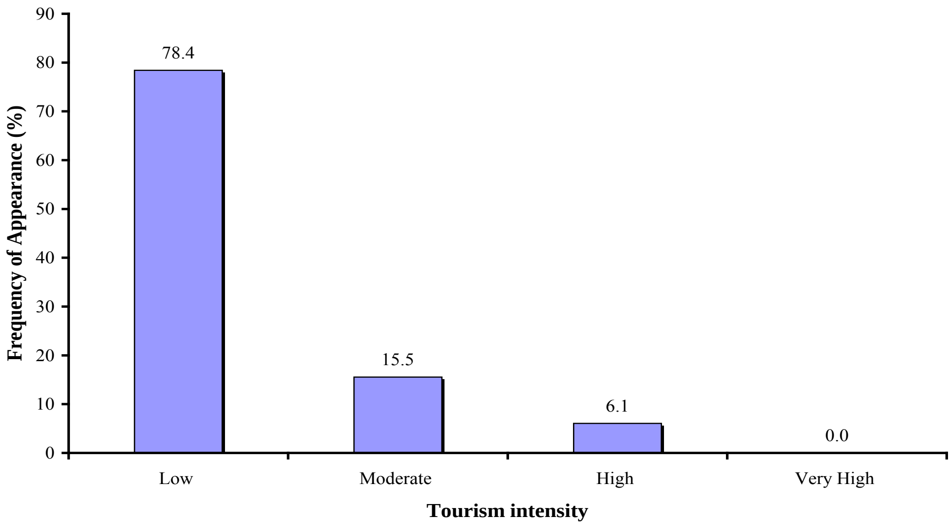

Fig. 26. Distribution of tourism intensity classes defined in 1342 field sites

Tourism intensity is related to water scarcity in areas affected by soil salinization. Tourism intensity has positively affected water scarcity. Areas with high tourism intensities require high quantities of water per capita inducing water scarcity in the broad area. Under such conditions, water is allocated for consumption accompanied with low priority for the amount and the quality of water allocated for irrigation, enhancing problems of soil salinization in irrigated land. Furthermore, water quality is significantly related to tourism intensity and population density. Areas high tourism intensity have good to moderate quality of water. This can be attributed to various factors such as: (a) the presence of rivers carrying high quantities of good quality water accompanied with adequate enrichment of ground water, (b) the expansion of necessary infrastructure for providing adequate quantities of good quality of remote water to satisfy the needs of local population including tourists during the summer period.

Measuring the indicator
Tourism intensity can be defined by collecting data from the local authorities or National Statistical Services. Tourism intensity is calculated by dividing the number of overnight stays (including second homes) with regard to a reference period (year) or within a peak season by the area of 10 square kilometres. The following classes are defined for this project: (a) low, number of overnight stays/10 km^2 areas = R <0.01; (b) moderate, R=0.01-0.04, (c) high, R=0.04-0.08; and (d) very high, R>0.08.

Tourism change

Definition
Tourism change assesses how the tourism destinations have changed in the last 10 years in a specific area.

Importance on land degradation process
Data for this indicator have been defined in 197 field sites corresponding to 6 study sites, located Mediterranean Europe, eastern Europe, Africa, and Latin America. The analysis of the data showed that 93.9% of the study field sites have been considered as subjected to low tourism change in the last decade.

Tourism change is an important indicator for areas affected by water scarcity. Areas under high tourism change (higher than 5%) are subjected to higher water scarcity and desertification risk. Furthermore, tourism change is related to land use intensity in areas affected by water stress. Areas of high rate of tourism change have been characterized by low land use intensity since local population is mainly concerned for tourism which is more profitable than agriculture.

Measuring the indicator
Tourism change can be defined by collecting data from the local administration authorities or National Statistical Service. It is calculated by comparing the number of overnight stays (including second homes) in a specific destination over one year by the average number of tourists overnight stays in the last 10 years. The following are used for this project: (a) low-number of overnight stays in a specific destination over one year / average overnight stays in the last 10 years = R<1%, (b) moderate-R = 2-5%, (c) high-R = 5-10%, and (d) very high-R>10%. Data for this indicator have been provided from the National Statistical Service.

Parallel employment

Definition

Parallel employment define the percentage of off-farm income as a percentage of the total family income (family farm income plus off-farm income) or simply as parallel employment in other sectors except agricultural such as industry, municipality, state, etc.

Importance on land degradation process

When farmers' income is low, then they move to other economic sectors in the area such as industry, tourism, etc., having a parallel employment. Under such economical conditions, farming becomes a second activity with limited actions for protection of the environment from desertification. In some cases, low productivity lands are abandoned with positive or negative consequences depending on the soil and climatic conditions of the area (Fig. 27).

Data for this indicator have been collected in 897 field sites, corresponding to 13 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The majority of the farmers (52.0% of the total field sites) do not work parallel in other economical sectors except agriculture. Parallel employment in industry has been recorded in 19.0% of the study field sites. Parallel employment in state, municipality, and other economical sectors has been described in some cases, covering 7.4%, 5.4%, and 16.2% of the study fields, respectively.

Fig. 27. Examples of negative (left) and positive effects of land abandoned due to parallel employment in other economical sectors outside of agriculture

The indicator parallel employment have been considered as important only in the assessment of desertification risk in agricultural areas. The farmers' income in he study sites is characterized as relatively low to moderate pushing them in parallel employment in other economical sectors such as tourism, industry, etc. Under such economical conditions, farming becomes a secondary activity resulting in low intensity of land use. Therefore, as the obtained data shows land degradation and desertification risk is reduced.

Parallel employment is related to soil erosion measures in pastures overgrazed or not. If farmers have a parallel employment in industry or in the local municipality, then no erosion or low erosion control measures have been applied in the study field sites.

Measuring the indicator
Parallel employment can be identified by contacting the land user.

Farm subsidies

Definition
The indicator is referred to subsidies allocated to the farmers on hectare bases (i.e. arable crop), on level of production (i.e. olive oil), on number of productive animals, etc.

Importance on land degradation process
This indicator aims to assess how the structure of CAP support influences the choice of farmers in terms of agricultural land use and land management practices. However, European Union farm subsidies support has ensured an adequate income to farmers for maintaining landscapes especially in less favoured areas, but this support has favoured the intensification and specialization process in agriculture by applying more fertilizers and pesticides, irrigating the land, increasing the number of animals, etc. Under this financial support, unproductive agricultural areas cultivated with cereals, critical to desertification, have remained under cultivation; further deteriorating soil conditions (Fig. 28). Number of animals has increased in unsustainable number causing severe degradation in vegetation and soils in grazing lands.

Fig. 28. Typical examples of overgrazing (left, Crete) and unproductive agricultural area cultivating with cereals (right, Portugal) highly degraded due to existing policies on subsidies allocation

Based on the new CAP, additional funds are available as a donation for people who apply measures for protection or improvement of the environment, and/or for improvement of the quality of the agricultural products. The support has been included in the so called "Integrated System". The system is implemented in the actions such as: compound support, special funding for the quality of the durum wheat, funding for the nutritious seeds, special support for rice, support for cultivation of plants for energy production, funding for the milk production and extra support, special support for cotton, support/1000 m^2 of the traditional olive orchards, production of durum wheat and corn, production of tobacco, production of olive oil and table olives, sugar beet production, beef meat production, sheep and goats feeding, etc.

Data for this indicator have been collected for 1056 study field sites, corresponding to 10 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The analysis of the data have shown that allocation of subsidies for production have been identified in 64.6% of the study sites. (Fig. 29). No subsidies allocation have been defined in 25.5% of the study field sites, corresponding mainly in areas outside of European Union. Subsidies allocated for environmental protection have been identified only in 9.9% of the study field sites.

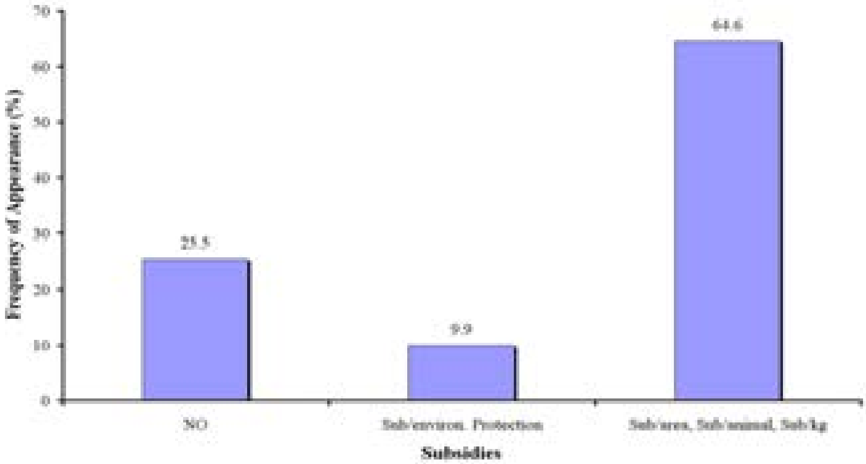

Fig. 29. Distribution of subsidies categories allocated for environmental or production purposes in the study field sites

Subsidies have been found important for assessing desertification risk in agricultural areas and pastures. The analysis of the data have shown that subsidies have promote land degradation an desertification, especially in pastures. Coefficient of linear regression for subsidies is about four times greater in pastures than those in agricultural areas.

Measuring the indicator

This indicator can be described by collecting data from local administration authorities. Subsidies have been classified for the purpose of this project in the following categories: (a) no subsidies, (b) subsidies for environmental protection, (c) subsidies for production provided in the basis of area cultivated, number of animals per farmer, amount of production, etc.

4.3 Indicators related to land management

Major land use

Definition

Major land use is a broad category defining general land use types such as agriculture, pastures, forests, recreation areas, etc (Fig. 30).

Importance on land degradation process

Vegetation is crucial factor which affects soils in all its dynamics including erosion control, water redistribution over and within the soil, and the microbial activity. Surface water runoff is greatly controlled by vegetation which can be readily altered in hilly areas depending on climatic conditions and the period of the year. By its microbial activity affects soil aggregation especially in the surface soil horizon and water infiltration.

Major land use types have been identified in 1324 field sites, corresponding to 16 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing major land use type described in the study field sites is agriculture, covering 50.2% of the total sites. Pasture land is the next important major land use in covering 24.9% of the study field sites. Field sites under forest have been found in 11.4% of the total sites. Shrub-land and other land uses have been identified in 5.3% of the study field sites. Other land uses corresponds to areas under specific regulations such as military installations, settlement places, etc.

Fig. 30. Typical examples of areas with forested (left) and agricultural (right) major land uses

The indicator major land use has been found as important in defined desertification risk in areas affected by tillage erosion, and forest fires. Tillage erosion has been identified in agricultural and grazing areas. Areas used as pastures are more sensitive to tillage than agricultural areas. This can be attributed to the steeper slopes prevailing in pastures.

Grazing control is related to the indicator major land use in pastures. The obtained data have shown that pastures are more intensively grazing in relation to other types of major land uses such as agriculture, forests and shrub-lands. Grazing animals in agricultural and forested lands used to remain for a shorter period since these are areas of secondary use for animal grazing.

Major land use is related to the rate of land abandonment. Areas used for agriculture are characterized by a higher rate of land abandonment than those used as pastures. This is especially important for Mediterranean areas in which an agricultural land after abandonment is usually change to pasture.

Measuring the indicator

Major land use of an area can been defined by: (a) simple field observation, (b) interpretation of aerial photographs or remote sensing images. The following categories of major land have been distinguished in the DESIRE project: agriculture (cropland), pasture, shrub-land, forest, mining area, recreation area, and urban area.

Vegetation cover type

Definition

Vegetation cover type defines the specific characteristics land uses such as vines, olives, cereals, pine forest, oak forest, etc (Fig. 31).

Importance on land degradation process

Extensive Mediterranean areas cultivated with rainfed crops such as cereals, vines, almonds and olives are mainly confided to hilly lands with shallow soils very sensitive to erosion. These areas become vulnerable to erosion and desertification because of the decreased protection effect of the vegetation cover from raindrop impact during heavy rains. Soil erosion measurements conducted along the Mediterranean Europe and Portugal during the execution of MEDALUS projects have shown that under the existing land management practices vines generate the highest amount of runoff and sediment loss followed by eucalyptus, cereals, shrub-land and olive groves in a decreasing rate. Olives present a particularly high adaptation and resistance to long term droughts and under semi-natural conditions support a remarkable diversity of flora and fauna even higher than some natural ecosystems, protecting hilly areas from erosion and desertification.


Fig. 31. Examples of vegetation cover type corresponding to agriculture-olives (left) and pasture-grassland (right)

Vegetation cover type for agricultural areas has been identified in 1108 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant agricultural land use identified in the study field sites is cereals, covering 36.4% of the total field sites (Fig. 32). Olive groves and vineyards have been found in about equal number of field sites, corresponding to 15.9%, 17.1%, respectively. Cotton and vegetables have been described in 10.5% and 7.8% of the study field sites. Land uses such as almonds, oranges, others have been found in few cases, covering 2.8%, 3.1%, and 6.8% of the study field sites, respectively.

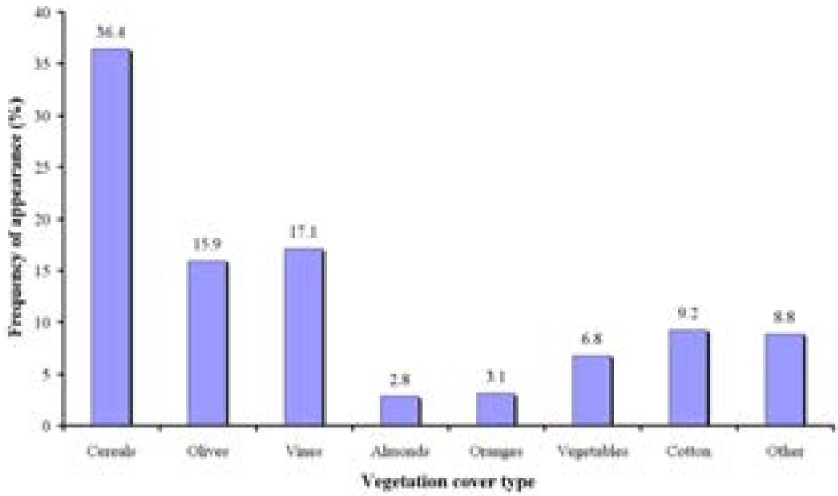

Fig. 32. Distribution of land use types identified in agricultural areas of the study sites

Vegetation cover type has been considered as significant indicator for assessing desertification risk in agricultural and forested areas affected by soil erosion. Agricultural areas covered with cereals are more vulnerable to desertification than areas covered with olives. Similarly, grasslands are more sensitive to land degradation than shrub-lands. The contribution of vegetation cover type is more significant in forested than agricultural areas.

Vegetation cover type is related to land use intensity in agricultural areas. High land use intensity is usually identified in areas cultivated with cereals, vegetables, and vines. Low land use intensity is found mainly in olive groves and almond plantations. Land use intensity in these areas is mainly high when the present land use exists for a period less than 10 years. In addition, policy implementation is usually low in areas cultivated with cereals, vegetables, and vines, while is mainly moderate to adequate in areas cultivated with olives, and almonds.

Vegetation cover type is also related to soil erosion control measures applied in pastures. Such measures are performed in evergreen forests followed with decreasing effectiveness in mixed Mediterranean Macchia and evergreen forests, Mediterranean Macchia and pine forests, permanent grassland, annual grasslands, and deciduous forests. Furthermore, the rate of burned area in overgrazed pastures is characterized as high in areas where the vegetation cover type is mixed Mediterranean Macchia and evergreen forests, Mediterranean Macchia and pines. The rate of burned area is relatively low in areas covered with permanent grass, annual grass and deciduous forests.

The indicator vegetation cover type is significantly related to actions for runoff water storage in forested areas. Adequate actions of runoff water storage have been mainly described in the study field sites in areas covered with evergreen forests, mixed Mediterranean Macchia and evergreen forest, Mediterranean Macchia, and pine forests. Furthermore, vegetation cover type has also affected policy implementation in these areas. Areas with vegetation cover type evergreen forests, mixed Mediterranean Macchia and evergreen forests or Mediterranean Macchia are better protected in relation to areas with annual grasses and deciduous forests.

Measuring the indicator

Land use types can be identified in an area by: (a) simple field observations, and (b) aerial photographs or remote sensing images interpretation. The following categories of plant cover have been distinguished in this project: (a) agricultural land uses: cereals, olives, vines, almonds, oranges, vegetables, cotton, bare land; and (b) forested areas: mixed Mediterranean Macchia/evergreen forest, Mediterranean Macchia, permanent grassland, annual grassland, deciduous forest, pine forest, and evergreen forest (except pines).

Plant cover

Definition

The percentage of soil which is covered by green vegetation is defined as plant cover. Leaf area index (LAI) is an alternative expression of the term plant cover which gives the area of leaves in m^2 corresponding to an area of one m^2 of ground.

Importance on land degradation process

Many studies have demonstrated that in a wide range of environments, both runoff and sediment loss decrease exponentially with increasing percentage of plant cover. Forest vegetation reduces significantly summer soil surface temperatures and it is necessary for the regeneration of many forest species in the Mediterranean. A vegetation cover 45-50% is considered as critical value since above this value soils are adequately protected from raindrop impact and soil erosion is significantly reduced.

Vegetation cover has been measured in 1141 field sites, corresponding to 15 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Field sites with vegetation cover classes greater than the critical value of 50% were found in 28.1% (cover 50-75%) and in 19.2% (cover >75%) of the study field sites. Vegetation cover classes <10%, 10-25%, and 25-50%, which are less than the critical value of 50%, have been measured in a significant number of field sites, covering 17.4%, 17.1%, and 18.1% of the total sites. Most of these field are moderately to severely eroded that the consolidated rock is in shallow depth or has been exposed on the soil surface generating high water runoff rates but low soil loss since there is no soil left to be eroded (Fig. 33). Of course there are cases in which vegetation has been cleared for installing a new plantation creating very adverse conditions for soil erosion, land degradation and desertification (Fig. 33).

Many studies have demonstrated that in a wide range of environments, both runoff and sediment loss are greatly affects by plant cover reducing raindrop impact. Furthermore, plant cover reduces significantly summer soil surface temperatures and soil water conservation. The analysis of the data has shown that plant cover is crucial indicator for assessing desertification risk in agricultural, pastures, and forested areas affected by soil erosion and overgrazing. The highest contribution to land degradation and desertification risk is attributed to pastures subjected to overgrazing or not.

Fig. 33. Areas with poor vegetation cover (<15%) in which soil erosion rates are low since bedrock has been exposed (left) or very high since vegetation has been cleared for new plantation exposing the soil to the raindrop impact (right)

Plant cover in pastures is greatly affected by the effectiveness of grazing control. Furthermore, plant cover is highly related to the biomass available for ignition and propagation of a fire. The conducted study have shown that as plant cover decreased rate of burned area decreased. Adverse soil and climatic conditions combined with high grazing intensity greatly reduces plant cover causing low rates of burned area.

Plant cover is a crucial indicator of land desertification especially in areas affected by water stress. The analysis of data o btained in the DESIRE project have shown that plant cover is greatly affected by various indicators related to climate, soil, vegetation, land management, husbandry, water use, institutional, and social characteristics (Fig 34). The most important indicators related to climate are annual air temperature, annual rainfall, and rain seasonality. High annual air temperatures promotes low plant cover due to high evapotranspiration demands. Furthermore, low amounts of annual rainfall negatively affects plant cover. In addition, high rain seasonality indices have mainly caused low plant cover percentages in the study field sites. The most important soil indicators identified in the study field sites affecting plant cover and desertification risk were soil depth, soil texture and exposure of rock outcrops. Soil depth and soil texture greatly affects soil water storage capacity and therefore plant growth and plant cover under semi-arid or arid climatic conditions.

Areas which are subjected to high water stress are usually used as pastures, therefore, the indicators grazing control or grazing intensity greatly affects plant cover and desertification risk. Field sites in which grazing intensity is moderate or low accompanied with grazing control such as fencing or sustainable number of animals is usually characterized by relatively adequate plant cover, low rates of water runoff, low water stress and desertification risk.

Soil water conservation measures such as temporary storage of water runoff, weed control, mulching greatly contribute to percentage plant cover. Land abandonment positively influenced plant cover in the study field sites. Areas in which land has been abandoned with moderate or high rates had mainly adequate plant cover due to partial recovery of natural vegetation.

Important indicators related to water stress affecting plant cover in the study field sites were water quality, water consumption, and water scarcity. Water resources in the study sites of good quality have contributed to more effective use in supporting vegetation growth and promoting higher plant cover percentages. Water consumption per sector with higher amounts distributed with high priority for tourism or domestic consumption removing water used for irrigation has been identified as an important cause for plant growth and plant cover decrease in the study field sites. Of course field sites located in areas characterized by high water scarcity plant cover had negatively affected.

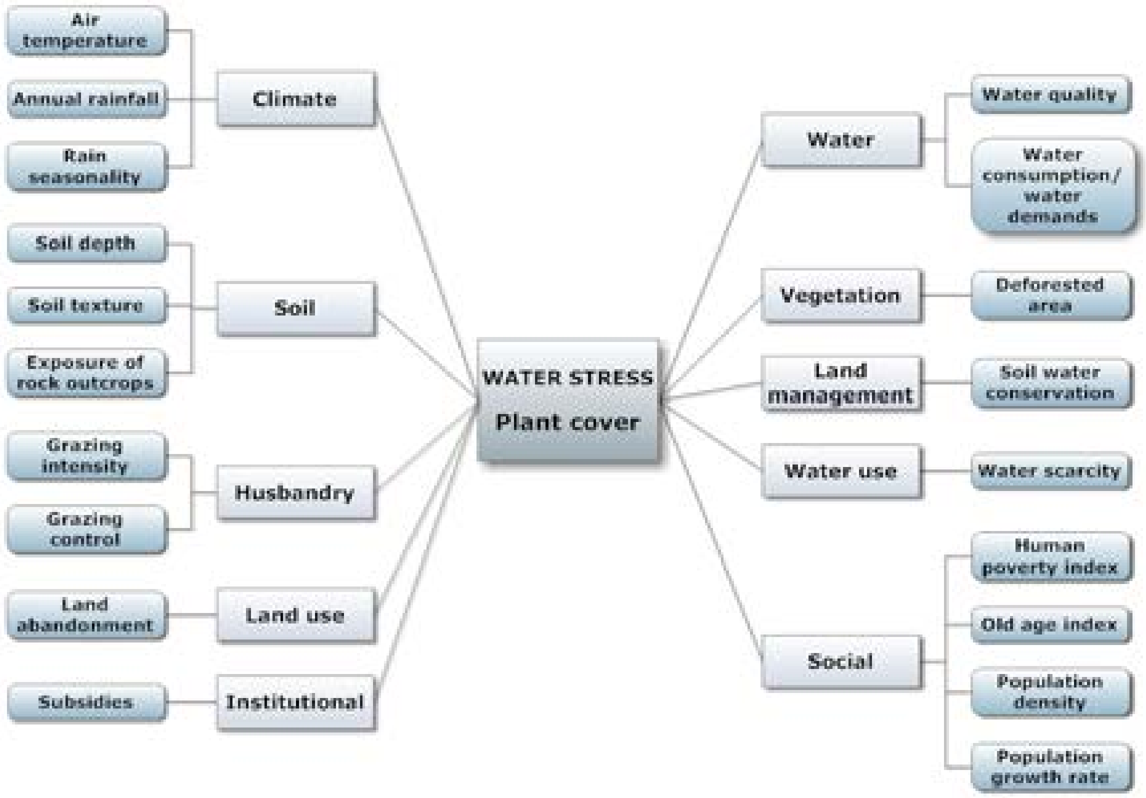

Fig. 34. Important indicators related to plant cover in field sites where water stress is the dominant process of land desertification

Important indicators related to social and institutional characteristics of the study field sites affecting water stress and desertification were human poverty index, old age index, population density, population growth rate, and subsidies. Field sites in areas with low plant cover have been characterized mainly with moderate or high poverty index. Plant cover is related to vegetation growth and generally to land productivity and farmer’s income. Furthermore, old age index is negatively related to plant cover. Field sites in areas with high old age indices have been mainly identified as supporting adequate plant cover subjected to lower desertification risk. On the contrary, field sites located in areas with high population density have supported low plant cover due to overexploitation of natural resources promoting high desertification risk. Similarly, field sites in areas characterized by high population growth rates have been characterized as supporting low vegetation cover. Finally, the presence of subsidies, allocated especially for animals have promoted areas with low plant cover accompanied by high desertification risk.

Measuring the indicator

Vegetation cover can be measured in the field by assessing the percentage of the ground that it is covered by the existing annual or perennial vegetation. Aerial photographs or satellite images can be also used for measuring vegetation cover of extensive areas. Four classes of vegetation cover have been used for the purpose of this project: (a) very low, vegetation cover<10%, (b) low, vegetation cover =10-25%, (c) moderate, vegetation cover = 25-50%, (d) high, vegetation cover = 50-75%, and (e) very high, vegetation cover >75%.

Period of existing land use

Definition

The period of existing land use provides information about the time interval in which a piece of land is under specific land use.

Importance on land degradation process

The present land use type and the period of existence of that land use type is an important indicator as it is related to cumulative long effects on land protection or on land degradation. The vegetation patterns which cover the landscape affect soil in all its dynamics, including water redistribution over and within the soil, soil erosion, soil organic matter content, microbiological activity, etc. Of course other factors such as land use intensity, climate, topography, etc. have a variable effect on s oil degradation. Long term experimental soil erosion studies conducted along the northern Mediterranean Europe under various land uses and exiting land management practices have shown the following average sediment loss range of soil erosion rates (Kosmas et *al*., 1997):

- Cereals: 15- 90 t km-2 yr-1
- Vines: 67- 460 t km-2 yr-1
- Eucalyptus: 1.4-65.6 t km-2 yr-1
- Olives: nill-5.3 t km-2 yr-1
- Shrub land: 0.5-13.8 t km^{-2} yr^{-1}.

Therefore, land use type over a long period is clearly important factors controlling soil loss and desertification risk.

The period of existing land use has been defined in 1206 field sites, corresponding to 13 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing period of existing land use is greater than 50 years, covering 42.2% of the study sites. The next important class of period of existing land use is 20-50 years, covering 29.4% of the study field sites. Period 10-20 years of existing land use has been defined in 11.7% of the study field sites. Very short period of exiting land use (less than 1 year) has been identified in 11.4% of the study field sites. The other classes of period of existing land uses 1-5, and 5-10 years have been defined in few cases, covering 3.7%, and 1.9% of the study field sites, respectively.

The period of existence of the present land use type, is an important indicator as it is related to cumulative long effects on land protection or on land degradation. This indicator is important for pastures with variable effects. Field sites located in pastures, having soil erosion as main process of land degradation, which have been used for short period under this use (less than 10 years) are subjected to higher desertification risk. In the opposite, field sites in pastures located in areas subjected to overgrazing and used for a short period have been subjected to lower desertification risk. This can probably attributed to the degree of farm organization.

Period of existing land use is related to tillage operations in agricultural areas. As the period of the existing land use increases tillage operations mainly decrease. In addition, in pastures affected by overgrazing, if period of existing land use increases, the rate of burned area is characterized mainly as low.

Measuring the indicator

The period of existing land use can be defined by contacting the land user or by interpretation of a chronological series of aerial photographs. The following 5 classes of period of land use are used for the purpose of this project: (a) period <5 years, (b) period 5-10 years, (c) period 10-20 years, (d) period 20-50 years, and (e) period >50 years.

Land use intensity

Definition

Land use intensity is referred to the intensity in which the land resources are used. It is assessed separately for the various land uses, namely agriculture, pastures, forests, etc.

Importance on land degradation process

Repeated cultivation of soils associated with other management practices (application of herbicides and pesticides) results in decreased organic matter content and aggregate stability favouring soil crusting, overland flow, and erosion. Soil compaction is also another form of soil degradation resulting from heavy machineries used in agricultural areas.

Land use intensity in pastures is related to the number of animals grazing the land compared to the sustainable number of animals based on the amount of biomass production (Fig. 35). Intensive grazing results in loss of vegetation cover, degradation of soil structure due to animal trampling, favouring overland flow and soil erosion.

Land use intensity in forested areas is related to yields in wood extraction compared to the sustainable wood extraction. In case that trees are removed in rate higher than the sustainable number, the stand density decreases gradually, the soil is partially covered with vegetation, and therefore from raindrop impact and soil erosion. In mining areas soils are usually disturbed with the bedrock or waste materials exposed in the surface. Such areas require rehabilitation by transporting and spreading soil for allowing the native vegetation to grow.

Fig. 35. Examples of intensive land use of agriculture area (left) and pasture (right)

Data for the indicator “land use intensity” have been collected in 1258 study field sites, corresponding to 16 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Low land use intensity is the dominant class, covering 37.1% of the study field sites. High land use intensity has been identified in 33.1% of the study field sites. Finally, medium land use intensity has been identified in 29.8% of the study field sites.

Land use intensity is especially important indicator in assessing desertification risk agricultural, forested areas and pastures. This indicator affects positively land degradation and desertification. Land use intensity accelerates land degradation and desertification. The highest contribution of land use intensity has been estimated for agricultural areas subjected to tillage erosion.

Important indicators affecting land use intensity and desertification risk in agricultural areas are related to vegetation, water use, land use, cultivation, agriculture, land management, and social characteristics (Fig. 36). High land use intensity has been mainly identified in areas cultivated with cereals, vegetables, and vines. Low land use intensity has been found mainly in olive groves and almond plantations. Furthermore, land use intensity is mainly defined as high when the existing land use has a period of less than 10 years.

Irrigation percentage of arable land has also related to land use intensity in cropland. Areas in which the percentage of irrigated arable land is low (less than 10%), land use intensity has been characterized as low. The high profitability of irrigated land has resulted in low land use intensity in non-irrigated areas.

Among the most important agricultural indicators affecting land use intensity are farm ownership and farm size. High land use intensity has been mainly identified in field sites characterized as tenant- or state-farmed. Under such conditions, farmers try to gain as much as they can, intensively cultivating the land without applying any protection measures. Also, as net farm income decreased due to small farm size land use intensity has mainly decreased since farmers have not the economic strength for applying fertilizers, cultivating the land, etc.

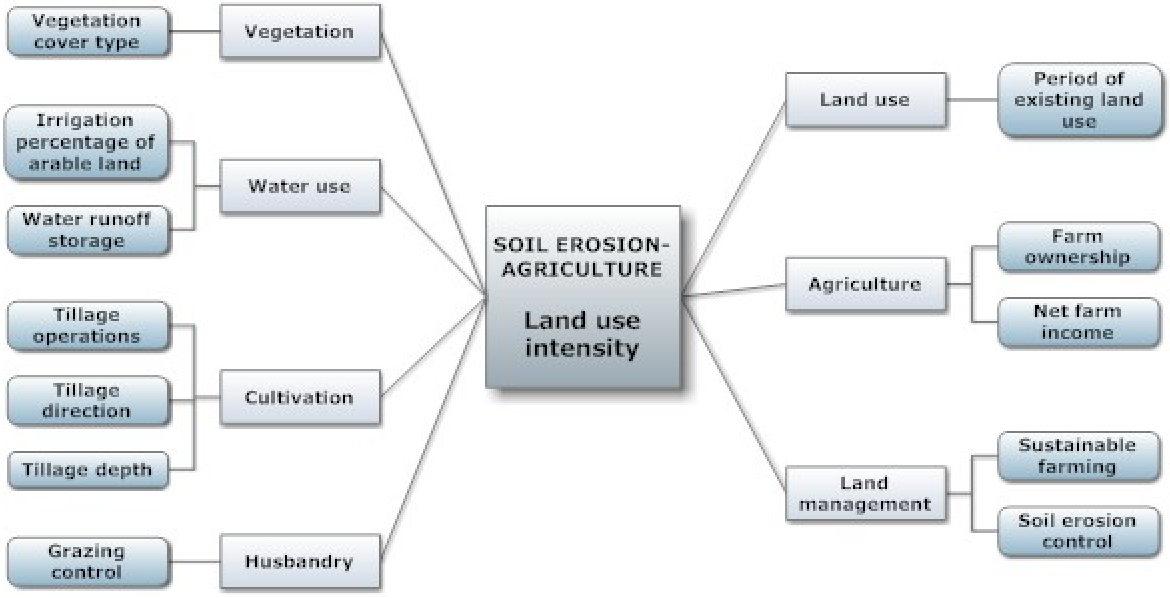

Fig. 36. Important indicators affecting land use intensity in cropland regions

Land use intensity is related to cultivation of the land. Field sites with soils ploughed by a mouldboard in directions perpendicular to the contour lines in depths greater than 30 cm have been mainly characterized as subjected to high land use intensity. On the contrary, field sites in which actions for the protection of the land have been undertaken such as sustainable farming, soil erosion control, storage of water runoff, grazing control have been mainly characterized as subjected to low land use intensity.

Land use intensity in forested areas is related to actions for runoff water storage. Such actions has been mainly identified in areas under adequate runoff water storage actions. Furthermore, policy implementation is related to land use intensity. Areas in which land use intensity has been characterized as high, policy implementation is mainly assessed al low to moderate.

Land use intensity affects water stress and desertification risk through a series of actions related to overexploitation of natural resources. Land use intensity in areas subjected to water stress is associated with several indicators related to the physical environment, land management, and social and economic characteristics (Fig 37). Among the climate indicators, rain seasonality, and aridity index are the most important. In areas with high aridity indices and high rain seasonality, land use intensity is mainly characterized as moderate or low. Under adverse climatic conditions in which water stress is the main limitation factor, land productivity is low discouraging farmers to cultivate intensively the land, partially reducing desertification risk.

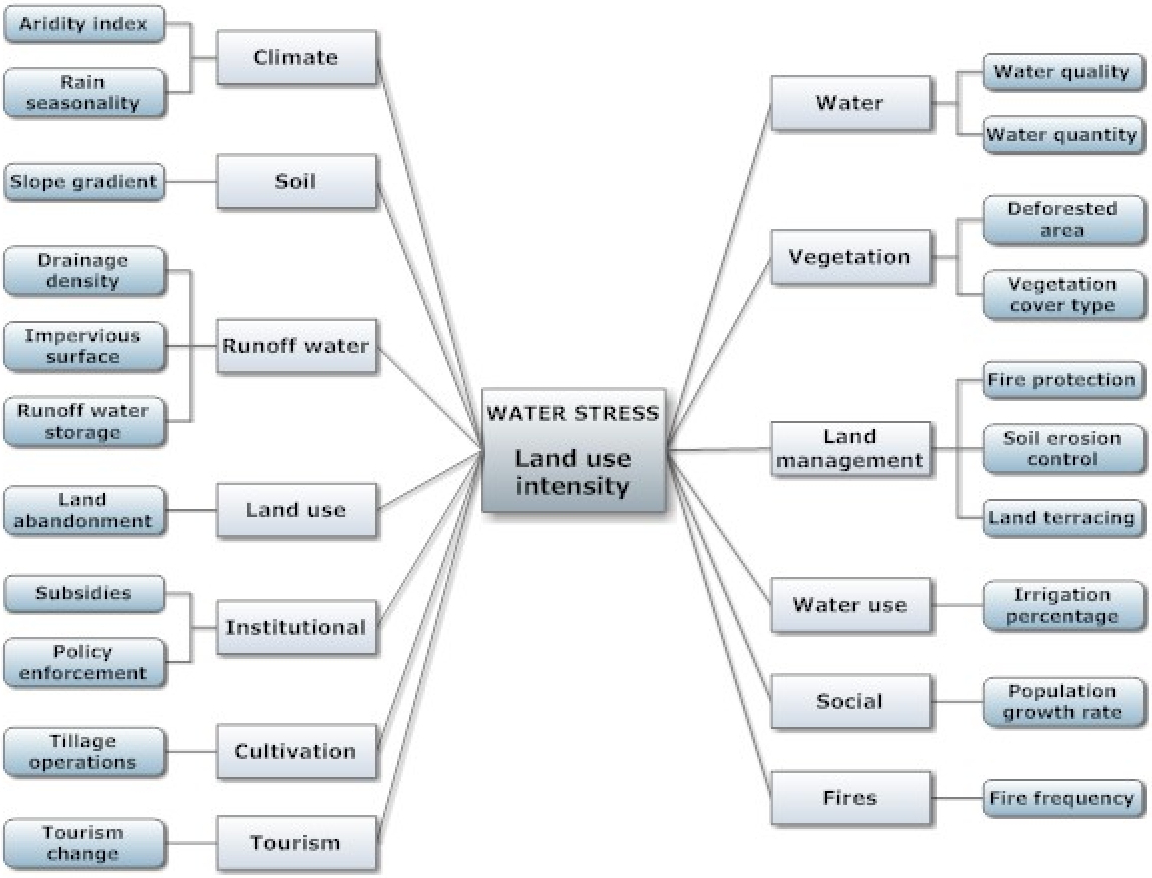

Fig. 37. Important indicators related to land use intensity in field sites where water stress was a dominant process of land desertification

Areas which are subjected to high water stress are usually used as pastures, therefore, the indicators grazing control or grazing intensity greatly affects plant cover and desertification risk. Field sites in which grazing intensity is moderate or low accompanied with grazing control such as fencing or sustainable number of animals is usually characterized by relatively adequate plant cover, low rates of water runoff, low water stress and desertification risk.

Soil water conservation measures such as temporary storage of water runoff, weed control, mulching greatly contribute to percentage plant cover. Land abandonment positively influenced plant cover in the study field sites. Areas in which land has been abandoned with moderate or high rates had mainly adequate plant cover due to partial recovery of natural vegetation.

Important indicators related to water stress affecting plant cover in the study field sites were water quality, water consumption, and water scarcity. Water resources in the study sites of good quality have contributed to more effective use in supporting vegetation growth and promoting higher plant cover percentages. Water consumption per sector with higher amounts distributed with high priority for tourism or domestic consumption removing water used for irrigation has been identified as an important cause for plant growth and plant cover decrease in the study field sites. Of course field sites located in areas characterized by high water scarcity plant cover had negatively affected.

Important indicators related to water runoff affecting land use intensity are drainage density, rate of expansion of impervious surface area, and storage of water runoff. Areas affected by water stress characterized by high drainage density are mainly intensively used for crop production or for grazing. Drainage density can be considered that indirectly affects land use intensity. Drainage density is related to parent materials in which soils have been formed. For example soils formed in shale parent material have been usually characterized by high drainage density, high productivity stimulating farmers for intensively use. Furthermore, high rates of expansion of impervious surface area in the study areas are associated with low land use intensity. Land use intensity is negatively related to actions for storage of water runoff.

Areas affected by water stress and subjected to high frequency of fires accompanied by low measures of fire protection are mainly characterized by moderate or high land use intensity. Forest fires are usually associated with an expansion of agriculture in physical areas or elimination of perennial vegetation for allowing palatable grass to be grown for the animals where land is then intensively cultivated or overgrazed.

Tillage operations are clearly related to land use intensity in agricultural areas. Field sites especially in areas cultivated by vines, olives or grass in pastures have been subjected to high land use intensity aggravating soil erosion, water stress and desertification risk.

The most important land management indicators related to land use intensity in areas with waters stress the main cause of land degradation are soil erosion control, land terracing, runoff water storage, and land abandonment. Field sites located in areas with low measures of soil erosion control, low percentage of terracing, and low actions for storage of runoff water are mainly subjected to high land use intensity. Furthermore, areas with high rates of land abandonment are mainly characterized by high land use intensity. Such areas are usually used as pastures which are mainly overgrazed, or since the arable land is limited, farmers cultivate it intensively for partial compensation of the missing production due to land abandonment. Also, policy implementation is related with the above actions for environmental protection is negatively related to land use intensity. Field sites in which policy implementation is characterized as moderate to low have been intensively used as agriculture or pasture land.

Finally, the most important indicators related to social and institutional characteristics and affecting land use intensity in areas with water stress considered as the main cause of land degradation are tourism change, population growth rate, and subsidies. Areas with high rate of tourism change are mainly characterized by low land use intensity since local population is mainly concerned in tourism which is more profitable than agriculture. Furthermore, areas with high population growth rates are usually characterized by low land use intensity. This trend needs further analysis since other factors may be associated with land use intensity. Also land use intensity is negatively related to subsidies. This can be true for areas of low productivity in which land is partially cultivated just to meet the requirements for subsidies allocation.

Measuring the indicator

Land use intensity can be characterized separately for the various major land uses, namely cropland, pastures, and forests. The land use intensity for cropland is assessed by characterizing the frequency of irrigation, degree of mechanization, the use of agrochemicals and fertilizers, the crop varieties used. Three levels of land use intensity are distinguished in this project:

- Low land use intensity (extensive agriculture): Local rain fed plant varieties are used, fertilizers and pesticides are not applied, yields depend primarily on the fertility of soils and environmental conditions. Mechanization is limited. In the case of seasonal crops, one crop is cultivated per year or the land remains fallow.
- Medium land use intensity: Improved varieties are used, insufficient fertilizers are applied and inadequate disease control is undertaken. Mechanization is restricted to the most important tasks such as sowing.
- High land use intensity (intensive agriculture): Improved varieties are used. Application of fertilizers and control of diseases are adequate. Cultivation is highly mechanized.

The land use intensity for pasture is by estimating the stocking rate (SR) of the area and comparing it with the sustainable stocking rate (SSR). The necessary formulas for assessing these values are given in the indicator "grazing intensity". The intensity of use has been estimated by comparing the SSR and the actual number of animals grazing the land (SR) and forming the ratio actual/sustainable. The following classes are distinguished: (a) low-SR<SSR, (b) moderate-SR = SSR to 1.5*SSR, and (c) high- SR>1.5*SSR.

The assessment of land use intensity for natural land (forests) requires a major distinction between natural forests and managed forest. In the case of natural forests the land use intensity is considered low as there is by definition absence of any management. In the case of managed forests, the intensity of use is determined by comparing the sustainable (S) and the actual (A) yield of the forest and forming the ratio actual/sustainable. The following classes are distinguished: (a) low-A/S = 0, (b) moderate-A/S <1, and (c) high-A/S = 1 or greater.

Mechanization index

Definition

Mechanization index is defined as the motor vehicles, machinery used by the agricultural holding expressed in terms of horsepower (HP) per hectare of the Utilized Agricultural Area.

Importance on land degradation process

This indicator gives a measure of how agricultural activities contribute to physical soil degradation.

Data for mechanization index of the study field sites have been collected in 262 field sites, corresponding to 4 study sites, located in Mediterranean Europe, Africa, and Asia. The prevailing class of mechanization index of the study field sites is characterized as moderate, covering 56.5% of the total fields. The next important class of mechanization index is low, covering 32.4% of the study field sites. Finally, high mechanization index has been defined in 11.1% of the study field sites.

Mechanization index has been defined as an important indicator in assessing desertification risk in agricultural areas in which the main process of land degradation is tillage erosion. The higher the mechanization index the lower the land degradation and desertification risk in agricultural areas. Of course the contribution of this indicator in the estimation of desertification risk is relatively low.

Measuring the indicator

According to the EUROSTAT Glossary the following categories of machineries are distinguished: (a) four-wheeled tractors, track-laying tractors, tool carriers, (b) cultivators, hoeing machines, rotary hoes, motor mowers, (c) combine harvesters, and (d) other fully mechanized harvesters (Fig. 38). Utilized Agricultural Area (UAA) is the sum of arable land, kitchen gardens, permanent pasture and meadow, permanent crops (EUROSTAT). For calculation of mechanization index the ratio of the total horsepower (HP) of each tractor, cultivator, and piece of machinery has been divided by the hectares of UAA.

Fig. 38. Machinery used for calculation of mechanization index of a farm

Tillage operations

Definition

Tillage operations includes the cultivation practices conducted by the various tillage implements such as mouldboard plough, chisel plough, duckfoot chisel, harrow, etc.

Importance on land degradation process

In the last decades soil management has changed dramatically by introducing new land cultivation implements. The availability of heavy powerful machinery favoured deep soil ploughing and high speeds in directions usually perpendicular to the contour lines. This resulted in the displacement of huge amounts of soil materials from the upper convex parts (summit, shoulder, backslope) of a hillslope to the concave parts (footslope, toeslope) and decreased significantly the production of the various crops. Such cultivation practices have greatly contributed to deterioration of soil quality for plant growth due to tillage erosion. Tillage erosion affects soil quality for long terms, by changing soil depth and consequently water holding capacity, nutrient availability, organic matter content, and crop yield.

Tillage operations include the cultivation practices conducted by the various tillage implements such as mouldboard, chisel, duck foot chisel, harrow, etc. (Fig. 39). The various tillage implements cause various erosion rates. For example a t andem disk may be more erosive than a mouldboard plough operation because it d isplaces more soil with greater variability throughout the landscape. The chisel plough may be equally erosive as the mouldboard plough. Large aggressive tillage implements, operating at excessive depths and speeds are more erosive than conventional ones.

Fig. 39. Tillage implement used for cultivation of hilly areas (left) preparing the soil for planting (right)

Data this indicator have been collected in 1143 field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The most important tillage operations are no tillage or minimum tillage recorded in 42.2% of the study field sites. No tillage operations have been defined in areas cultivated with perennial crops such as olives and in areas used as pastures. The next important class is ploughing, covering 33.5% of the study field sites. Ploughing of the soil has been mainly conducted in areas cultivated with annual crops such as cereals, cotton, vegetables, etc. Disking and harrowing operations have been identified in 16.1% of the study field sites. Such tillage operations have been applied mainly in perennial crops such as olives, vines, oranges, etc. Tillage operation by cultivator has been defined in very few cases (2.4%) of the study field. Finally other types of cultivation of the land have been defined in 5.8% of the study fields. This corresponds to the cultivation of hilly areas with very steep slopes, in which the land is cultivated by hand in rows located parallel to the contour lines in order to conserve water and reduce soil erosion by surface water runoff (Fig. 40).

Tillage operations are considered especially important in assessing desertification risk in agricultural areas subjected to water erosion or/and tillage erosion. As it was expected, land degradation and desertification risk of sloping field sites is higher in mouldboard ploughing than using cultivator.

The analysis of the obtained data have shown that tillage operations such as ploughing, disking, harrowing, etc. were affected by various indicators related to the physical environment, land management characteristics, social and economic characteristics (Fig. 41). Tillage operations in the study field sites are negatively affected by climate characteristics such as potential evapotranspiration, rain seasonality, and rain erosivity. Field sites remain mainly uncultivated under dry climatic conditions characterized by high evapotranspiration rates and high rain seasonality since soils conditions were not favourable for growing a crop. Also tillage operations were negatively related to rain erosivity.

Fig. 40. Cultivation of the land in rows parallel to the contour lines (left) and experimental station assessing the effectiveness of these cultivation practices in conserving water and reducing soil erosion in Santiago Island-Cape Verde

Among the soil indicators, slope gradient and soil depth are mainly related to tillage operations. As slope gradient increased, or soil depth decreased tillage operations are rather limited in the study field sites. Thus, field sites with shallow soils or steep slopes are rarely cultivated.

The rate of change of impervious soil surface has negatively affected tillage operations. Areas with high rate of change in impervious soil surface are usually related to tourism or industrial activities in which agriculture is rather a secondary branch of economy resulting in less intensive agriculture accompanied by limited number of tillage operations.

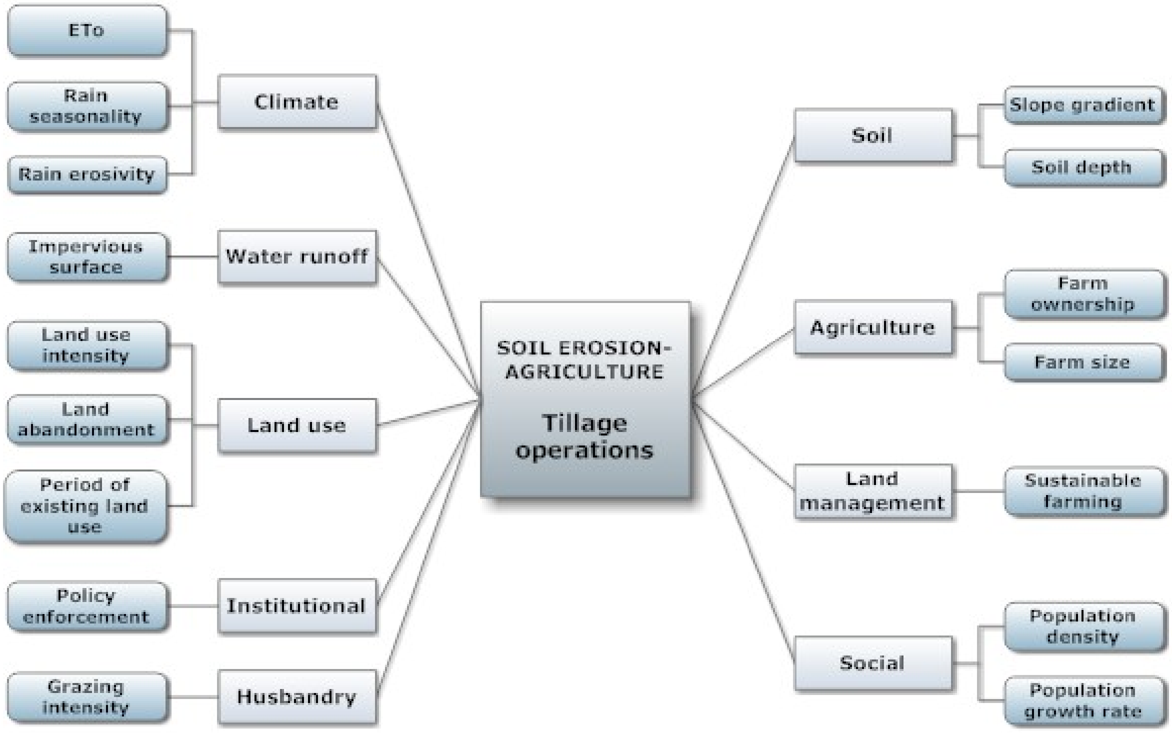

Fig. 41. Important indicators affecting tillage operations in 1143 field sites in agricultural areas

Agricultural characteristics significantly affecting tillage operations in the various field sites are land ownership and farm size. As farm ownership changes from owner-farmed to shared-farmed, tenant-farmed tillage operations are reduced. In addition, as farm size decreases tillage operations usually decrease since farmers are not usually organized on a professional basis.

Important indicators related to land use and affecting tillage operations are land use intensity, land abandonment, and the period of existing land use. Land use intensity has affected tillage operations in different ways. In case that the agricultural land is additionally used for grazing animals for a certain period of the year, then tillage operations are reduced. On the contrary, when the land is exclusively used for agriculture, land use intensity increases by applying irrigation, fertilization, etc., accompanied by increased number of tillage operations. Furthermore, as the period of the existing land use increases tillage operations mainly decrease. The rate of land abandonment in the study field sites is positively related to tillage operations. As the rate of agricultural land abandoned increases, the remaining land is more intensively cultivated for compensation of the loss in crop production.

As it is expected sustainable farming is negatively related to tillage operations. Furthermore, policy implementation of existing regulations for environmental protection is positively related to tillage operations. When no measures for protecting the land from degradation are applied, the land is usually intensively cultivated leading to high erosion and degradation rates.

Among the social characteristics of the study field sites population density and population growth rate are closely related to tillage operations. In field sites with high population densities and high rates of population growth, tillage operations are mainly identified as low. These are opposite trends than are expected. Perhaps people in these circumstances are more likely to have off-farm income. Finally, it seems that some other social and economic conditions prevailing in the study field sites are also influencing the cultivation of the land such as the ratio of rural/urban population, net farm income, etc.

Measuring the indicator

Tillage operations can be defined after contacting the land user. The following tillage operations are distinguished for the DESIRE project: no tillage, ploughing, disking, harrowing, and cultivator operation.

Tillage direction

Definition

Tillage direction defines the direction of tilling the soil. The soil can be tilled parallel or perpendicular to the contour lines or in oblique lines depending on land characteristics.

Importance on land degradation process

The various cultivation practices such as tillage direction, direction of furrow reversion, and plough depth have variable effect on soil displacement (Fig. 42). By ploughing the soil at shallow depth in any direction of tillage operation, tillage erosion is significantly reduced.

When the physiographic conditions allowed the movement of tractor along the contour lines, then soil displacement is highly restricted. Any other direction of tillage operation increases tillage erosion. If the plough layer is moved to the up s lope position under any tillage operation, then soil displacement could be considered as an operation for restoring and conserving degraded hilly areas. In hilly areas with steep slopes, where contour farming is impossible, then the soil can be ploughed perpendicular or in oblique lines but ploughing the soil at shallow depth and moving preferably the plough layer to the up slope direction.

Fig. 42. Ploughing the soil perpendicular to the contour lines (left) and in oblique line (right)

Data for this indicator have been collected in 1040 field sites, corresponding to 12 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dom inant direction of ploughing in the study field sites is down slope, covering 19.2% of the total fields. This type of tillage direction causes the highest rates of soil displacement in hilly areas. The next important tillage direction defined is p arallel to the contour line with up-slope reversion of furrow, covering 11.1% of the study fields. The next important tillage direction is p arallel to contour lines with down-slope reversion of furrow, covering 6.5% of the study fields. Down slope ploughing in oblique direction has been found in 8.2% of the study field sites. Upslope or upslope oblique tillage direction has been defined in few cases (0.3%, and 3.2% of the study sites). Finally, no tillage has been defined in half of the study field sites (51.5%).

Tillage direction has been defined as an important indicator for assessing desertification risk in pastures. When the physiographic conditions allow movement of tractor along the contour lines, then soil displacement is highly restricted and desertification risk is low. In cases that contour farming is impossible and soil is ploughed perpendicular to the contour lines, soil displacement is high and desertification risk is high.

Measuring the indicator

Tillage direction can be easily defined in the field by looking the lines of ploughing in relation to the contour lines or by conducting the land user. Also The following categories of tillage direction are distinguished in this project: (a) down slope, (b) upslope, (c) parallel to contour-upslope furrow, (d) parallel to contour-down slope furrow, (e) down slope oblique, and (f) upslope oblique.

Tillage depth

Definition

Tillage depth corresponds to the depth that tillage implements such as mouldboard, cultivator, chisel plough, harrow etc. is disturbing the soil.

Importance on land degradation process

Tillage depth greatly affects soil redistribution along a catena. The deeper the soil is ploughed the greater the soil displacement in the direction of tillage. Studies on tillage erosion conducted during the execution of the EU research project TERON have been shown that soil displacement is reduced to about one third when plough depth is decreased from 40 cm to 20 cm. The effect of plough depth on soil displacement is especially pronounced on steep slopes where the furrow slice with shallow ploughing sometimes do not completely reverse, but it remains in an angle usually perpendicular to the soil surface, so that soil displacement is greatly reduced (Fig. 43). When furrow slice is reversed in the down or up slope direction (independently of tractor travel direction), soil displacement is greater because gravity acts as an additional force displacing farther the soil. Of course other parameters besides ploughing depth and slope gradient could affect reversion and breaking down of furrow such as tractor speed, soil moisture content, soil consistence, rock fragment content, etc.

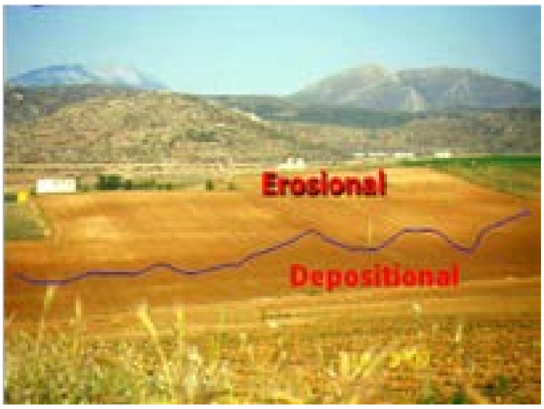

Fig. 43. Displacement of soil to the direction of ploughing accompany with reversion of plough slice due to the deep ploughing (left) and displacing huge amounts of soils from the upper convex and linear part of the slope and depositing in the lower concave part (right)

Data for this indicator have been collected in 1040 study field sites, corresponding to 13 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of tillage depth is 20-30 cm covering 26.7% of the study field sites. The next important class of tillage depth is less than 20 cm, covering 20.4% of the total fields. Deep (30-40 cm) and very deep (>40 cm) ploughing has been defined in few cases, covering 5.1% and 2.3% of the study field sites. Finally, the dominant class is no tillage operations, covering 45.5% (Fig. 44) of the total fields, with all the positive effects on soil quality and soil erosion protection.

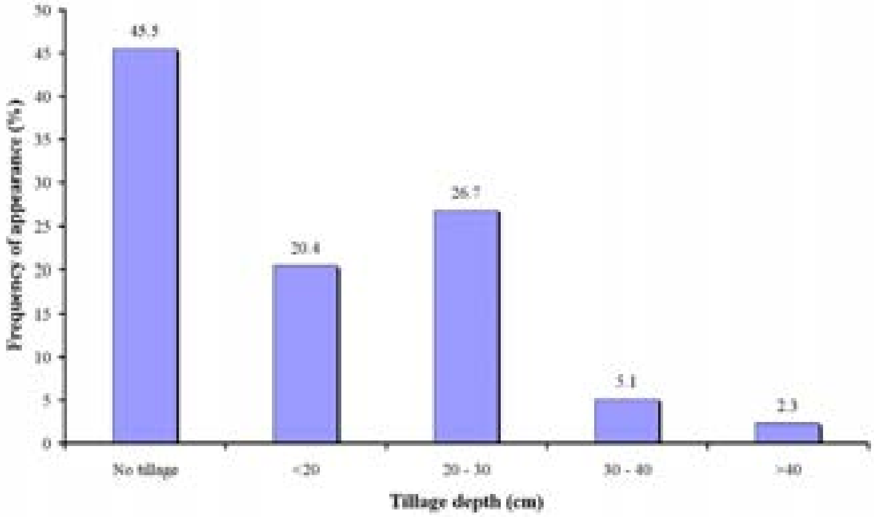

Fig. 44. Distribution of tillage depth classes defined in the study field sites

Tillage depth is an important indicator for assessing desertification risk especially in agricultural areas and pastures. Desertification risk increases as plough depth increases in agricultural areas. Opposite trends are found for pastures. The deeper the ploughing depth the lower the desertification risk. Pastures in the study field sites are seldom ploughed. Of course a minimum tillage at the depth of 15-30 cm every 3-5 years can be beneficial for soil physical properties by mixing soil organic matter and fertilizers, improving aggregate stability and reducing soil erosion and desertification risk.

Land use intensity is reacted to the tillage depth. Field sites with soils ploughed by a mouldboard in directions perpendicular to the contour lines in depths greater than 30 cm are subjected to high land use intensity. Furthermore, policy implementation is characterized mainly as low under these cultivation practices. On the contrary, field sites in which tillage operations are limited combined with actions for soil erosion control, policy implementation is characterized as moderate or high.

Measuring the indicator

Tillage depth can be defined by conducting the land user or the extension services of the related institutes. Also plough depth is easily measured in the field by digging the upper soil layer and measuring the depth in which tillage implements reach. The following classes are used for the purpose of DESIRE project: (a) shallow, tillage depth <20 cm; (b) moderate deep, tillage depth 20-30 cm; (c) deep, tillage depth 30-40 cm; and (d) very deep, tillage depth >40 cm.

Grazing control

Definition

Grazing control defines the actions such as sustainable number of grazing animals, fencing of grazing land, etc. taken in a pasture for land protection.

Importance on land degradation process

Grazing control is a management action aiming at the establishment of equilibrium between herbivores and the resource base of rangelands so that sustained production is ensured. This equilibrium suggests that animal grazing should be practiced so that range condition is maintained at a productive state and rangelands stay healthy. Generally, there are two main systems of grazing a land, namely: (a) continuous, and (b) rotational. In the continuous grazing system, animals remain throughout the grazing land during whole growing period or all the period of the year (Fig. 45). Such a system is beneficial to the animals since they are free to walk around and to select the best plants or plant parts available in the pasture. However, such a system is detrimental for the pasture since plant species do not have the chance to recover and in many cases soil remains partially covered by vegetation for protecting it from the raindrop impact. On the opposite, a rotational grazing system, involves division of the grazing land in pieces allowing the animals graze sequentially over the growing season of the year. Such a grazing control system allows the vegetation to recover and to protect soil from erosion.

Desertification of grazing lands and landscapes caused by grazing animals is a complex process affecting both vegetation and soil characteristics. Grazing animals remove in the first stage the more palatable species followed by less palatable ones, which finally these species dominate in the grazed area. In addition, trampling on the soil surface by the animal hooves exerts high pressure resulting in soil compaction, digging and soil structure deterioration. Therefore, degradation of vegetation accompanied by decrease in plant cover and destruction of surface soil aggregates favours surface water runoff generation and soil loss. Soils in grazing lands are usually shallow overlying bedrock. Thus, any loss of soil negatively affects vegetation growth and water storage capacity leading in extreme cases to desertification.

Fig. 45. Pastures under continuous grazing subjected to high vegetation degradation and soil erosion (left) and under overgrazing and sustainable grazing systems (right)

Data for this indicator have been collected in 1141 field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing grazing system in the study field sites is no grazing control, covering 57.7% of the total fields sites. Sustainable number of animals have been defined almost in the rest of the study field sites (35.3% of the total fields. Other grazing systems such as fencing has been identified in few cases (6.0% of the total field sites).

The analysis of the obtained data have shown that grazing control is an important indicator related to land degradation and desertification risk in pastures and forests. As it is expected land degradation and desertification risk is significantly reduced under grazing control such as keeping sustainable number of animals or fencing and alternately grazing the land. The contribution to land protection is especially important for area s subjected to forest fires. In cases that forested areas are sustainable grazed, an amount of flammable biomass affecting ignition of wildfires are removed by the animals and farmer remains into the forest for long time during the year protecting the land from man induced forest fires. Under no grazing conditions, forests are more vulnerable to forest fires and desertification risk becomes higher.

The analysis of collected data in areas used as pastures sites have shown that grazing control in the study field sites is r elated to the physical environment, land management practices, and socio-economic conditions (Fig. 46). Annual evapotranspiration and rain seasonality are among the most important climatic indicators. As annual evapotranspiration increases, grazing control is diminished since land productivity is reduced accompanied with lack of measures for soil erosion control. Furthermore, rain seasonality is positively related to grazing control. Under long periods of drought, grazing control is not easily achieved, since the produced palatable biomass is not adequate to feed even a medium number of grazing animals.

Grazing control is also affected by the major land use and vegetation cover type in the areas used for pastures. Land used as pasture is usually intensively grazing in relation to other types of major land uses such as agriculture, forests and shrub-lands. Grazing animals in agricultural and forested lands used to remain for a shorter period since these are areas of secondary use for animal grazing. Furthermore, in areas under natural vegetation, grazing control is m ore limited in annual and perennial grasslands, Mediterranean Macchia, and deciduous forests, than in evergreen forests, mixed Mediterranean Macchia/evergreen forests. Furthermore, plant cover remains high in areas under grazing control.

Among the most important soil indicators affecting grazing control is soil depth, and soil texture. Grazing control in areas with shallow soils is almost absent since biomass production is hi ghly limited to satisfy the basic needs of the grazing animals. Highly degraded areas with shallow soils are usually considered as badlands by the farmers avoiding any actions against soil erosion through grazing control. Soil texture is related to soil water storage capacity. Field sites with soils of low water storage capacity or coarse-textured have low productivity and grazing control is usually absent.

Grazing control is positively related to land protection actions such as soil erosion control and fire protection in pastures. Such land protection actions are usually associated with grazing control. No actions for controlling soil erosion has been defined in the majority of the study field sites, when the land is intensively grazed. Furthermore, the rate of land abandonment is negatively related to grazing control. Field sites in which the rate of abandonment is high, grazing control is mainly characterized as low, further deteriorating the already degraded lands.

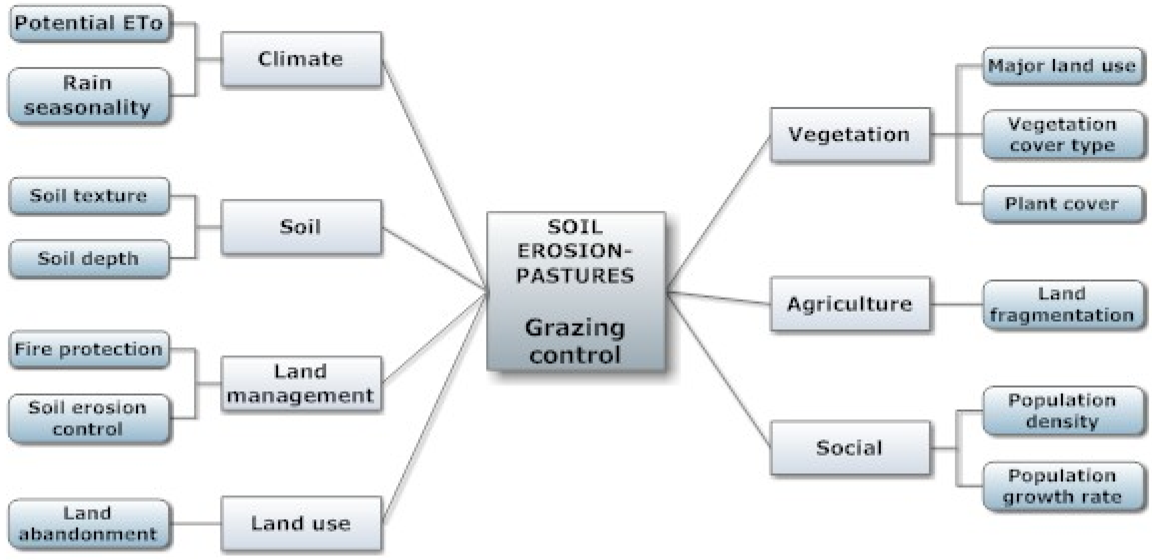

Fig. 46. Main indicators related to grazing control in pastures where the main process of land degradation is soil erosion

Grazing control in pastures is significantly related to land fragmentation. Grazing control is usually decreased as land fragmentation increases. Farmers used to keep the animals for longer period in highly fragmented land or the available biomass for even medium number of animals is rather limited overgrazing it.

Among the social characteristics affecting grazing control in pastures, the most important indictors in the study field sites are population density and population growth rate. Grazing control is more effective in areas with low population density. On the contrary, in areas with high population growth rate, grazing control is mainly characterized with some actions such as sustainable number of animals, fencing grazing land, and alternative grazing.

Areas subjected to high water stress are usually used as pastures, therefore, the indicators grazing control or grazing intensity have greatly affected plant cover and desertification risk due to water stress. Field sites in which grazing intensity is moderate or low accompanied with grazing control such as fencing or sustainable number of animals has been characterized by relatively adequate plant cover, low rates of surface water runoff, low water stress and desertification risk. High grazing intensities accompanied without any grazing control measures result in low plant cover, high rates of water runoff, and high desertification risk due to water stress.

Measuring the indicator

The existing grazing system in an area can be defined by conducting the land user. The following actions are considered as controlled grazing in the DESIRE project: (a) assigning a sustainable number of grazing animals, (b) fencing of grazing land and alternatively grazing,

(c) avoidance of grazing when soils are very wet, (c) fire protection of grazing land, and (d) other specified.

Grazing intensity

Definition

Grazing intensity is a measure of the pressure imposed on the growing vegetation by the grazing animals.

Importance on land degradation process

The number of animals is the main factor that affects the productivity of the grazed lands. A standard way to express this impact is to calculate the stocking rate, namely the number of animal units per unit area during the grazing period. If the stocking rate in a grazing land is higher than its grazing capacity then overgrazing occurs (Fig. 47). An overgrazing land is vulnerable to desertification if the high number of animals remains for long period in the pasture, and the soil, topographic and climatic conditions are adverse.

Besides overgrazing, undergrazing can also cause desertification due to the growth of high amount of flammable biomass affecting ignition of wildfires and leading to high erosion rates and land degradation. In addition, undergrazed lands which are not burned are invaded by woody species resulting in loss of biodiversity due to high plant competition which is also a form of ecological decline. Therefore, a sustainable grazing of the pasture land is considered the best land management practice for protecting such areas from desertification.

This indicator have been described in 1141 field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The prevailing class of grazing intensity in the study field sites is characterized as low, that means the stocking rate is lower than the grazing capacity, covering 53.7% of the total fields. The next important class of grazing intensity is high, covering 33.2% of the study field sites. Finally, moderate grazing intensity has been defined only in 12.4% of the total field sites.

Fig. 47. Grazing land under high (left, Botswana) and low stocking rate (right, Crete) subjected to high and low desertification risk, respectively

Grazing intensity has been found as an important indicator for assessing desertification risk in forested areas and pastures. The obtained data of the study field sites have shown that grazing intensity has opposite effects in forested areas and in pastures overgrazed. An overgrazing land is vulnerable to desertification if the high number of animals remains for long period in the pasture. Field sites located in forested areas under low grazing intensity or undergrazed are more vulnerable to land degradation and desertification since high amount of flammable biomass affecting ignition of wildfires is growing leading to high erosion rates after a fire event. In the opposite, pastures under high grazing intensity are vulnerable to desertification due to low plant cover. Therefore, a sustainable grazing of a forest or a pasture is considered as the most appropriate land management practice for protecting such areas from desertification.

The analysis of the obtained data have shown that grazing intensity in forested areas is related to c limate, soil, forest fires, land use, land management, agriculture, water runoff, institutional, and social characteristics (Fig. 48). As annual rainfall decreases grazing intensity mainly decreases since the understory vegetation grazed by the animals is highly restricted. This is further explained by the annual potential evapotranspiration. Grazing intensity is mainly characterized as low in areas with high annual potential evapotranspiration. Furthermore, under high rainfall seasonality index, grazing intensity is also defined as high.

Important soil indicators related to grazing intensity in forested areas are parent material, percentage of rock fragments in the soil surface, slope gradient, soil texture, organic matter in the surface horizon, and soil water storage capacity. Grazing intensity is mainly characterized as moderate to high in soils formed in conglomerates, shale, and basic igneous rocks. Soils formed in such soil parent materials are usually more productive than soils formed in limestone and acid igneous rocks. Soils formed on l imestone and acid igneous rocks are usually dry for long period or highly degraded with low biomass production resulting in low grazing intensity. Also, high grazing intensity has been identified in areas in which soils have low amount of rock fragments in the soil surface. Rock fragments in the soil reduce effective soil depth and probably biomass production. Both indicators of parent material and rock fragments under conditions of low biomass production are usually accompanied with low grazing intensity. Furthermore, grazing intensity has been mainly defined as low in field sites with steep slope gradients. Soil indicators affecting water availability to growing plants such as soil textures and soil water storage capacity are related to grazing intensity. Areas with coarse-textured soils of low water storage capacity have been subjected to high grazing intensity since the produced palatable biomass is rather limited. Finally, high grazing intensities have been defined in areas with soils of low organic matter content since high soil erosion rates are expected in such cases. Of course, soil organic matter content can been affected by other factors such as climate, type of vegetation, other soil characteristics, etc.

Field sites located in forested areas with high drainage density have been subjected to low grazing intensity. Such land management can be attributed to various factors such as type of parent material (biomass production), degree of soil erosion, accessibility by animals, etc.

Field sites located in areas of high burned rates have been subjected to low grazing intensity. This can be attributed to the existing regulations of land management of forested areas after fire, or to the willingness of local people to protect fire affected areas for recovering.

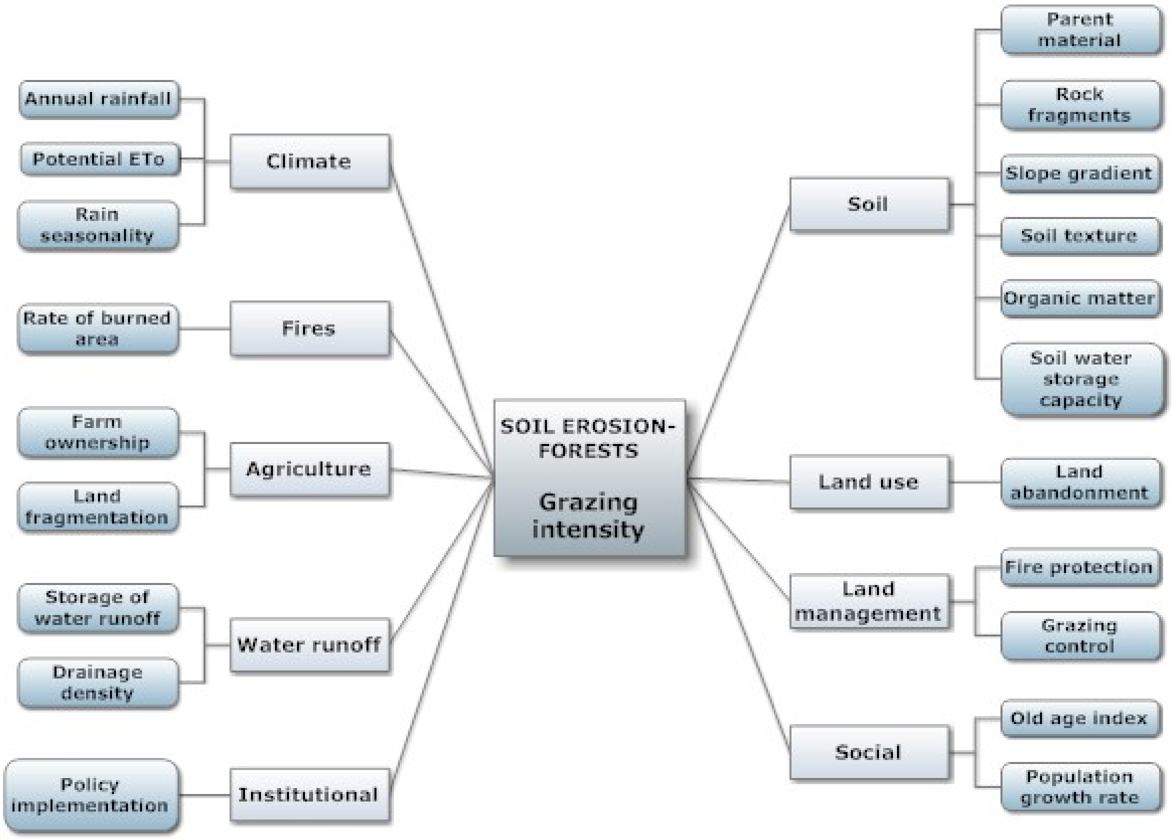

Fig. 48. Important indicators related to grazing intensity in forested areas where the main process of land degradation is soil erosion

Agriculture indicators such as farm ownership and land fragmentation have affected grazing intensity in forested areas. Field sites characterized as state or tenant have been subjected to high grazing intensity. On the contrary, field sites characterized as owned or shared have been better managed, subjected to medium or low grazing intensity. Land fragmentation has negatively affected grazing intensity. Field sites in areas with high land fragmentation are mainly characterized as subjected to medium or low grazing intensity.

An important indicator related to land use characteristics is land abandonment. Field sites located in forested areas with low rate of land abandonment have been mainly subjected to high grazing intensity since animals have to remain for longer periods in certain regions including abandoned land.

Social characteristics such as old age index, and population growth rate have identified as important indicators affecting grazing intensity in forested areas. Field sites in areas with low age indices and population growth rates have been mainly characterized as subjected to high grazing intensity. Such social conditions favour the establishment of professional farms with large numbers of animals overgrazing the land. P opulation density can be a better indicator affecting grazing intensity, but the analysis of the existing data has not shown good relationship.

Policy implementation of existing regulations for environmental sustainability of forested areas are associated with actions such as fire protection, grazing control, storage of water runoff. Areas in which actions for natural resources sustainability have been applied such as grazing control, or storage of water runoff, grazing intensity is mainly characterized as low or moderate.

Areas subjected to high water stress are usually used as pastures. Grazing intensity is greatly affecting plant cover and desertification risk. Under low or moderate grazing intensity, plant cover is mainly subjected to low rates of water runoff, and lower desertification risk. Areas highly grazed support low plant cover, resulting in high rates of water runoff, and high desertification risk due to water stress.

Measuring the indicator

The stocking rate (SR) can be assessed by calculating grazing capacity or sustainable stocking rate (SSR) and comparing these two values. If SR equals SSR then pasture is properly grazed. Furthermore, if SR is greater than SSR, then grazing is improper and irrational and should be adjusted. The corresponding formulas for calculation of SR and SSR are used in the DESIRE project:

$$\textbf{SR (animals/ha) = Number of grazing animals / area grazed,}$$

$$\textbf{SSR (animals/ha)} = \mathbf{X * P * F / R}$$

Where X is the percentage of grazing efficiency (0.5 in case of grazing and 0.25 if land is not grazed), P is the average dry palatable biomass production after the dry period in Kg/ha, F is the percentage cover of land with palatable biomass, and R is the required amount of biomass. The following classes are used: (a) low grazing intensity: SR<SSR, (b) moderate grazing intensity: SR = SSR to 1.5*SSR, and (c) high grazing intensity: SR>1.5*SSR.

Deforested area

Definition

The rate of deforestation defines the total deforested surface annually in a certain period, expressed as a percentage of the total land surface.

Importance on land degradation process

Large scale deforestation of semiarid and dry sub-humid areas accompanied by intensive cultivation and overgrazing resulted in accelerated erosion and the formation of badlands with very shallow soils. Such areas are very sensitive to land degradation and desertification (Fig. 49). Deforested area represents an important indicator for addressing political measures for protecting natural vegetation and combating desertification.

Data for deforested areas have been collected in 403 field sites, corresponding to 9 study sites, located in Mediterranean Europe, eastern Europe, Africa, and Asia. The dominant class of deforestation in the study areas is low, covering 84.9% of the total sites. Moderate to high rate of deforestation have been identified in few field sites.

Rate of deforested area (% of the total area per year) is important indicator only for areas affected by water stress. Desertification risk is negatively affected by deforestation rate since water stress is reduced for the growing plants (less transpiration due to smaller leaf area index). Of course deforestation is expected to generate higher soil erosion and degradation rates. Also field sites located in areas with high rates of deforestation have been usually subjected to high land use intensity. Furthermore, deforestation rate is positively related to the rate of burned area in pastures subjected to overgrazing.

Fig. 49. Examples of deforested area to be used for pasture (left) and planting vines (right)

The indicator deforestation rate is important for forested areas with forest fires considered as the most important cause of land degradation. Fire protection is mainly characterized as high in areas where the rate of deforestation is high. This can be explained by the reduction of forests or available flammable biomass by clearing them for changing land use. Furthermore, the rate of deforested areas is positively related to the rate of land abandonment. Areas with moderate or high rate of land abandonment are predominately subjected to high rates of deforestation.

Measuring the indicator

Data of rate of deforestation are available for forested areas for different periods and territory levels from different organizations such as FAO, EUROSTAT, ISTAT, CFS, etc. This indicator is measured by using a combination of satellite-based earth observation and intensive field data collection to estimate deforestation process on a definite territory. Such data have been provided mainly from the national forestry departments. The following four classes of deforestation have been used in the DESIRE project: (a) low, <1.5 % of total deforested surface/total territorial surface/per year; (b) moderate, 1.5-2.5 % of total deforested surface/total territorial surface/per year; (c) high, 2.5-3.5 % of total deforested surface/total territorial surface/ per year; (d) very high, >3.5 % of total deforested surface/total territorial surface/ per year.

Fire frequency

Definition

Fire frequency defines the frequency or return time in which a fire occurs in an area.

Importance on land degradation process

Fire frequency adversely affects regeneration of many plant and animal communities, with some of them experiencing loss of species diversity, followed by site degradation. For example if a pine forest destroyed by fire twice in a period of 15 years, then this species can not be recovering in the burned area naturally. Forest fires are frequent in pine forest. The frequency of fire occurrence is lower in grasslands, and mixed Mediterranean macchia with evergreen forests. Pastures are frequently subjected to man-induced fires in order to renew the biomass production. Burned ecosystems lack partially or totally vegetation covers for a period ranging from months to years (Fig. 50). During this period, the soil is exposed to wind and water erosion followed by flooding of lowland and siltation of water reservoirs. Furthermore, forest fires greatly contribute to climate change by increasing greenhouse gasses.

The majority of fires occurs in areas with high xerothermic indices and moisture deficits. Soil dryness and wind speed are the principal factors of fire evolution. As it has been recognized by the UNCCD, dry sub-humid to semi-arid regions are especially prone to large wildfires. In contrast, drier areas do not support adequate vegetation, restricting fires propagation and spread. Human activities in densely populated areas are an important cause of fire ignition. In the last fifty years there has been a socio-economic transformation in Mediterranean Europe from rural to urban. As a consequence there has been a reduction of grazing animals, firewood exploitation, and land abandonment resulting in a dramatic increase in the availability of vegetation fuel. Furthermore, afforestation practices in many Mediterranean countries have been based on establishing coniferous and eucalyptus plantations without considering adequate forest management in the plantations once has been established. All these transformations have led to an increase fire frequency of fire-prone ecosystems in the various landscapes.

Fig. 50. Extensive areas burned in Greece in 2007 causing severe problems of soil erosion, vegetation degradation and land desertification

Data for fire frequency have been collected in 403 field sites, corresponding to 8 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. Fire frequency has been characterized as low (once every 50-100 years) in the majority of the study field sites, covering 81.9% of the total sites. Very high fire frequency has been identified in 11.7% of the study fields. Moderate and high frequency (once every 25-50, 15-25 years, respectively) has been recorded in few field sites.

Fire frequency has been identified as an important indicator for areas where the main cause of land degradation is water stress or overgrazing. The analysis of the obtained have shown that areas characterized by high fire frequency (once every 25 years or more frequent) are less affected by water stress since evapotranspiration demands are reduced due to lower leaf area. In the opposite, field sites located in areas of high fire frequency and subjected to overgrazing are very vulnerable to desertification risk due to soil erosion. Pastures are frequently subjected to man-induced fires in order to renew the biomass production and then overgrazed with very adverse impacts on natural resources.

Fire frequency is interrelated to rain seasonality, water scarcity, population growth rate, and tourism change in areas affected by water stress of the growing plants or forest fires. Areas under long rain seasonality accompanied with high population growth rate or tourism change are subjected to higher frequency of forest fires. In addition, areas subjected to high fire frequency accompanied by low measures of fire protection are mainly characterized by moderate or high land use intensity. Forest fires are usually associated with expansion of agriculture in physical areas or with elimination of perennial vegetation for allowing palatable grass to grow for the animals, where land is then intensively cultivated or overgrazed.

Measuring the indicator

This indicator requires information on both historic and current fire frequency. While current fire frequency data are not difficult to collect for large areas, it is not easy to determine the historic fire frequency on a restricted forest covered area. Fire frequency shows lately an increasing trend in forest located in the vicinity of urban areas. The limits of the indicator include the difficulty in finding statistical fire data and homogeneous data on burned surfaces for different European countries, at a municipality level. Data on historic fire regimes, as well as recent data have been provided by EUROSTAT and National Statistics Services. Satellite data has been also used to measure current fire frequencies through systematic registration of ignition points. The following classes are distinguished in this project: (a) low, ecosystem burned every 50-100 years; (b) moderate, ecosystem burned every 25-50 years; (c) high, ecosystem burned every 15-25 years; (d) very high, ecosystem burned every <15 years.

Burned area

Definition

Rate of burned area defines the average area burned per decade on a defined territorial surface. It is defined per decade using the annual data of natural and agricultural areas burned by wildfires, at municipality level at least.

Importance on land degradation process

Every year, millions of hectares of the world's natural and agricultural areas are being consumed by fires, causing tremendous damage to the environment. The ecological and environmental impacts of fires are manifested by degradation of the quality of vegetation, accelerated soil erosion, loss of biodiversity, pollution of surface waters, and overall ecological retrogression. Furthermore, fires contribute to global climate change and warming. Biomass burning also results to the loss of an important sink for atmospheric carbon.

Rate of burned area has been defined for 1038 field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America . The prevailing class of burned area rate is low (<10 ha per 10 years per 10 km^2 of territorial surface), covering 88.0% of total study field sites. Moderate rate of burned area has been defined in 6.1% of the total study field sites. Very high rate of burned area (>50 ha $decade^{-1}$ 10 km^{-2} of territorial surface) has been recorded in 5.3% of the study field sites.

The rate of burned area has been found as a very important indicator for assessing desertification risk especially in pastures, and forests. Field sites located in forested areas with high rate of burned area (greater than 26 ha per 10 years per 10 km^2 of territorial) are characterized by high land degradation and desertification risk under semi-arid or dry sub-humid climatic conditions. Opposite trend has been found for pastures and areas subjected to overgrazing. Field sites located in areas with high rates of burned area have been subjected to lower desertification risk. This can be attributed to the removal of animals from the broad affected area due to existing regulations or to the reduction of the number of animals due the protection of the grazing land.

Fires in grazing land are usually deliberately ignited by farmers to promote the growth of palatable biomass. Of course there are some factors related to the physical environment and to the socio-economic conditions favouring fires. The analysis of the collected data of the study field sites has shown that the rate of burned area is mainly related to climate, soils, vegetation, water runoff, land management, and social characteristics (Fig. 51). Indicators related to climate such as annual rainfall, and rain seasonality greatly affects the rate of burned area in the study sites. As rainfall decreased rate of burned area increased. Low amounts of rainfall combined with long rainfall seasonality favours extensive fires.

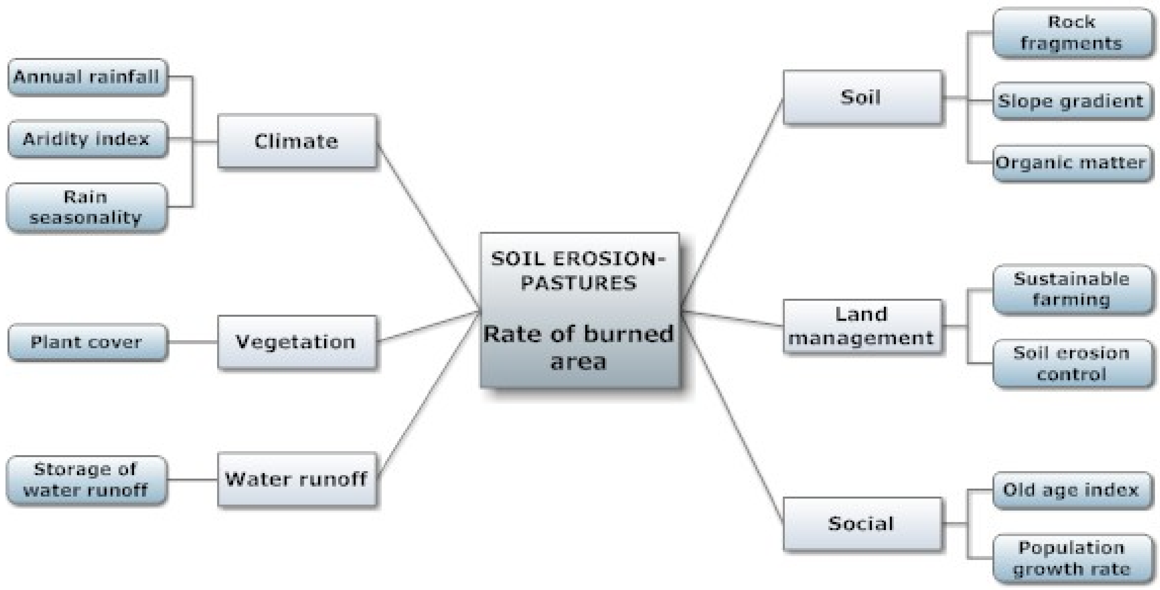

Fig. 51. Important indicators related to rate of burned area in pastures where the main process of land degradation is soil erosion

Important soil indicators related to the rate of burned area are the percentage of rock fragments on the soil surface, slope gradient, and organic matter content on the soil surface. A large amount of rock fragments on the soil surface reduces annual biomass production since soil surface is covered by stones, reducing fire risk and therefore rate of burned area. The rate of burned area increased as slope gradient increased since steep slopes favours fast expansion of a fire but only in the upslope direction. Also as organic matter content in the soil surface decreased the rate of burned area is also decreased since the amount of organic matter is usually low under limited amounts of biomass production, which favours ignition and propagation of a fire.

Plant cover is related to the biomass available for ignition and propagation of a fire. The obtained data showed that as plant cover decreased rate of burned area decreased. Plant cover is affected by various factors including climate, soil, grazing intensity, etc. Adverse soil and climatic conditions combined with high grazing intensity greatly reduced plant cover causing low rates of burned area.

Actions related to the protection of pastures from soil erosion such as fire protection, soil erosion control, runoff water storage are negatively related to rate of burned area. When actions for land protection are applied, the local population is usually aware of the impacts of fires on soil erosion and measures are applied to protect the existing vegetation from burning. These actions of land protection are related to policy implementation on existing regulations for environmental protection study field sites.

Social indicators related to rate of burned area in the study field sites are old age index and population growth rate. Areas with population of high old age index usually do not keep large numbers of animals, therefore, land is extensively grazed leaving high amounts of dry biomass in the land favouring ignition of fires. On the contrary, in areas with high population growth rate, farmers intensively grazed the land with large number of animals. In such cases farmers use to put fires for generation of palatable grass growth for feeding the high number of animals.

The statistical analysis of the indicators affecting rate of burned area in field sites, where the main cause of land degradation and desertification is overgrazing, has shown that 18 indicators are significantly related, in comparison with 12 indicators for pastures affected by water erosion. Furthermore, the majority of the indicators between them is different, even though some common indicators present different trends in relation to desertification risk. As figure 52 shows, rate of burned area in pastures subjected to overgrazing are related to climate, soil, vegetation, forest fires, agriculture, land use, land management, water use, runoff water, social and institutional characteristics. Annual potential evapotranspiration and rainfall are the most important indicators related to climate and affecting burned area. The rate of burned area has been mainly defined as moderate to high in field sites located in areas characterized with high evapotranspiration rates and low annual rainfall. The occurrence of forest fires under such climatic conditions is expected to be high in grazing lands.

Among the soil indicators, only the presence of rock fragments in the soil surface appeared to affect the rate of burned area in the study field sites. The rate of burned area is characterized as low in field sites where rock fragments percentage in the soil surface is relatively low. This is an opposite trend observed in pastures where the main process of land degradation is water erosion.

Important indicators related to vegetation characteristics are vegetation cover type and rate of deforested area. Rate of burned area has been characterized as high in areas where the vegetation cover type is mixed Mediterranean Macchia and evergreen forests, Mediterranean Macchia and pines. The rate of burned area is relatively low in areas covered with permanent grass, annual grass and deciduous forests. In addition, the rate of burned area is positively related to the rate of deforested areas.

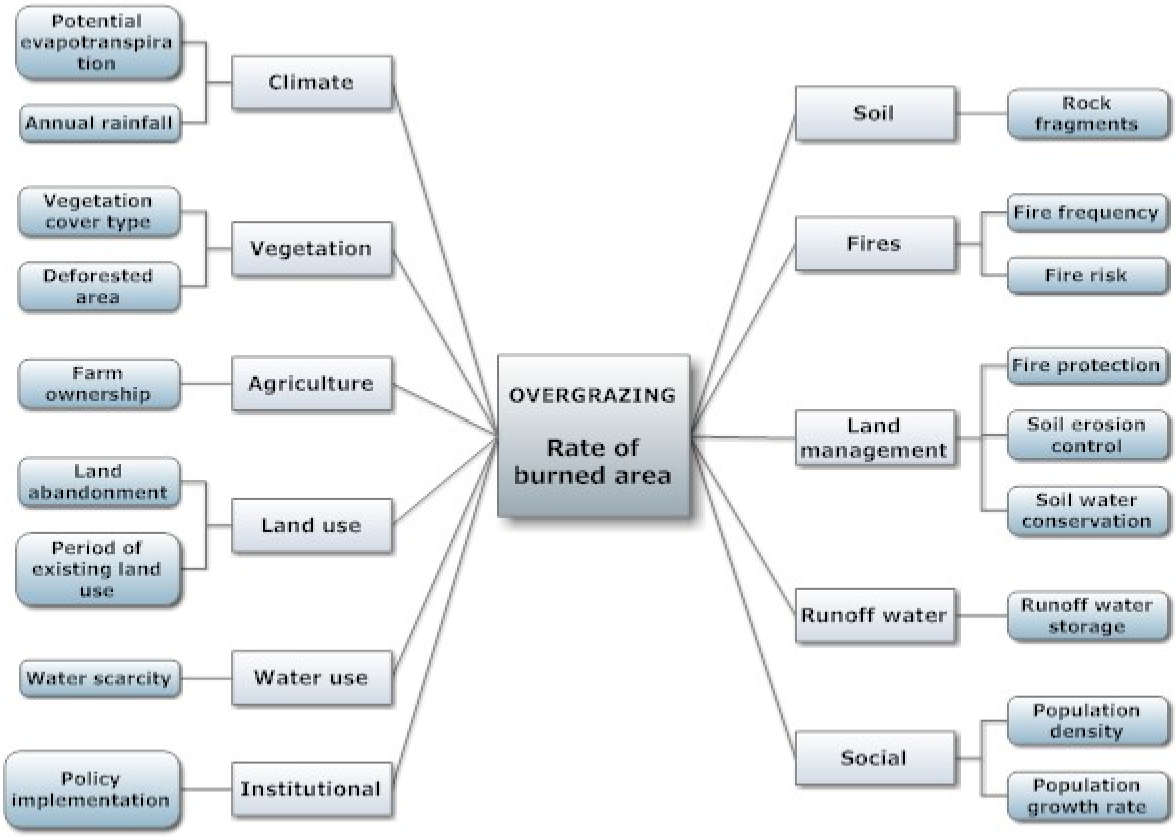

Fig. 52. Important indicators related to rate of burned area in field sites where overgrazing is the dominant process of land desertification

The rate of burned area in the study field sites is highly related to fire risk and fire frequency. Areas covered with vegetation of high fire risk are subjected to high fire frequency and therefore the rate of burned is high, enhancing desertification risk.

Among the indicators related to agriculture only farm ownership is s ignificantly related to rate of burned area. Tenant or state-farmed field sites are usually subjected to higher rates of burned area than owner or shared-farmed field sites. Farmers used to put fire in grazing land to simulate the growth of palatable biomass production for the grazing animals aggravating the problem of desertification in these areas.

Regulations related to actions such as fire protection, soil erosion control, soil water conservation, and runoff water storage are affecting rate of burned area and degree of policy implementation in the study field sites. The rate of burned area is relatively low in areas where adequate measures for fire protection are undertaken. Also existing actions of soil erosion control, soil water conservation, or runoff water storage are negatively related to the rate of burned area.

The rate of land abandonment is negatively related to the rate of burned area. Areas in which the rate of land abandonment has been characterized as high, the rate of burned area is relatively low. Furthermore, field sites in which the period of existing land use is long, the rate of burned area is relatively low.

An important indicator related to water use and affecting rate of burned area is water scarcity. Field sites located in areas with high water scarcity are subjected to low rates of burned area. Probably people living in such areas are more aware of the importance of protecting the environment by fighting against forest fires which greatly affects water availability.

Important indicators related to social characteristics and affecting rate of burned area are population density and population growth rate. Field sites located in areas of high population density or high population growth rate are subjected to high rates of burned area. Such actions are very common in many areas with high population density due to imposing high pressure on the natural resources.

Measuring the indicator

Data on burned area can be provided by EUROSTAT and National Statistic Organizations. The following classes of burned area has been used in this the DESIRE project: (a) low, <10 ha of total burned area per decade on 10 km^2 of territorial surface; (b) moderate, 10-25 ha of total burned area per decade on 10 km^2 of territorial surface; (c) high, 26-50 ha of total burned area per decade on 10 km^2 of territorial surface; and (d) very high, >50 ha of total burned area per decade on 10 km^2 of territorial surface.

Fire protection

Definition

This indicator assess the existence of protective infrastructures against forests fires and managed natural resources.

Importance on land degradation process

This indicator contributes to the definition of the level of control and protective management against forest fires in a territory affected by desertification processes over a long period.

Data on fire protection have been collected in 1141 study field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of fire protection is no measures for protection at all, covering 69.1% of the study field sites. Probably in some areas, especially those affected by soil salinization, fire protection measures are not so necessary since environmental conditions do not favour fires. Low fire protection measures have been defined in few field sites, covering 13.7% of the total cases. Moderate measures for fire protection have been defined in 12.9% of the study field sites. Finally, high and very high measures for fire protection has been defined in very few cases 1.3% and 3.1%, respectively.

This indicator has been defined as especially important in forested areas, and pastures subjected to overgrazing. The contribution of forest fire protection in assessing desertification risk (coefficient of linear regression) in those areas is high compared to other indicators.

Fire protection is an important indicator affecting desertification risk in forested areas in which the main cause of land degradation is forest fires. indicators related to climate, soils, land management, and social characteristics (Fig. 53). The obtained data of the study sites have shown that fire protection measures are affected by climate, soil, vegetation, land use, husbandry, social and institutional characteristics. The most important climate indicators are annual air temperature, annual rainfall, and rain seasonality. Fire protection measures have been mainly characterized as low in areas characterized by high annual air temperature and low annual rainfall. Such climate conditions favour the production of dry biomass of high flammability and combustion promoting ignition and propagation of forest fires. Furthermore, fire protection measures are positively related to rain seasonality. Forest fire measures are mainly characterized as low in areas of high rain seasonality.

The most important soil indicator affecting fire protection identified in the study field sites is soil depth. Fire protection is negatively related to soil depth. Fire protection in areas with deep soils is mainly characterized as moderate to low. Areas with deep soils generally produce high amounts of biomass, usually less flammable that fires can relatively easily controlled.

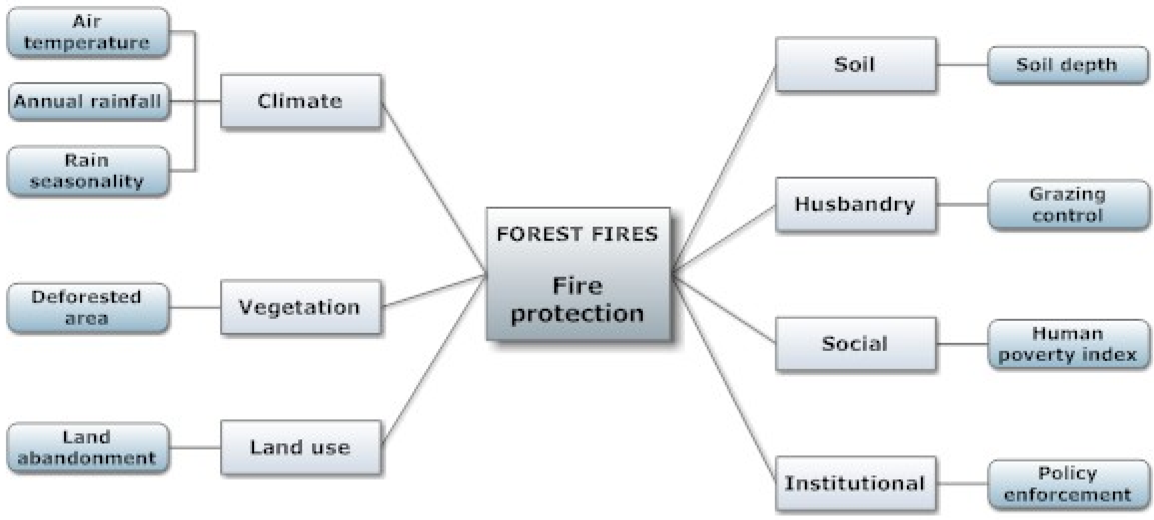

Fig. 53. Important indicators related to fire protection in areas where forest fires is the dominant process of land desertification

Fire protection in forested areas is significantly related with the rate of deforested area, grazing control, rate of land abandonment, and policy implementation. Fire protection measures are mainly characterized as high in areas with high rate of deforestation. This can be attributed to the reduction of forests or available flammable biomass by clearing them for changing land use. Grazing control is positively related to fire protection. Farmers protecting the land from overgrazing use to protect the land from fires too. Furthermore, areas with low rate of land abandonment are mainly highly protected against fires. Finally, areas under adequate policy implementation of existing regulations for environmental sustainability are also adequate protected from forest fires.

Among the social indicators only human poverty index is significantly related to fire protection in forested areas affected by fires. Areas characterized by high poverty indices are mainly inadequately protected from fires. Under such conditions, funds available for environmental protection are usually limited or absent.

Runoff water storage actions in forested areas are mainly related to fire protection measures. Adequate measures of runoff water storage are associated with adequate measures of forest fire protection.

Fire protection is related fire frequency in areas subjected to water stress. A reas subjected to high frequency of fires are usually accompanied by low measures of fire protection. Forest fires are usually associated with the expansion of agriculture in physical areas, or elimination of perennial vegetation for allowing palatable grass to grown for the animals.

Measuring the indicator

The indicator can be assessed by calculating the ratio between surface of forest and other wooded land designated or planned to be protected by infrastructures and natural resources managed against fire vs. the total territorial surface area. Data can be found in the local Forestry Department administration. The following classes are distinguished for the purpose of this project: (a) no protection, (b) low protection, <25 % of total surface protected/total territorial surface; (c) moderate protection, 25-50 % of total surface protected/total territorial surface; (d) high protection, 50-75% of the total surface protected/total territorial surface; (e) very high protection, >75% of total surface protected/total territorial surface.

Sustainable farming

Definition

Sustainable farming is defined as an agricultural system evolving towards greater human utility, increased efficiency of resource use, minimum depletion of non-renewable resources, and environmental interaction, favourable to humans and to most other species.

Importance on land degradation process

Sustainable farming may include actions such as: (a) land utilization schemes within the land capability limits, (b) minimum tillage, (c) enhancing vegetation cover, (d) tillage of soil in the up-slope direction, (e) minimum depth of ploughing, etc (Fig 54). Minimum tillage may have favourable effects on soil aggregation and reduction of soil crusting and soil erosion. If the soil moisture level is optimal, a minimum tillage is generally favourable because the implements break up the clods, incorporate the organic matter into the soil, kill weeds, and create a more favourable seed bed. Therefore, tillage is considered necessary in the normal management of some soils. However, frequent tillage operations, especially those involving heavy equipments have detrimental effects on surface soil degradation such as accelerating oxidation of soil organic matter, breaking down stable soil aggregates. M aximum soil degradation occurs when a soil is tilled with a mouldboard plough followed by several disking. In a no-till system, plant residues are concentrated on the soil surface enhancing aggregate stability and protecting the soil from erosion. Enhancing vegetation cover comprises an effective sediment filter, usable in agricultural and other lands. Irregularly shaped and unproductive dry areas can be kept under natural vegetation for controlling runoff and sediment loss.

Fig. 54. Examples of sustainable farming including no tillage (left) and minimum tillage -inducing plant cover (right)

Data for the indicator sustainable farming have been collected in 808 field sites, corresponding to 10 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. No sustainable farming has been defined in the majority of the study fields sites (53.8% of the total fields). The next important action of sustainable farming is no tillage, defined in 21.0% of the study field sites. Minimum tillage has been found in 14.0% of the study field sites. Minimum depth of ploughing has been defined in 8.4% 0f the study field sites. Finally, land management practices of sustainable farming such as inducing plant cover, and up-slope tillage have been defined in very few cases (Fig. 55).

This indicator has been defined as important in assessing desertification risk in agricultural areas. As it is expected sustainable farming is negatively related to tillage operations.

Sustainable farming has been related to rate of burned area in pastures. Such land management practice is negatively related to rate of burned areas. When actions related to the protection of pastures from soil erosion such as sustainable farming are applied, the local population is usually aware of the impacts of fires on soil erosion and actions are undertaken to protect the existing vegetation from burning.

Measuring the indicator

This indicator can be defined by contacting the land user or can be identified by field observations. The possible land practices of sustainable farming are presented above.

Soil erosion control measures

Definition

Soil erosion control measures includes actions undertaken to reduce soil erosion caused by various factors such as surface water runoff, tillage operations, wind blowing, etc.

Importance on land degradation process

Soil erosion control measures may include: conservation tillage, contour farming, stabilization structures, vegetated waterways, strip cropping, enhancement of understory growing vegetation, adequate plant cover, terracing, small water reservoirs, etc. Conservation tillage is a land management practice which can significantly reduces rill and interill erosion in hilly areas cultivated with annual crops. The incorporation of plant residues into the soil after harvesting increases soil organic matter content and improve soil aggregate stability.

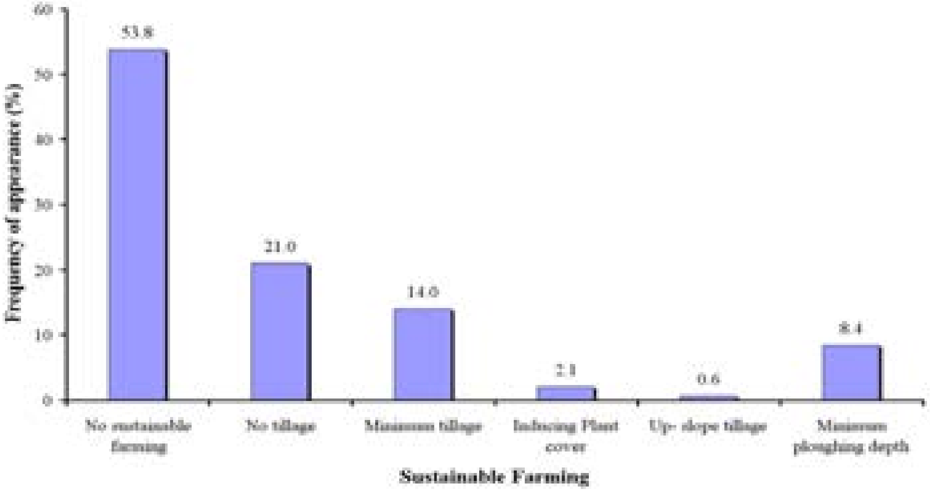

Fig. 55. Distribution of the various land management practices applied for sustainable farming defined in 808 field sites

Contour farming is considered a very effective practice for reducing soil erosion, but in many cases farmers faces security problems when slope gradient is greater than 12%. Following the contour farming, each furrow acts as a reservoir to receive and retain runoff water. However this type of ploughing can led to accelerated soil erosion and deposition in the lowland. Following the contour farming, each furrow acts as a reservoir to receive and retain the runoff water. On long length slopes and under heavy and prolonged rainfall events, contoured rows can cause considerable riling or gulling.

Stabilization structures protect soil erosion in channels where water is concentrated. Such structures reduce runoff water velocity to non-erosive rates. Such structures can be are permanent consisting of reinforced concrete or monolithic reinforced concrete such as drop spillways, drop inlets, as well as temporary structures made of rocks, logs, brush, woven wire and other nondurable materials to dissipate the energy of falling water (Fig. 56).

Fig. 56. Temporal stabilization structure for reducing water runoff in channel to non-erosive rates (left) and enhancement of understory vegetation for reducing soil erosion after a fire in a olive grove (right)

Enhancement of understory annual vegetation is an appropriate land management for reducing soil erosion in hilly areas cultivated with perennial crops such as olives, vines, almonds, etc (Fig. 56). Many studies have been shown that such vegetation cover reduces soil erosion to minimum values. The only dispute for this management practice is the adsorption by this vegetation of an amount of soil water stored in the upper soil layers. This soil erosion control measure can be combining with vegetated waterways in which soil erosion is expected to be limited.

Terracing is an alternative management practice for water conservation and erosion control. Terracing decreases the slope length and reduces the damage by surface water runoff. It is actually a very old practice having been used for centuries in many places of the world.

Strip cropping is a practice in which hilly areas are not cultivated uniformly with the same crop. There are alternative strips with various crops growing in different period. Therefore, if runoff occurs form one field which is not well vegetated then this water is trapped in next field which is well vegetated. Furthermore, Small water reservoirs are constructed at farm level or in collaboration of nearby farmers. Water is temporarily stored into the reservoir reducing down slope water runoff.

Data for this indicator have been collected in 1305 field sites, corresponding to 16 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. No soil erosion measures have been undertaken in the majority of the study field sites, covering 74.2% of the total sites (Fig. 57). Low soil erosion control measures have been identified in 14.3% of the study field sites. Adequate measures of soil erosion control have been defined in 7.7% of the study field sites. Finally, moderate measures for soil erosion control have been found only in 3.8% of the study field sites.

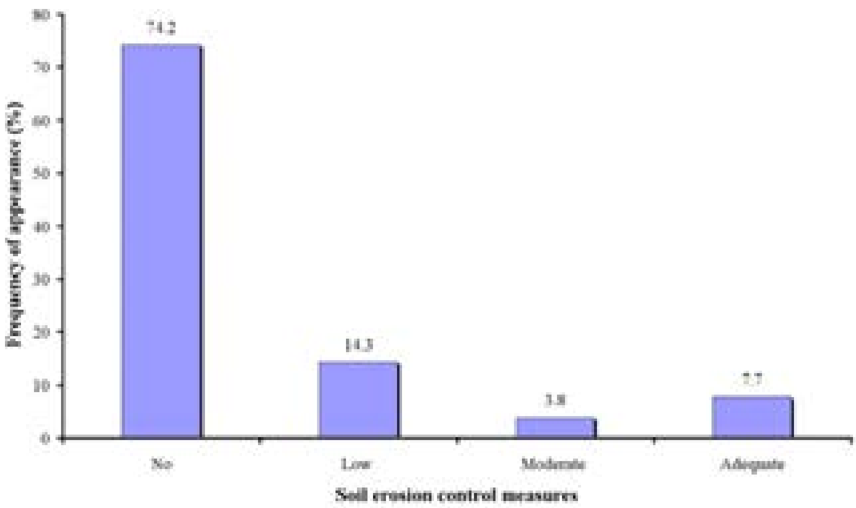

Fig. 57. Distribution of soil erosion control measures described in 1305 field sites

Soil erosion control measures have been found particularly important for assessing desertification risk in areas subjected to water stress and overgrazing. Soil erosion control identified in the study sites includes actions for reduction of surface water runoff such as conservation tillage, contour farming, stabilization structures, vegetated waterways, strip cropping, enhancement of understory growing vegetation, small water reservoirs, etc.

Soil erosion control in agricultural areas is related to tillage operations. Soil erosion control measures are in agricultural areas area associated with rather limited tillage operations, accompanied with moderate to adequate policy implementation.

Soil erosion control measures are associated with grazing intensity in areas used as pastures and subjected to water erosion No actions for controlling soil erosion are defined in the majority of the study field sites, when the land is intensively grazed. Furthermore, soil erosion control measures are negatively related to rate of burned area. Soil erosion control measures are more pronounced in pastures with low rate of burned area.

Land use intensity is related to soil erosion control in areas subjected to land degradation due to water stress. Areas with low measures of soil erosion control are mainly subjected to high land use intensity.

Soil erosion control is affected by various indicators in pastures in which the main cause of land degradation is overgrazing. These indicators are related to climate, soil, topography, land management, water availability, and social characteristics (Fig. 58). Among the indicators related to climate, aridity index and rain seasonality have the highest correlation with soil erosion control measures. Under high aridity indices and high rain seasonality, soil erosion control measures are mainly characterized as moderate to adequate. Under such adverse climatic conditions plant growth is highly restricted and grazing of the land is not profitable discouraging farmers to use it.

Areas with poorly drained soils have been mainly characterized as subjected to overgrazing. Such areas are usually wetlands in which during the dry period after water is withdrawn from the surrounding very poorly drained soils, animals are moved to graze them. Also, soil erosion control measures by enhancing plant cover are positively related to slope gradient. Field sites with low slope gradients are subjected to higher grazing intensity without any actions for controlling soil erosion.

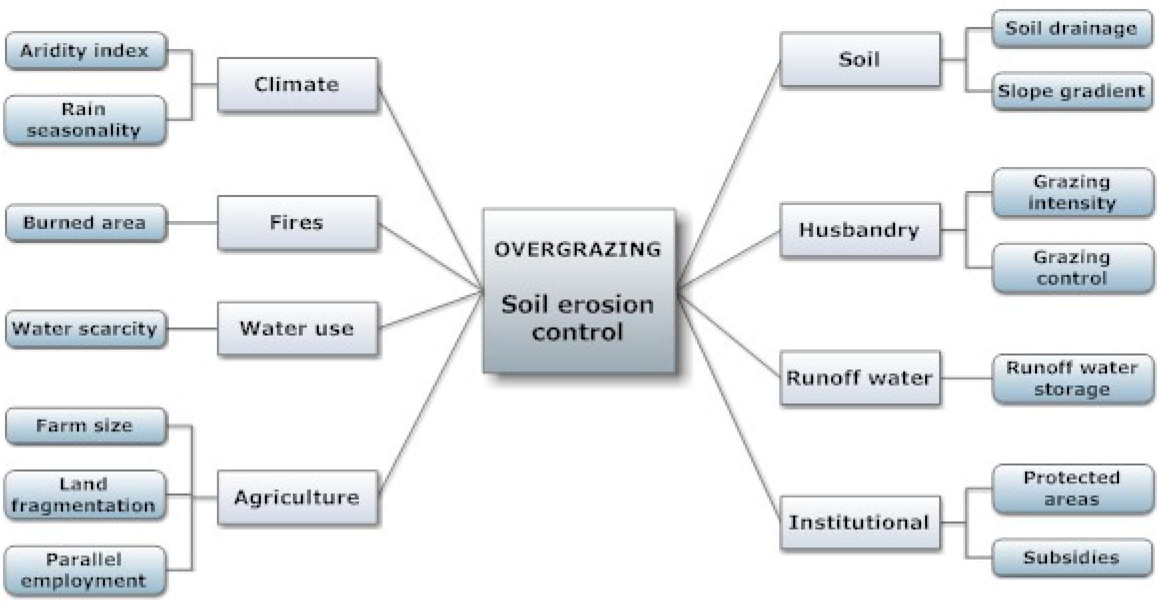

Fig. 58. Important indicators related to soil erosion control in areas where overgrazing is the dominant process of land desertification

The rate of burned area is pos itively related to soil erosion control measures in pastures overgrazed. It seems that in the study sites, the existing regulations for protection of the land after fire are effectively applied.

Soil erosion control measures are negatively related to water scarcity in pastures overgrazed. Field sites located in areas characterized by high water scarcity are usually overgrazed without any measures for soil erosion control.

Land fragmentation and farm size are significantly related to soil erosion control in pastures overgrazed. Field sites located in farms of small size are mainly characterized by moderate or adequate soil erosion control measures. Such actions are probably related with small numbers of animals kept by the local farmers avoiding overgrazing. Furthermore, land fragmentation is usually positively related to soil erosion control. Field sites belonging to farms with low land fragmentation are subjected to overgrazing since animals use to remain in the same area for a long period. In addition, farmers having some kind of parallel employment in tourism or other economic activities, usually do not apply measures for soil erosion control since they spend most time far from their farm.

Soil erosion control measures are associated with actions against overgrazing such as grazing control, and runoff water storage. Pastures are not overgrazed if soil erosion control measures are applied. Furthermore, protected areas such as national parks or protected landscape included in areas subjected to overgraze are usually moderately protected from soil erosion. The mentioned actions for soil erosion control accompanied with low grazing intensity are associated with policy implementation.

Measuring the indicator

The efficacy of the existing soil erosion control measures can be defined in the field based on a self explanatory estimation as following: (a) no actions undertaken, (b) low, incomplete protection, less than 25% of the area is protected; (c) moderate, partial protection, 25-75% of the area is protected; (d) adequate, complete protection, >75 of the area is protected.

Soil water conservation measures

Definition

Soil water conservation measures includes actions undertaken to conserve soil water for plant growth.

Importance on land degradation process

Soil water conservation techniques may include the following: mulching, weed control, management of soil surface for maximum water infiltration and vapour adsorption, cultivation, etc. Weed control usually takes place by means of mechanical tillage or chemical sprays such as glyphosate, paraquat, etc., whereas mulching or grazing is alternatively applied in organic farming. Grazing is the removal of entire plants or parts of them by herbivores in order to feed themselves (Fig. 59).

Considering that the amount of rain occurring under arid or semi-arid climatic conditions are compared to the evapotranspiration rates during the dry period (May-October), water vapour adsorption becomes one of the most important sources of available water at least for the growing annual vegetation. Under such climatic conditions, soil physical characteristics such as surface mulching, and density of the growing plants greatly affect water vapour adsorption and soil water conservation. Management of the land by: (a) reducing the density of the growing vegetation and increasing the soil-atmosphere interface, (b) using surface mulches such as rock fragments or plant residues partially covering the soil surface, and (d) ploughing the soil for increasing macro porosity can beneficially and significantly affects water vapour adsorption and soil water conservation.

Cultivation of the land using various tillage implements such as mouldboard, chisel, duck foot chisel, harrow, etc is considered as a management practice for conserving subsoil water. However, ploughing the soils in hilly can cause severe problems of land degradation due to mechanical displacement of soils usually down slope.

Data for this indicator have been collected in 1051 field sites, corresponding to 12 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. S oil water conservation measures have not identified in 58.2% of the study field sides. Soil water conservation measures such as mulcting, weed control, temporal storage of runoff water etc., have been defined in 41.8% of the study field sites.

Fig. 59. Examples of controlling weeds by using herbicides (left) and grazing (right)

Soil water conservation techniques have been included in the analysis of assessing desertification risk only for pastures in which the main cause of land degradation is water erosion. As it is expected soil water conservation techniques reduce land desertification risk.

Soil water conservation measures can greatly affect plant cover in area in which the main cause of land degradation is water stress. Actions such as temporary storage of water runoff have contributed in percentage plant cover, reducing of desertification risk in the study field sites.

Runoff water storage is affecting rate of burned area in pastures affected by overgrazing. The analysis of the obtained data have shown that the rate of burned area is relatively low in areas where adequate measures soil water conservation are undertaken.

<u>*Measuring the indicator*</u>

This indicator can be defined by contacting the land user or can be identified by field observations. The possible land practices of storage of water runoff storage are presented above.

Irrigation percentage of arable land

Definition

Irrigation percentage of arable land defines the land area under irrigation as a percentage of total arable land. In addition, irrigation percentage of arable land defines the intensity in which arable land and water resources are used.

Importance on land degradation process

Areas with adequate amount of good quality of water available for irrigation are subjected to lower desertification risk (Fig. 60). Because the expected warmer and drier climate accompanied with increase in aridity and drought hazard, the extension of irrigation will be necessary over large areas for efficient agricultural production and protection of the environment. The expansion of irrigated land will probably aggravate the existing problem of brackish water intrusion in aquifers through diminishing groundwater recharge or reduced amount of rainfall. The sustainable use of water resources and the appropriate land management systems and land management practices will be the appropriate tools for combating desertification in those areas.

The uncontrolled use of water resources in the last decades for both irrigation and domestic consumption resulted in severe environmental impact on the water quality of the most productive aquifers and on soil degradation due to salinization. As it is expected, the areas facing water shortages and overexploitation problems are those located in semi-arid and arid climatic conditions having high population density, and intensive agriculture activities.

Fig. 60. Non-irrigated land under moderate desertification risks (left) and irrigated land with good quality of water under low desertification risk (right)

Data for this indicator have been collected in 1169 field sites, corresponding to 12 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The analysis of the data shows that 65.4% of the study field sites are located in areas in which less than 5% of the surrounding land is irrigated (Fig. 61). The next important class of irrigation is greater than 0% of the total arable land irrigated, covering 18.5% of the total study field sites. The following class of irrigation percentage of arable is 25-50%, covering9.5% of the study sites. The class 5-10% of the arable irrigated has been defined in 6.0% of the study field sites.

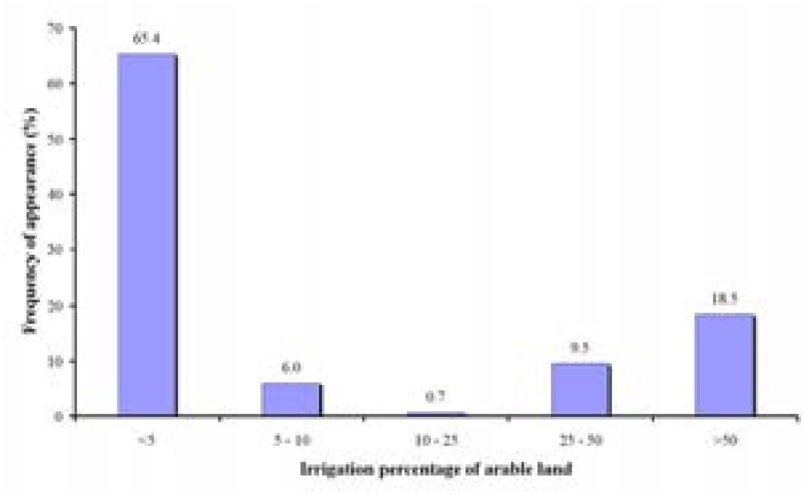

Fig. 61. Distribution of irrigation percentage classes of arable land defined in the study field sites

This indicator is especially important in assessing desertification risk in areas affected by soil salinization. Areas under conditions of adequate supply of good quality of water for irrigation are subjected to lower salinization and desertification risk.

Irrigation percentage of arable land is also related to land use intensity. Areas in which the percentage of arable land is low (less than 10%), land use intensity is mainly characterized as low. The high profitability of irrigated land has resulted in low land use intensity in non-irrigated areas.

Measuring the indicator

This indicator can be defined by contacting the local authorities of water resources management. The following classes of irrigation percentage of arable land (IP) are distinguished in this project: (a) very low, IP<5% of the total area irrigated; (b) low, IP=5-10% of the total area irrigated; (c) moderate, IP=10-25% of the total area irrigated; (d) high, IP=25-50% of the total area irrigated; and (e) very high, IP >50% of the total area irrigated.

Ground water exploitation

Definition

Ground water exploitation describes the degree to which the amount of water pumped from aquifers in relation to the water that is available. This indicator considers the potential supply in relation to what is actually used.

Importance on land degradation process

Agriculture plays a major role in water extraction and consumption especially in Mediterranean coastal areas where intensive irrigated horticulture is widespread. Nevertheless, in many areas a large contribution to aquifers overexploitation is due to the industrial and residential sectors and, seasonally, to tourism.

Ground water exploitation data have been collected in 361 field sites, corresponding to 5 study sites located in Mediterranean Europe, eastern Europe, and Africa. The obtained data have shown that ground water exploitation trends is without problems of over-exploitation in 62.6%) of the study field sites. The ground water exploitation is greater than 80% of recharge but recharge never reach to the quantities consumed by the various users in 22.4% of the study field sites.

Ground water exploitation is defined as very important indicator in areas vulnerable to soil salinization or water stress. Overexploitation of ground water leads to brackish water intrusion in the aquifers, resulting in water shortage or salinization problems in areas prone to desertification.

Measuring the indicator

Ground water exploitation can be estimated by "the exploitation index" that is defined as withdrawal of conventional freshwater resources (surface and groundwater) over total renewable resources (expressed in %). Over-exploitation can be quantitatively analyzed by comparing groundwater recharge amounts with the amount of water actually used, but it can also be seen from undesirable effects such as the drop in well levels, disappearance of rivers and springs. Specifically, this indicator is estimated by assessing: (a) water consumption by various sectors, (b) the decrease in river and spring flow, ground water monitoring, and (c) comparing by an appraisal of the recharge rate in a certain hydrological area.

Runoff water storage

Definition

Runoff water storage is defined as the volume of runoff rain water stored into the soil or in small ponds by various actions such as construction of small ponds, keeping adequate plant cover on the soil surface, etc.

Importance on land degradation process

Surface water runoff is the most important direct driver of soil erosion in hilly areas. There are many factors and processes affecting water runoff such as vegetation density, biological activity, soil crusting, micro-topography, soil texture and structure, plant cover, rainfall amount and intensity, slope gradient, land management practices, etc. The degree of crusting of soil surface has a strong influence on infiltration rates and therefore surface water runoff rates. Micro-topography of the soil surface consisting of random roughness on the surface, together with cultivation features such as plough ridges retards water flow and increases amount of water infiltrating into the soil.

Runoff water storage is defined as the volume of runoff water stored into the soil or in small ponds. Storage of water runoff is defined in terms of land management for reducing surface water runoff and increasing soil infiltration rates. For example, presence of adequate shrubby or annual vegetation cover, high biological activity, construction of terraces, shallow ploughing of soil parallel to the contour lines, concentration of runoff water in small ponds and retarding runoff, keeping plant residues on the soil surface, etc. are some practices for runoff water storage (Fig. 62).

Fig. 62. Typical examples of surface water runoff storage, small ponds constructed around the tree and concentrating the nearby runoff (left) or in a water way storing runoff from larger area (right)

Data for this indicator have been defined in 1054 study sites, corresponding to 12 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. No runoff water storage actions have been identified in the majority of the study field sites, covering 61.8% of the total field sites. Low actions of surface water runoff storage is the next important class, covering 18.1% of the study field sites. Moderate to adequate actions of surface water runoff storage have been defined in 10.2% and 9.9% of the study field sites, respectively.

Runoff water storage actions have shown opposite trends in assessing desertification risk in agriculture and pastures affected by soil erosion. The contribution of runoff water storage actions for assessing desertification risk is relatively low with negative impacts. This can occur in cases of tilling the soil parallel to the contour lines. Such land management practice can generate high runoff and sediment losses under heavy rainfall events. Water is temporarily stored into the furrow and after a heavy rainfall water can not be stored breaking the furrow and flowing downslope causing severe rill erosion. In the opposite, runoff water storage actions in pastures are very effective highly contributing i n reducing land degradation and desertification risk.

Runoff water storage actions are affected by various indicators related to climate, soil, vegetation, land use, runoff water, land management, social and institutional characteristics in forested areas (Fig. 63). A dequate actions of runoff water storage have been mainly described in areas covered with evergreen forests, mixed Mediterranean Macchia and evergreen forest, Mediterranean Macchia, and pine forests.

Among the indicators related to climate, annual potential evapotranspiration and rain seasonality are mainly related to runoff water storage. Field sites located in areas with low or moderate rates of evapotranspiration with moderate to high rain seasonality have been characterized as subjected to moderate or adequate runoff water storage actions.

Soil indicators such as parent material, slope aspect and gradient, soil texture, and organic matter in the soil surface have been significantly related to runoff water storage actions in forested areas. Storage of water runoff actions are mainly identified in areas with soils formed on m arl, basic igneous, shale, and alluvial deposits. R unoff water storage actions have been mainly described in sites located in north-facing slightly to moderately sloping areas. Steep south-facing slopes have been mainly characterized by the absence of runoff water storage actions. Furthermore, runoff water storage actions have been more often described in coarse- to medium-textured soils than in fine- to very fine-textured soils. Finally, field sites located in soils with low organic matter content have been characterized as subjected to low runoff water storage actions.

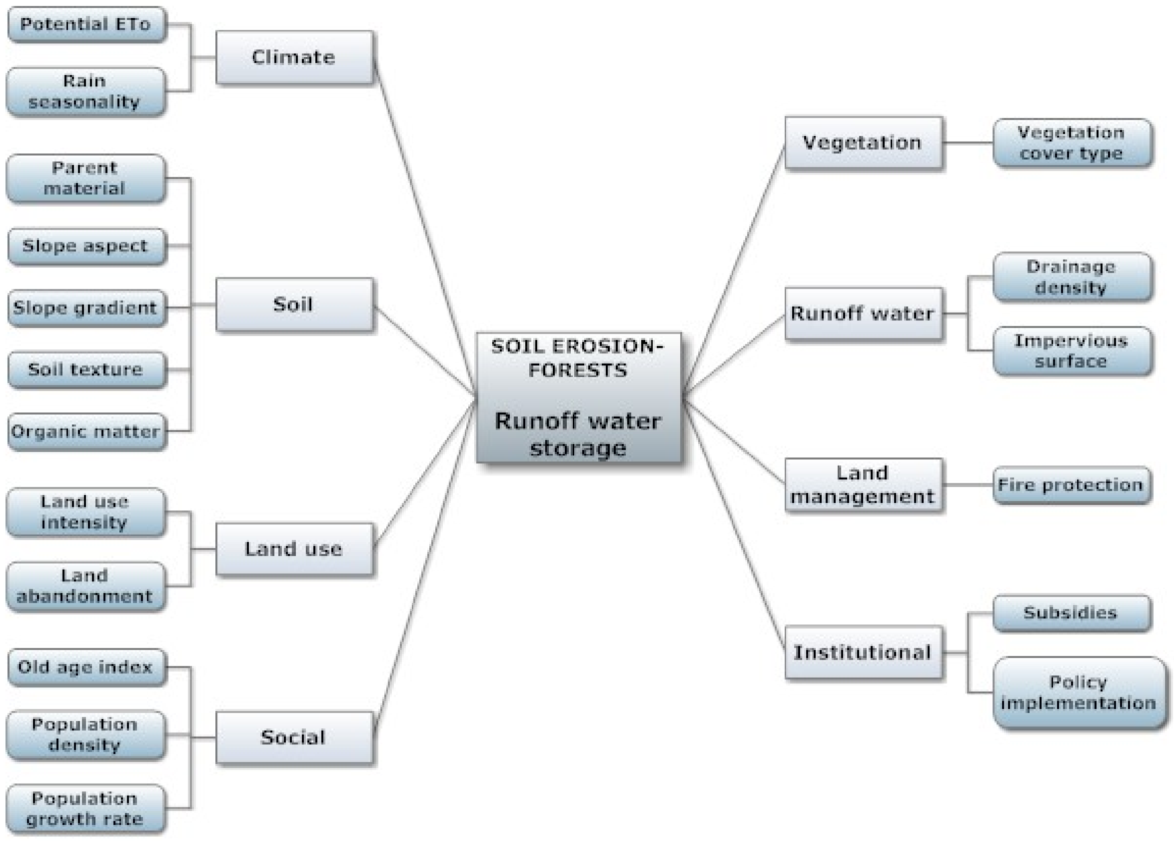

Fig. 63. Important indicators related to runoff water storage in forested areas where soil erosion is the main process of land degradation

Drainage density and impervious surface are related to runoff water storage actions in forested areas. In areas with fine or very fine drainage density, runoff water storage actions are rather limited. Areas w ith coarse to medium drainage density have been usually characterized by moderate to adequate runoff water storage actions. Furthermore, runoff water storage actions are usually found in areas with low rates of impervious surfaces expansion.

Runoff water storage actions are usually identified in areas under adequate forest fire protection measures. Also, such actions are mainly defined in areas subjected to low land use intensity. Furthermore, runoff water storage actions are usually found in areas with low rates of land abandonment. Policy implementation and runoff water storage are positively related. In case that subsidies are allocated on the basis of number of animals, runoff water storage actions are mainly absent in the study areas.

Important indicators related to social characteristics and affecting runoff water storage in forested areas are old age index, population density, and population growth rate. Field sites located in areas with high old age indices, low population densities, or high population growth rates are mainly characterized by the absence of runoff water storage actions.

Measuring the indicator

This indicator can be defined by field observations. Measurement of the indicator is based on self-assessment subject to personal judgment if existing management practices for runoff water storage are applied, and how efficient they are for the study field site. The following classes are distinguished: (a) no actions for runoff water storage, (b) low actions for runoff water storage, (c) moderate actions for runoff water storage, and (d) adequate actions for runoff water storage.

Presence of terraces

Definition

Presence of terraces defines the extent in which an area is covered by terraces. Terraces are constructions built mainly in hilly areas to reduce water erosion losses from cultivated erodible soils and for water conservation.

Importance on land degradation process

Terracing of hilly areas is a measure to combat desertification. Adsorption of water by the soil increases during heavy rainfall events and soil erosion is reduced in terracing land. If terraces are well designed, terraces control sheet and gully erosion by reducing slope length. Water runoff from the upper side of the terraced interval is held within the terrace, infiltrates and is stored in the soil.

Land terracing is the construction of relatively flat surfaces of reasonable size to allow cultivation of sloping areas. It is accomplished by removing strips of soil parallel to contours lines and accumulating the removed material over the soil surface just below the trench, transforming the natural slope in a stair-like anthropogenic environment. Techniques of terrace construction have been changed through centuries. In early practice, the land was shaped into a series of nearly level benches or step-like formations bounded on the lower side by an almost vertical bank usually protected by a stone wall. Modern practice in terracing, however, consists of nearly level benches constructed using machines which are wide enough to be cultivated, seeded, and harvested with ordinary machinery (Fig. 64).

Land terracing is a none naturally sustainable land utilization type. Therefore, it must be properly constructed and effectively maintained, taking in consideration slope gradient and length, soil parent material and depth, avoiding exposure of highly erodible and undesirable materials. Above all economical sustainability of the terraced land must be secured for long periods of time. Otherwise, it may cause high soil erosion rates, accelerating severe land deterioration.

Data for this indicator have been collected in 1239 study sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. No land terracing has been identified in 85.5% of the study field sites. All the other classes of land terracing have been found in less than 14.5% of the study field sites. The most important actions for soil erosion control and water conservation using terraces has been identified in the following 4 study sites: Santiago Island-Cape Verde, Guadalentin Basin Murcia-Spain, Zeuss Koutine-Tunisia, and Loess Plateau, China.


Fig. 64. Examples of traditional (left) and modern (right) land terracing

Terracing, an alternative land management practice for water conservation and erosion control, has been especially important for agricultural areas subjected to water or tillage erosion. Terraces are reducing desertification risk in agricultural areas.

Presence of terraces are related to land use intensity in areas affected by water stress. Field sites located in areas with low percentage of terracing are mainly subjected to high land use intensity.

Measuring the indicator

The assessment of land terracing can be done by defining the extent in which an area is covered by terraces. It is defined as the ratio of the area protected to the total area, expressed as a percentage using the following classes: (a) no terracing, (b) low, <25% of the area is protected; (c) moderate, 25-50% of the area is protected; (d) high, 50-75% of the area is protected; (e) very high, >75% of the area is protected. The assessment can be conducted by: (a) simple field observations, or (b) using aerial photography interpretation.

Land abandonment

Definition

Land abandonment (rate) defines the extent in which the cultivated land is abandoned over a certain period and territory.

Importance on land degradation process

Land abandonment is related to decreasing of land profitability, usually resulting in change land use from agriculture to grazing land. The extensive deforestation and intensive cultivation of hilly areas especially during the last decades has led to soil erosion and the formation of shallow skeletal soils. As the soil is eroded, land use is usually shifted from agriculture to pasture due to increasingly poor yields from the various agricultural crops. Such a pasture land in the Mediterranean region is defined as an abandoned land today. Various authors have simultaneously used the terms ‘abandoned land’ and ‘grazing land’, but grazing or hunting an abandoned land is considered a traditional use in the Mediterranean region. Land abandonment does not necessarily mean that land is no longer used, either by agriculture or any other rural economical activity. It means a change in land use from the traditional or recent pattern to another, less intensive pattern.

Land abandonment may have positive or negative impacts on desertification depending on the soils and climatic conditions of the area. Soils under favourable climatic conditions that sustain plant cover may improve with time by accumulating organic materials, increasing floral and faunal activity, improving soil structure, increasing infiltration capacity, and therefore decrease erosion potential and desertification risk (Fig. 65). In the opposite, areas with soils relatively shallow, of low organic matter content, with thin and of low resilience capacity vegetation cover, in steep slopes, with adverse climatic conditions, and overgrazed it results in negative impacts of land abandonment. The natural restoration processes in these areas are really slow, almost impossible, and persistent erosion processes can lead to severe soil degradation and desertification.

Fig. 65. Examples of areas with positive (left) and negative (right) effects of land abandonment on desertification

Data for this indicator have been collected in 1141 study field sites, corresponding to 14 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The majority of the study field sites have been characterized by low rate of land abandonment (<10 ha per 10 years per 10 km^2), covering 63.8% of the study sites. Moderate rate of land abandonment (10-25 ha per 10 years per 10 km^2) has been defined in 18.2% of the study field sites. High rate of land abandonment (26-50 ha per 10 years per 10 km^2) has been identified in 15.1% of the study field sites. Finally, very high rate of land abandonment (>50 ha per 10 years per 10 km^2) has been defined in few cases in Zeuss Koutine-Tunisia study site (Fig. 66).

This indicator is very important in assessing desertification risk especially in agricultural and forested areas in which the main process of land degradation is water erosion, and in areas subjected to overgrazing and water stress. The rate of land abandonment has negatively affected land degradation in agricultural areas, and in areas subjected to water stress or overgrazed. That means high rates of land abandonment (higher than 26 ha 10 yrs^{-1} 10 km^{-2}) have positive effect on land protection. In the opposite, field sites located in forested areas under high rates of land abandonment have adversely affected.

The rate of land abandonment in the study field sites is positively related to tillage operations in agricultural areas. As the rate of agricultural land abandoned increases, the remaining land is more intensively cultivated for compensation of the loss in crop production.

The rate of land abandonment is negatively related to grazing control in pastures with water erosion the main process of land degradation. Areas characterized with high rate of abandonment, grazing intensity is mainly characterized as high, further deteriorating the already degraded lands.

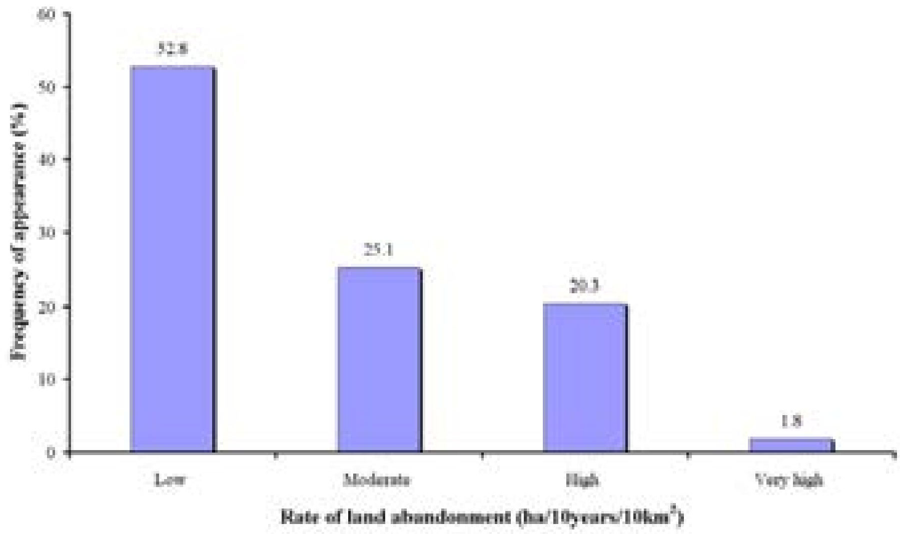

Fig. 66. Distribution of rate of land abandonment classes identified in 1141 field sites

The rate of land abandonment has positively influenced plant cover in areas with water stress considered as the main cause of land degradation. Areas in which land has been abandoned with moderate or high rates have mainly adequate plant cover due to partial recovery of natural vegetation. Furthermore, areas with high rates of land abandonment are mainly characterized by high land use intensity. Such areas are usually used as pastures which are mainly overgrazed, or since the arable land is limited farmers cultivate it intensively for partial compensation of the missing production due to land abandonment.

The rate of burned area is negatively related the rate of land abandonment in pastures overgrazed. Areas in which the rate of land abandonment has been characterized as high, the rate of burned area is relatively low.

The rate of land abandonment is especially considered as an important indicator in forested areas particularly affected by fires. The rate of land abandonment is negatively related to desertification risk due to forest fires. Areas under low rates of land abandonment are subjected to high rates of forest fires and high desertification risk. Land abandonment can affect desertification positively or negatively depending on the physical conditions at the time of abandonment and the management characteristics afterwards. The analysis of data has shown that land abandonment is mainly affected by indicators related to climate, vegetation, soil, husbandry, fires, water use, land management, and social characteristics (Fig. 67). Among the indicators related to climate, air temperature, annual rainfall, and rain seasonality are mainly related to rate of land abandonment in the study sites. Areas with high annual air temperature are usually characterized by low to moderate rate of land abandonment. Similarly, areas with moderate annual rainfall are mainly subjected to high rates of land abandonment. Also, areas with high rain seasonality are characterized by low rates of land abandonment. These trends of rate of land abandonment may be attributed both to high rates of land abandonment in previous decades resulting in low rates in the last decades in areas with high annual air temperatures and to high rates of land abandonment in the last decade due to low prices of agricultural products in areas with high annual rainfall or low rain seasonality.

Important vegetation indicators related to rate of land abandonment in forested areas affected by fires are major land use, vegetation cover type, and rate of deforested area. Areas used for agriculture are characterized by a higher rate of land abandonment than those used as pastures. Also areas cultivated with olives, vines and almonds have higher rate of land abandonment than areas with cereals. The rate of deforested areas is positively related to the rate of land abandonment. Areas with moderate or high rate of land abandonment are predominately subjected to high rates of deforestation.

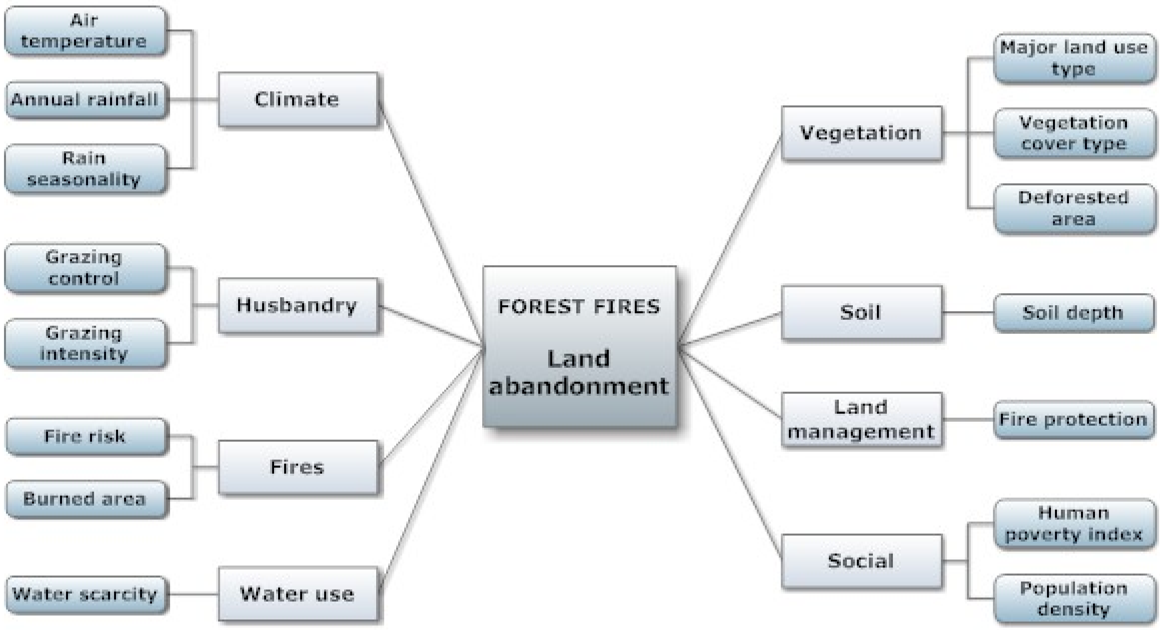

Fig. 67. Important indicators related to land abandonment in areas where forest fires are the dominant process of land desertification

Soil is a major determinant in land abandonment in forested areas affected by fires. Soil depth greatly affects water storage capacity and water available for plant growth. Areas with shallow soils are usually abandoned with higher rates than areas with deep soils since crop production becomes unprofitable.

Some important animal husbandry indicators related to the rate of land abandonment are grazing control and grazing intensity. The rate of land abandonment is negatively related to grazing control actions. Areas with adequate grazing control actions have higher rates of land abandonment. This is true for areas that land after abandonment is under low rates of grazing intensity. In addition, areas subjected to high grazing intensities are predominately characterized by low rates of land abandonment since farmers cultivated the land for feeding the animals.

Indicators related to fires and affecting rate of land abandonment in forested areas are fire risk and rate of burned area. Fire risk is positively related to rate of land abandonment.

Areas covered with vegetation of high fire risk have been subjected to higher rates of land abandonment. Fires in such areas are frequent, causing high soil erosion rates and land degradation followed by abandonment. In addition, the rate of land abandonment is positively related to the rate of burned area. Areas characterized by high rates of burned area are usually combined with high rates of land abandonment.

Among the land management characteristics only fire protection is significantly related to rate of land abandonment. Fire protection negatively affected rate of land abandonment. Areas characterized by low measures of fire protection have been mainly subjected to low rates of land abandonment.

An important water use indicator affecting land abandonment was water scarcity. Areas characterized by low water scarcity are predominately subjected to high rates of land abandonment. This may be attributed to the low prices of agricultural products leading to land abandonment even in areas with adequate water supplies.

The rate of land abandonment is related to social characteristics such as human poverty index and population density. Areas with high human poverty indices are mainly characterized by high rates of land abandonment. Also, areas with low population density are particularly characterized with high rates of land abandonment. This can be explained with the migration of rural population to urban areas or working parallel in other economical sectors such as tourism or industry.

Measuring the indicator

Data on land abandonment can be obtained from the National Statistical Service or by consultation with the local cooperatives. The analysis of ortho-photomaps of different periods or satellite data can be also used. The rate of land abandonment is expressed in hectares of land abandoned every 10 years on 10 km^2 territory. The following four classes of rate of land abandonment are used in this project: (a) low-abandoned area <10 ha per 10 years per 10 km^2 of territory, (b) moderate-abandoned area 10-25 ha per 10 years per 10 km^2 of territory, (c) high-abandoned area 26-50 ha per 10 years per 10 km^2 of territory, and (d) very high-abandoned area >50 ha per 10 years per 10 km^2 of territory.

Policy implementation

Definition

This indicator is related to the implementation of existing regulations on environmental protection.

Importance on land degradation process

The policy implementation indicator is used to assess the degree of application of the specific regulation on environmental protection. For example in a cultivated area a typical management practice for environmental protection is reduction of tillage and water erosion achieved by: (i) no tillage or minimum tillage, (ii) tillage of soil in the up-slope direction, (iii) contour farming, (iv) enhancement of vegetation cover. Therefore, protection of the land from soil erosion depends on the effectiveness of the implementation /implementation of such actions (Fig. 68).

Fig. 68. Examples of no implementation of existing regulations on environmental protection from soil erosion in grazing land (left) and fully implementation in olive grove by building terraces (right)

The information needed for policy implementation depends on the policy under consideration. For example, in the case of terracing protection policy, a relevant piece of information might be the ratio of protected to existing terraces. In the case of extensive agriculture policy, a relevant piece of information might be the percentage of farms (or farmers) or the percentage of area under extensive agriculture.

Data for this indicator have been collected in 1582 field sites, corresponding to 17 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant class of policy implementation in these areas is low, covering 39.8% of the field sites (Fig. 69). The next important class for this indicator is none regulation on environmental protection is implemented, covering 33.3% of the study field sites. Moderate policy implementation has been identified in 16.1% of the study field sites. Finally, adequate policy implementation has been identified only in 10.9% of the study field sites.

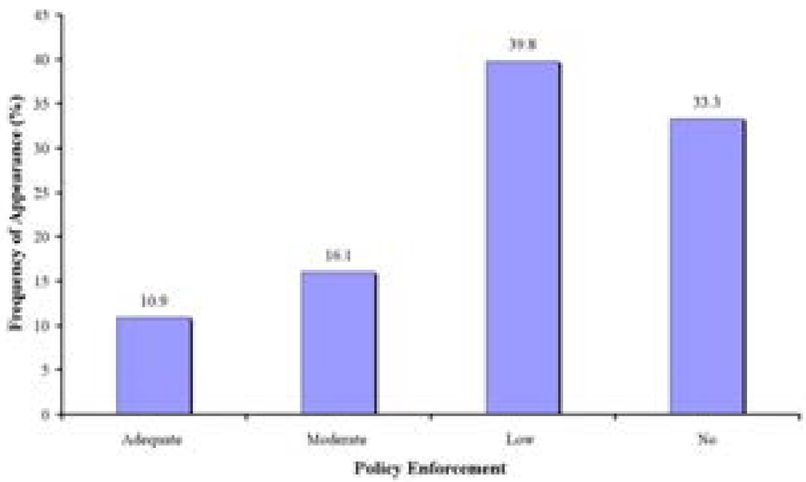

Fig. 69. Distribution of degree of policy implementation of existing regulations for environmental protection defined in 1582 field sites

Policy implementation is an important indicator in assessing land desertification risk especially in pastures and agricultural areas affected by soil erosion, and in areas affected by water stress. The statistical analysis of the obtained data have shown that policy implementation is positively related to the protection of natural resources by land degradation and desertification. Areas in which existing policies on environmental protection are adequate implemented, land degradation and desertification risk is significantly reduced. T he contribution of policy implementation is especially effective in areas affected by water stress.

Policy implementation in agricultural areas affected by soil erosion is related to: climate, soils, vegetation, land management, social and economical characteristics (Fig. 70). Among the cl imate characteristics, annual potential evapotranspiration has a g reat contribution to policy implementation. Policy implementation has been characterized mainly as low in areas with high annual evapotranspiration rates. Areas under high evapotranspiration rates are usually less developed and more remote in which policy implementation is usually low.

The most important vegetation indicators related to policy implementation in agricultural areas are vegetation cover type, and plant cover. In areas cultivated with cereals, vegetables, and vines, policy implementation is mainly low, while in areas cultivated with olives, and almonds policy implementation is mainly characterized as moderate or high. In addition, plant cover is positively related to policy implementation.

Important soil characteristics related to policy implementation in agricultural areas are soil texture, and soil water storage capacity. In areas with soils characterized as medium-, moderately fine-, and fine-textured with high water storage capacity, police implementation has mainly been characterized as high. Such soils usually support an adequate crop production providing an adequate farm income with a higher possibility for investment by the farmer on land protection. Furthermore, increasing rates of impervious surface are accompanied with low policy implementation.

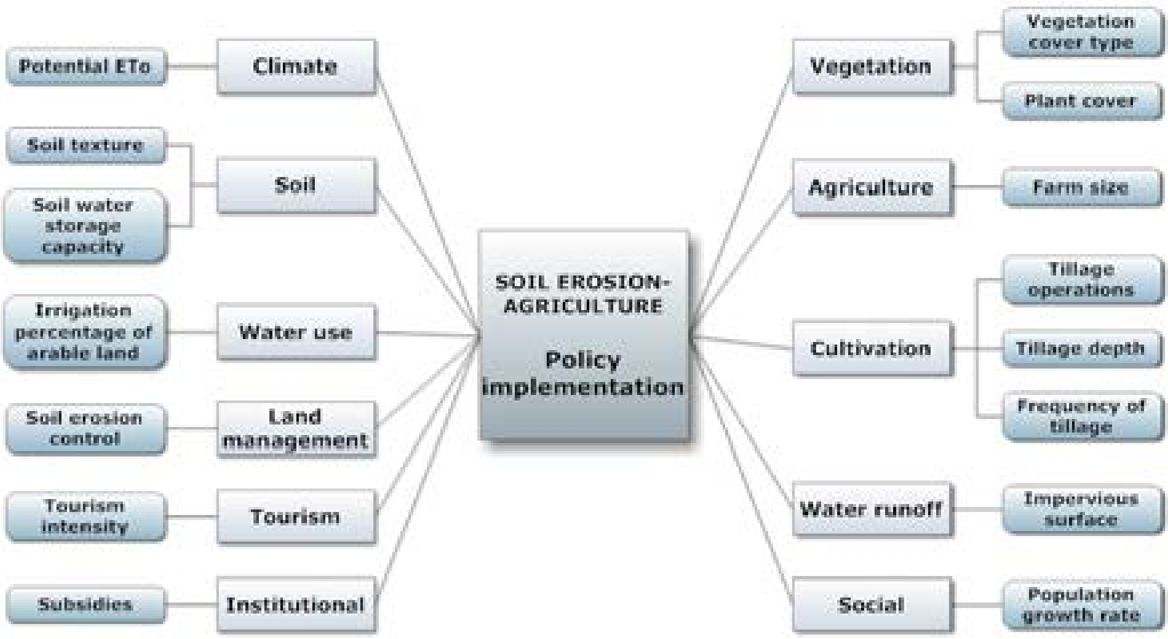

Fig. 70. Important indicators related to policy implementation in the study field sites under agricultural crops

Policy implementation has been related to farm size. In large farm sizes (greater than 30 ha), the policy implementation has been usually defined as low. Farmers occupying large farm sizes used to organize crop production on more professional basis, systematically cultivating the land for maximum production usually avoiding measures for land protection. Furthermore, irrigation percentage of arable is negatively affected policy implementation. In areas with high percentage of arable land, policy implementation has been mainly characterized as low.

Important indicators related to cultivation practices and affecting policy implementation in the study field sites are tillage operations, frequency of tillage, and tillage depth. Cultivation practices in which the soil is ploughed mainly with a mouldboard or a disk, in depths greater than 30 c m in more than two tillage operations per year, policy implementation has been mainly characterized as low. On the contrary, field sites in which tillage operations are limited, combined with actions for soil erosion control, policy implementation is mainly characterized as moderate or high.

Policy implementation is also significantly affected by tourism intensity and population growth rate in agricultural areas affected by soil erosion. Areas with high population growth rates have been mainly subjected to low policy implementation, independently of population density. Furthermore, areas with high tourism intensity are mainly characterized with moderate or high policy implementation. Under such conditions, local people consider agriculture as a secondary branch of their economy, usually accompanied by under-exploitation of natural resources.

Policy implementation in forested areas in which the main process of land degradation is soil erosion has been affected in the study field sites by various indicators related to physical environment, land management, and social characteristics (Fig. 71). The most important indicators related to climate are annual potential evapotranspiration, rain seasonality, and rain erosivity. Policy implementation has been mainly characterized as moderate to low in areas of high annual evapotranspiration, accompanied with low rain seasonality. Furthermore, policy implementation is mainly assessed as low in areas of low rain erosivity.

Vegetation cover type has also affected policy enforcement in forested areas. Field sites with vegetation cover type evergreen forests, mixed Mediterranean Macchia and evergreen forests or Mediterranean Macchia are better protected in relation to field sites with annual grasses and deciduous forests.

Indicators related to soil characteristics in forested areas such as parent material, slope aspect and gradient, and soil texture have affected policy enforcement. Areas in which the soils have been formed in limestone, acid igneous rocks, and sandstone have been less protected, than areas with soils formed in marl, basic igneous, shale, schist, and alluvial deposits. This can be attributed to the land productivity which is generally higher in the last types of parent materials. Furthermore, policy implementation has been mainly characterized as low to moderate in areas with steep south-facing slopes. In addition, policy implementation has been characterized as medium to low in field sites with fine- to moderately fine-textured soils.

Important indicators related to water runoff and affecting policy implementation in forested areas are drainage density and impervious surface area. As drainage density and impervious surface area increases, policy implementation has been mainly characterized as low to moderate in the study field sites.

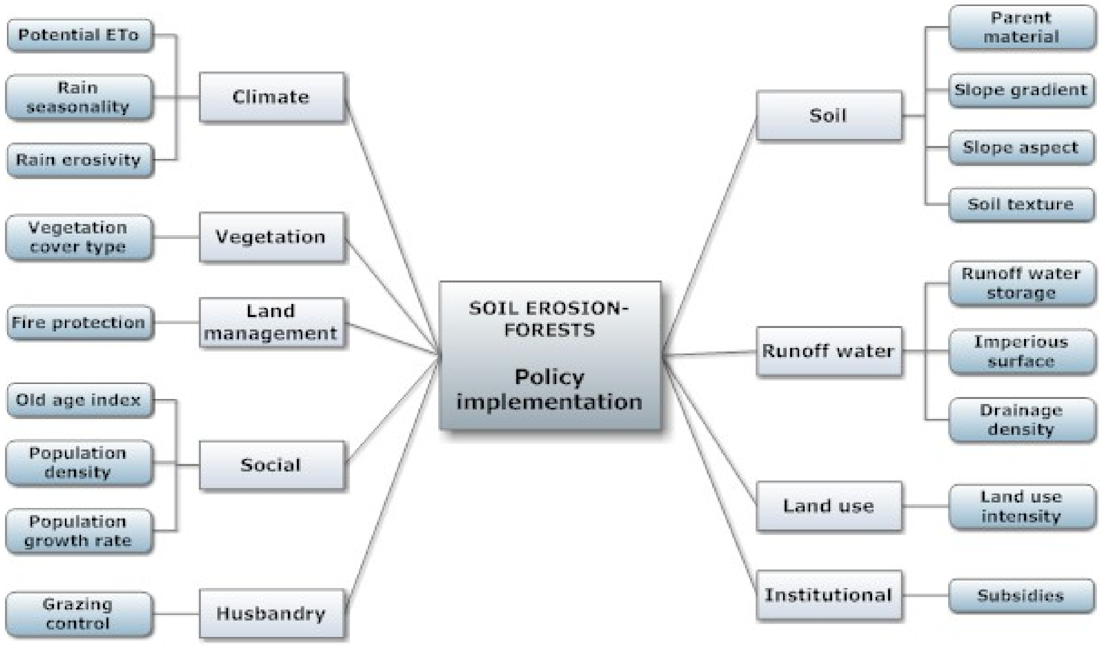

Fig. 71. Important indicators related to policy implementation in the study field sites of forested areas where the main process of land degradation was soil erosion

Policy implementation has been mainly performed in forested areas by the actions of grazing control, fire protection, and storage of water runoff. Areas in which land use intensity has been characterized as high, policy implementation is mainly assessed al low to moderate.

Important social indicators affecting police implementation in the forested areas are old age index, population density, and population growth rate. In areas with high old age index, low population density, and high population growth rate, policy implementation is mainly characterized as low. Since the social characteristics used here cover broad areas and the urban/rural distribution of the local population is not clear, the conclusions on how such indicators are affecting policy implementation for environmental sustainability needs more investigation. Finally, in areas where subsidies have been allocated, policy implementation is negatively affected.

Measuring the indicator

The policy implementation in a field site can be assessed by considering the existing regulations for environmental protection in each study site and estimating the degree in which the regulations are applied by personal judgment. Four classes of policy implementation are distinguished in this project: (a) adequate, >75% of the land is protected; (b) moderate, 25-75% of the land is protected; (c) low, <25% of the land is protected; and (d) no protection of the land.

Impervious surface area

Definition

Impervious surface area (rate) defines the surface area sealed over a specific territorial surface and time period.

Importance on land degradation process

Impervious surface area or soil sealing occurs when agricultural or other rural land is taken into built environment (littoralization). Soil sealing is the result of the development of housing, industry, transport and other physical infrastructure, including utilities (e.g. waste disposal) and military installations (Fig. 72). The EU Thematic Strategy for Soil Protection identifies soil sealing as one of the eight recognized threats to Europe's soil resources. One major driver of soil sealing in the Mediterranean region is population pressure. Over the last three decades the Mediterranean countries have experienced a tremendous growth in population increase. In 2000 the 22 Mediterranean countries housed 428 million people, compared to 285 million in 1970. Population pressure in the Mediterranean is exacerbated also by the tourism development which is the most preferred destination for European tourists. The impacts of soil sealing expansion in conjunction with climatic changes has greatly contributes to loss of fertile agriculture soils, expansion of agriculture in marginal lands, frequent flooding in the lowland due to artificial infrastructure cover of soil surface reducing water infiltration, water pollution due to overuse of pesticides and fertilizers, soil salinity due to irrigation with saline water, decrease in ground water enrichment, and sea water intrusion into the aquifers. All these processes greatly contribute to land degradation and desertification.

This indicator has been described in 877 field sites, corresponding to 11 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America. The dominant rate of soil sealing is low (<10 ha 10 km^{-2} 10 $years^{-1}$), covering 43.4% of the study field sites. The next important class of soil sealing is moderate (10-25 ha 10 km^{-2} 10 $years^{-1}$), covering 35.6% of the study field sites. Very high rate of soil sealing (>50 ha 10 km^{-2} 10 $years^{-1}$) has been defined in 17.1% of the study field sites, corresponding to the most tourist areas. High rate of soil sealing has been identified in few cases, corresponding to 6.1% of the study field sites.

Fig. 72. Soil sealing due to cover of the soil surface with inert material causing severe problems of land degradation

Rate of change of impervious surface area or soil sealing has been found as an important indicator especially for areas subjected to water stress. Under high rates of change of impervious surface (rate greater than 26 ha per 10 km^2 of territorial surface per 10 years[1]), desertification risk is negatively affected. Impervious surface is a regional indicator which can have negative effects on water resources of a broad region, but at local level in the study field sites water stress in the growing plant is relatively alleviated. In addition, high rates of expansion of impervious surface area in the study areas were associated with low land use intensity.

The rate of change of impervious soil surface negatively affects tillage operations in cropland. Areas with high rate of change in impervious soil surface are usually associated with tourism or industrial activities in which agriculture is rather a secondary branch of economy, resulting in less intensive agriculture accompanied by limited number of tillage operations.

Soil erosion control is related to impervious surface area in pastures. As impervious surface area increases, soil erosion control actions in those areas is highly limited. This correlation is mainly attributed to high degree of land degradation accompanied with low productivity, negatively affecting farmers for investing money in soil erosion control measures.

Impervious soil surface is related to runoff water storage in forested areas. Runoff water storage actions are more frequently found in areas with low rates of impervious surfaces expansion. Furthermore, policy implementation in forested areas has been mainly characterized as low to moderate as rate of impervious surfaces increased.

Measuring the indicator

The rate of change of impervious surface area can be estimated by using a series of aerial photographs taken in different periods. This indicator is measured as the surface area sealed in hectares per 10 km^2 of territorial surface per 10 years. The following classes are distinguished for this project: (a) low: <10 ha area sealed in a territorial of 10 km^2 per 10 years, (b) moderate: 10-25 ha per 10 km^2 of territorial surface per 10 years, (c) high: 25-50 ha per 10 km^2 of territorial surface per 10 years, and (d) very high: >50 ha per 10 km^2 of territorial surface per 10 years.

5. Processes and causes of land degradation and desertification

Land desertification is an important issue for many areas around the world. The selected study sites of the DESIRE project are typical examples of areas affected by various processes or causes of land degradation leading to desertification. The degree of desertification risk depends both on the severity of acting processes and causes of land degradation and the state of the physical environment. The main processes or causes of desertification identified in the study field sites are soil erosion (including water and tillage erosion), soil salinization, water stress, overgrazing, and forest fires.

5.1 Desertification risk in the study sites

The study sites are located in areas affected or sensitive to land degradation and desertification by a variety of processes and causes such as soil erosion, soil salinization, water stress, overgrazing, forest fires, and urbanization. The main biophysical and socio-economic factors affecting desertification are adverse climatic conditions, sloping terrain, moderately deep or shallow soils, moderate availability of water resources over-exploited in many cases, relatively frequent fires in forested areas, intensively cultivated agricultural land or overgrazed grazing land, inadequate measures for land protection, low or moderate implementation of existing regulations for environmental protection.

Under the mentioned land and management characteristics, the study field sites are mainly characterized by high or moderate desertification risk. Very high desertification risk has been defined in 18% of the study field sites (Fig. 1). The analysis for each study site separately shows that some field sites have high percentage of desertification risk. Specifically, very high desertification risk has been defined in all the study field sites in Rendina Basin Basilicata-Italy due to high erosion rates caused by surface water runoff and tillage operations. Also, very high desertification risk due to soil erosion and water stress has been identified in the Santiago Island-Cape Verde, and Zeuss-Koutine-Tunisia study sites, covering 57.3% and 43.3%, respectively, of the corresponding study field sites. Very high desertification risk has been estimated in 40% of the study field sites in the Nestos Basin Maggana-Greece, caused exclusively by soil salinization due to poorly drained soil conditions and the low quality of groundwater. In the field sites of the Mação Gois- Portugal, Guadalentin Basin Murcia-Spain, Boteti Area-Botswana, Mamora Sehoul-Morocco, Loess Plateau-China, Secano Interior-Chile, Crete-Greece, and Cointzio Catchment-Mexico study sites high desertification risk has ranged from 3.3% to 23.0% due to soil erosion, soil salinization, and forest fires.

High desertification risk has been assessed in most of the cases of the study field sites covering 37.4% (Fig. 1) considered all field sites together. This class of desertification risk has been defined in all field sites of Konya Karapinar and Eskisehir Plain-Turkey study sites, caused mainly by surface water runoff. The next important percentage of high desertification risk has been assessed for the study sites of Novij Saratov and Djanybek-Russia, Boteti Area-Botswana, and Mamora Sehoul-Morocco, covering 61.4%, 48.1%, and 47.5% of the total study field sites, respectively, caused mainly by soil erosion, soil salinization, water stress, and overgrazing. High desertification risk has been estimated for some of the study sites of

Nestos Basin Maggana-Greece, Crete-Greece, Mação Gois- Portugal, Guadalentin Basin Murcia-Spain, Zeuss Koutine-Tunisia, Boteti Area-Botswana, Loess Plateau-China, Secano Interior-Chile, Cointzio catchment-Mexico, ranging from 16.4% to 35.6% of the study field sites, caused mainly by soil erosion, water stress, soil salinization, overgrazing, and forest fires.

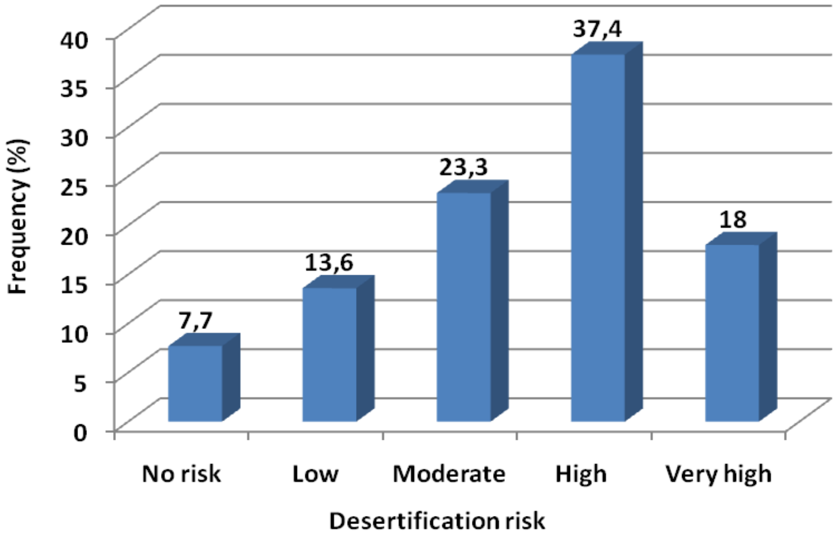

Fig. 1. Distribution of desertification risk defined in the various study sites of DESIRE project

Moderate desertification risk has been defined in 23.3% of the total study field sites (Fig. 1). This class of desertification risk has been estimated in all study sites except for Rendina Basin Basilicata-Italy, Karapinar and Eskisehir Plain-Turkey, in a percentage ranging from 16.0% to 45.5% of the study field sites in each area. The main processes responsible for this class of desertification risk are soil erosion, soil salinization, water stress, and overgrazing.

Low or no desertification risk has been defined in some of the study field sites covering 13.6% and 7.7% of the total field sites. The highest number of field sites characterized with slight or no desertification risk has been estimated in the study sites of Loess Plateau-China, Gois and Mação-Portugal, and Secano Interior-Chile covering 44.5%, 44.4%, and 50% respectively. About 1/3 of the study field sites of Crete-Greece, Guadalentin Basin Murcia-Spain, and Cointzio catchment-Mexico have been characterized by these classes of desertification risk. Low to no desertification risk has been defined in few field sites of Nestos Basin Maggana-Greece, Zeuss Koutine-Tunisia, Boteti Area-Botswana, Santiago Island-Cape Verde, and Mamora Sehoul-Morocco, ranging from 3.3% to 14.6%.

5.2 Water erosion

Soil erosion by water is a widespread problem throughout the study field sites of the DESIRE project. Water erosion has been identified as the most important process of land degradation and desertification in 798 of the study field sites or 47.7% of the total studied sites. It has been defined as one of the major process of land degradation in 9 study sites, located in Mediterranean Europe, eastern Europe, Africa, Asia, and Latin America.

Soil erosion was described by assessing the degree of soil erosion during the field survey. It was characterized according to: (i) the presence or absence of the soil surface A-horizon, (ii) the existence and percentage of eroded spots, (iii) the degree of exposure of the parent material on the soil surface, and (iv) the presence of erosional gullies. The following five classes of erosion were used: no erosion, slight, moderate, severe, and very severe erosion.

Moderate erosion was the most important identified class, covering 33.6% of the study field sites (Fig. 2). The majority of the study field sites with moderate erosion are located in agricultural or forested areas subjected mainly to high or moderate desertification risk. The next important classes of soil erosion identified in the study field sites were severe and very severe erosion, covering 24.0% and 11.9% of the corresponding study field sites, respectively (Fig. 2). Severe erosion was associated with the presence of gullies found mainly in agricultural or grazing lands. No erosion or slight erosion has been defined in the rest of field sites covering 12.6% and 17.9% of the study field sites, respectively. Such classes of soil erosion have been mainly identified in field sites located in agricultural or forested areas with adequate plant cover, or properly managed and protected from degradation by applying soil erosion control measures such as sustainable number of animals, fire protection, storage of water runoff, sustainable farming, etc.

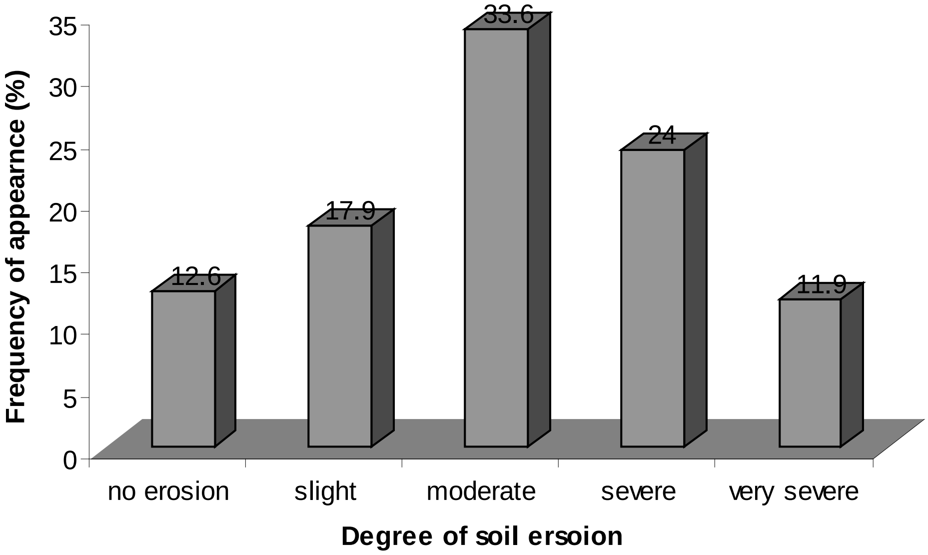

Fig. 2. Distribution of degree of soil erosion classes identified in the study field sites

Important indicators affecting soil erosion

The analysis of the obtained data including all land uses (cropland, pastures, and forests) have shown that the most important indicators affecting soil erosion in the study field sites are related to climate, vegetation, soil, agriculture, land management, husbandry, water use, land use, social, and institutional characteristics of the study field sites (Fig. 3). Plant cover is the most important vegetation indicator. The lower the plant cover the higher the degree of soil erosion. Field sites with permanently plant cover greater than 50% are adequately protected from soil erosion.

The most important soil indicators affecting degree of soil erosion in the study field sites are slope gradient, slope aspect, and presence of rock fragments in the soil surface.

Moderate and severe soil erosion classes have been usually identified in slopes greater than 12%. Field sites located in steep south-facing slopes are usually highly eroded compared to field sites with lower gradients of north-facing slopes. The presence of high percentage of rock fragments in the soil surface in amounts greater than 15% have reduced surface water runoff and therefore degree of soil erosion.

Annual potential evapotranspiration and rain seasonality are the most important climate indicators affecting degree of erosion in the study field sites. Potential evapotranspiration is positively related to degree of soil erosion. Field sites located in areas of high evapotranspiration rates (greater than 1200 mm) are characterized with moderate or severe degree of soil erosion. In addition, field sites located in areas with rainfall seasonality characterized as rather seasonal and s hort dry season precipitation regime (rainfall seasonality index lower than 0.40) have been subjected to higher soil erosion.

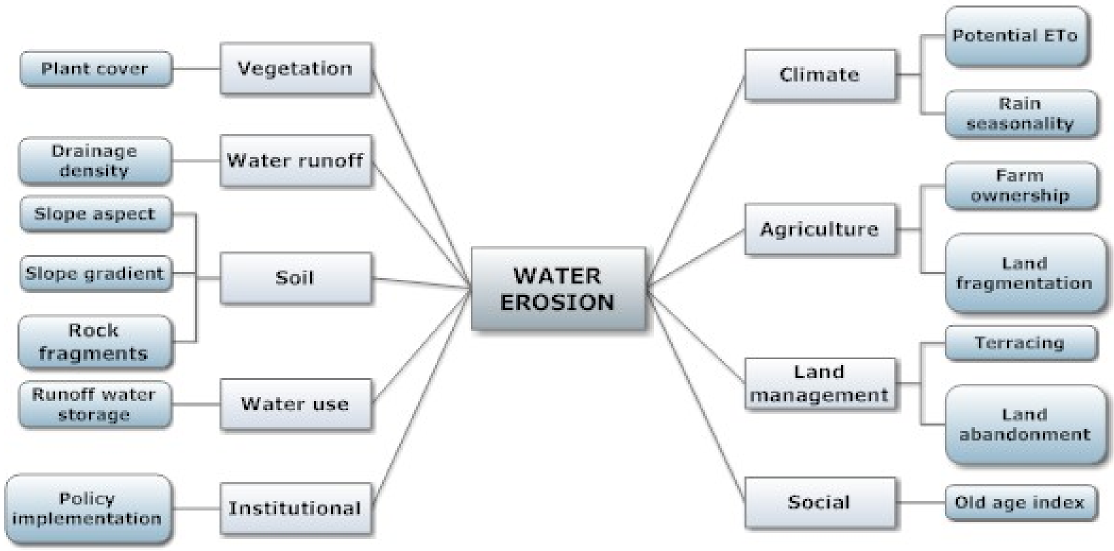

Fig. 3. Important indicators affecting soil erosion by surface water runoff in field sites located in agricultural, grazing or forested areas

The most important water runoff indicator affecting soil erosion is drainage density. Drainage density is positively related to soil erosion. Moderate to severe erosion has been defined in field sites with high drainage density network. This indicator is interrelated with the type of surface geological formations affecting infiltration rates and therefore drainage density and soil erosion.

As it is expected, actions for soil erosion control have a great effect on the degree of erosion identified in the study field sites. T he most important action identified by the analysis of the data obtained is runoff water storage. Field sites, in which actions for storing surface water runoff have been undertaken, have usually subjected to slight or no e rosion. Furthermore, land terracing is positively related to degree of soil erosion. Field sites with high percentage of land terracing have higher soil erosion due to poor designing or managing of terraces. The correlations estimated for other actions such as sustainable farming, soil erosion control measures, etc. are relatively low. Finally, field sites in which the exiting regulations for environmental protection are applied, the degree of soil erosion is mainly characterized as moderate to low.

Rate of land abandonment is an important indicator of soil erosion. Filed sites located in areas with high rate of land abandonment (higher than 25 ha per 10 years per 10 km^2) are subjected to higher soil erosion. Abandoned agricultural land is usually highly degraded or located in areas of adverse climatic conditions. After abandonment, land is usually used as grazing land, in many cases overgrazed subjected to high erosion and desertification risk.

Among the most important indicators related to agriculture and affecting soil erosion are land fragmentation, farm ownership, and old age index. Field sites belonging to a farm with high land fragmentation (higher than 10 parcels per farmer) are mainly subjected to moderate or severe soil erosion. Tenant-farmed or shared-farmed field sites are mainly characterized with moderate to slight soil erosion. Furthermore, field sites located in areas with high old age index (higher than 10%) are subjected to moderate or severe erosion due to unwillingness of old-aged farmers to apply measures for soil erosion protection.

Interrelated indicators

The analysis of variance among indicators affecting desertification mainly due to soil erosion in agricultural, pastures and forested areas have shown the following interrelated pairs of indicators in the study field sites:

- Rainfall seasonality – land fragmentation (-)
- Rainfall seasonality – rate of land abandonment (-)
- Potential evapotranspiration – old age index (+)
- Potential evapotranspiration – runoff water storage (+)
- Rainfall – tillage direction (-)
- Population density – farm ownership (+)
- Population density – sustainable farming (-)
- Population density – soil erosion control (-)
- Population growth rate – rate of burned area (+)
- Grazing intensity - old age index (-)
- Sustainable farming - soil erosion control (+)
- Sustainable farming – soil water conservation measures (+)
- Grazing control – rate of land abandonment (-)

The climate indicators rainfall seasonality, potential evapotranspiration, and rainfall are interrelated with the land management and social indicators land fragmentation, land abandonment, runoff water storage, tillage direction, and old age index. Under long rainfall seasonality (greater than 0.6) land fragmentation is mainly low (lower than 5 parcels per farm). Furthermore, under climatic conditions of long rain seasonality, the rate of land abandonment is mainly characterized as low to moderate (less than 10 ha/10 years/10 km^2). Potential evapotranspiration is closely related to old age index and runoff water storage actions. In other words, in dry areas with high evapotranspiration rates (higher than 1200 mm per year), old age index is usually high (higher than 10%) and runoff water storage actions are limited. In addition, grazing land characterized by high old age indices is usually subjected to low grazing intensity. Also annual rainfall is related to tillage direction. Under low amounts of rainfall (lower than 650 mm), farmers used to plow the soil parallel to the contour lines for conserving rainfall water.

The population density is interrelated with the agriculture and land protection indicators farm ownership, soil erosion control, and sustainable farming. High population density (higher than 100 people per km^2) is usually accompanied by tenant- or state-farmed land characteristics. Furthermore, under high population density, the soil protection measures of sustainable farming and soil erosion control are usually inadequate. In addition, Population growth rate is positively related to the rate of burned area. High population growth rate (higher than 0.4% per year) is usually related to high rate of burned area (greater than 25 ha burned/10 years/10 km^2 of territorial).

The land management indicator sustainable farming is positively related with the indicators soil water conservation and soil erosion control measures. Finally, grazing control is closely related to the rate of land abandonment. Areas under adequate grazing control such as fencing, sustainable number of animals, are usually characterized by low rates of land abandonment.

5.2 Tillage erosion

Tillage erosion is attributed to the soil displacement caused by the tillage implements. It is a progressive downslope soil translocation caused mechanically by tillage implements (Govers *et al*., 1994, 1996). In the previous decades due the mechanization of agriculture (introduction of tractor), the availability of heavy powerful machineries favoured deep soil ploughing at high speeds in directions usually perpendicular to the contours, resulting in the displacement of huge amounts of soil materials from the upper convex hillslope parts (summit, shoulder, backslope) to the lower concave parts (footslope, toeslope), significantly decreasing the productivity of the upper hillslope parts of a field.

Tillage erosion has been identified as an important process of land degradation in 283 field sites, corresponding to the following 4 study sites: Rendina B asin Basilicata-Italy, Boteti Area-Botswana, Loess Plateau-China, and Crete-Greece.

Cultivation of the land by ploughing has been defined in 36.5% of the total study field sites, while no tillage operations were identified in 35.7% of the cases. The main tillage frequency defined was twice per year in 33.7% of the field sites. Dominant depths of cultivation were less than 20 cm and 20-30 cm in 23. % and 26.6% of the cases, respectively. Tillage direction was mainly downslope in 37.6% and parallel to the contour lines in 41.6% of the cases.

Important indicators of tillage erosion

Important indicators affecting desertification risk with tillage erosion the main process of land degradation in the study field sites are related to soil, cultivation, land management, and instructional characteristics (Fig. 4). The obtained data showed that soil erosion is positively related to slope gradient. Field sites located in agricultural areas with slopes greater than 12% are subjected to moderate or severe erosion. Furthermore, field sites with low organic matter content (lower than 2.0%) in the surface horizon are mainly characterized with moderate or severe erosion. High amounts of organic matter content favour soil aggregate stability, reducing soil displacement by the forces applied by the tillage instruments.

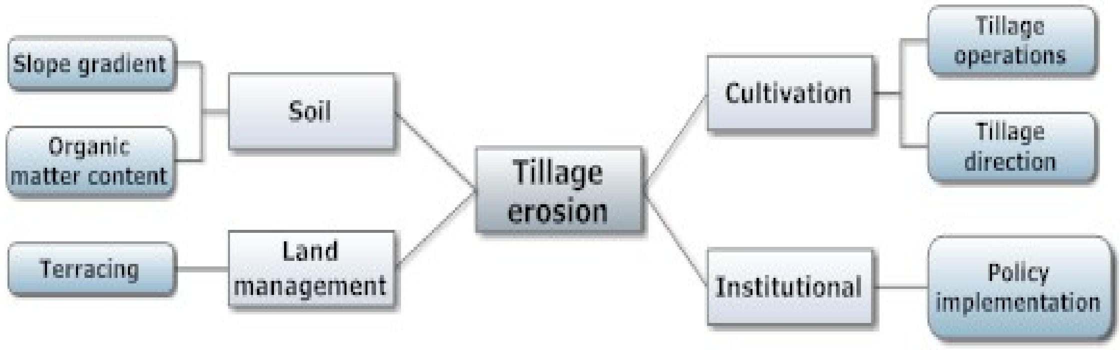

Fig. 4. Important indicators affecting tillage erosion in the study field sites

Among the indicators related to cultivation, tillage operations and tillage direction are significantly affecting tillage erosion. Field sites subjected to ploughing, disking or harrowing were mainly characterized by moderate or severe erosion. Furthermore, field sites where cultivation is conducted in the down slope or oblique direction are mainly characterized by moderate to severe erosion. Tillage depth is of course a very important factor affecting tillage erosion. In the present study was not introduced in the final list of important indicators since no significant variance was recorded in the study field sites.

Land terracing is negatively related to tillage erosion. Field sites with high percentage of terraces (greater 50%) are usually subjected to slight degree of erosion, since in such cases land is usually not cultivated or cultivation is carried out along the contour lines. Finally, agricultural areas in which some measures of soil protection are applied or policy on environmental protection is implemented tillage erosion is significantly reduced.

Interrelated indicators

The analysis of variance among indicators affecting desertification risk mainly due to tillage erosion in agricultural areas have shown the following interrelated pairs of indicators in the study field sites:

- Tillage direction – tillage operations (+)
- Tillage direction – mechanization index (+)
- Tillage direction – land use intensity (+).

Tillage direction is positively related to the indicators tillage operations, mechanization index, and land use intensity. If tillage direction is perpendicular to the contour lines in the downslope direction, tillage operations are usually conducted by a moldboard, a disk or a harrow. Furthermore, under this cultivation practices, mechanization index is usually characterized as high. Downslope tillage direction perpendicular to the contour lines is usually related to high land use intensity.

5.3 Soil salinization

Soil salinization is an important land degradation and desertification process especially affecting plain areas. Soil salinization becomes an important degradation process under specific soil, topography, climate and land management characteristics. Poorly drained soils located in the lower parts of a valley floor or alluvial plain with low quality of groundwater are very susceptible to salinization under arid and semi-arid climatic conditions. Climate acts directly on soil salinization through high evaporation rates, and indirectly as the driving force behind soil salinization associated with irrigation. Soil salinization can be distinguished as primary or secondary salinization processes. Primary salinization involves accumulation of salts through natural processes such as physical and chemical weathering and transport processes from salty geological deposits or groundwater. Secondary salinization is caused by inappropriate irrigation practices, such as the use of salt-rich irrigation water and/or poorly drainage conditions.

Soil salinization has been considered as an important land degradation and desertification process in 258 field sites from the total 1672 study sites. It has been defined as an important process of land degradation in the following 6 study sites: Nestos Basin Maggana-Greece, Boteti Area-Botswana, Konya Karapinar plain-Turkey, Novij Saratov-Russia, Djanybek-Russia, and Crete-Greece.

Important indicators of soil salinization

Among the most important indicators affecting soil salinization in the study sites are related to climate, soil, water, water use, land use, social and institutional characteristics (Fig. 5). Aridity index and annual rainfall are the most important climate indicators. Areas of high aridity indices (Bagnouls-Gaussen aridity index >125) combined with low amounts rainfall (lower than 650 mm) are more likely to be affected by soil salinization.

Indicators related to water resources or water use have a great impact on soil salinization. Among the most important indicators identified in the study field sites are water quantity, ground water exploitation, water consumption/water demands, irrigation percentage of arable land, and water scarcity (Fig. 5). Areas of low quantity of available water resources accompanied with over-exploitation of ground and surface water resources are more vulnerable to secondary soil salinization. Furthermore, under high rates of water consumption/water demands (WC/WD>1), soil salinization is more likely to occur. In addition, when water of good quality is available for expansion of irrigation of the land, soil salinization risk is reduced. Also areas characterized by high water scarcity (Water available supply per capita / water consumption per capita during the last 10 years (WAC/WCC) greater than 0.5) are more vulnerable to soil salinization.

The most important soil indicator affecting soil salinization in the study sites is soil water storage capacity. Soils of high water storage capacity are more vulnerable to soil salinization. Soil water storage capacity is affected by various soil properties such as soil texture, soil porosity, etc., therefore moderately fine and fine-textured soils are more likely to affected by salinization.

Period of existing land use is the most important indicator among land use indicators related to soil salinization in the study field sites. Areas with a period of existing land use greater than 30 years are more likely to be affected by soil salinization. This can be attributed to factors such as climate change, expansion of irrigation, over-exploitation of water resources, and low policy implementations of exiting regulations on natural resources protection.

Fig. 5. Important indicators related to soil salinization defined in 258 study field sites

Population density has been defined as the most important indicator related to soil salinization in the study sites. High population density (greater than 100 people per km^2) leads to overexploitation of water resources, chemical degradation of water quality, and soil salinization in the irrigated land. Finally, if existing policies on environmental protection are implemented, then salinization risk is highly reduced.

Interrelated indicators

The analysis of variance among indicators related to soil salinization have shown the following interrelated pairs of indicators in the study field sites:

- Air temperature - irrigation percentage of arable land (-)
- Aridity index - tourism intensity (+)
- Farm ownership - irrigation percentage of arable land (+)
- Distance from seashore - irrigation percentage of arable land (-)
- Aquifer overexploitation - irrigation percentage of arable land (-).

Irrigation percentage of arable land increased with increasing annual air temperature, increasing rate of exploitation of ground water, and decreasing distance from the seashore. Furthermore, owner-farmed land is more frequently irrigated than tenant-farmed ones. Finally tourism intensity which affects water consumption is higher in areas characterized by high aridity index and salinization risk.

5.4 Water stress

Water stress in the growing plants is mainly related to soil and climate characteristics. Areas with soils of relatively shallow depth, under low annual rainfall, high aridity index, high evapotranspiration rate and long rainfall seasonality are vulnerable to desertification risk due to water stress.

Water stress has been defined as an important process of land degradation and desertification in 203 field sites from the 1672 studied in the DESIRE project. These study field sites are located in: Boteti Area-Botswana, Konya Karapinar plain-Turkey, Novij Saratov-Russia, and Crete-Greece. The greatest number of candidate indicators among the studied processes or causes (50 indicators) for assessing desertification risk has been described in the field sites subjected to water stress.

Important indicators of water stress

Twelve indicators have been defined as the most important affecting desertification risk in field sites where water stress has been recognized as the most important degradation process. The defined indicators are related to climate, soil, water and water use, vegetation, land use, fires, water runoff, land management, tourism, social and institutional characteristics (Fig. 6).

Desertification risk is defined as high due to water stress in field sites characterized by long rainfall seasonality. Such conditions are usually found in areas characterized by arid or semi-arid climatic conditions. Desertification risk increases as ground water exploitation and water scarcity increases. Areas characterized by high rate of impervious surface area (greater than 25 ha /10 km^2 of territorial /10 years) are subjected to lower desertification risk due to water stress.

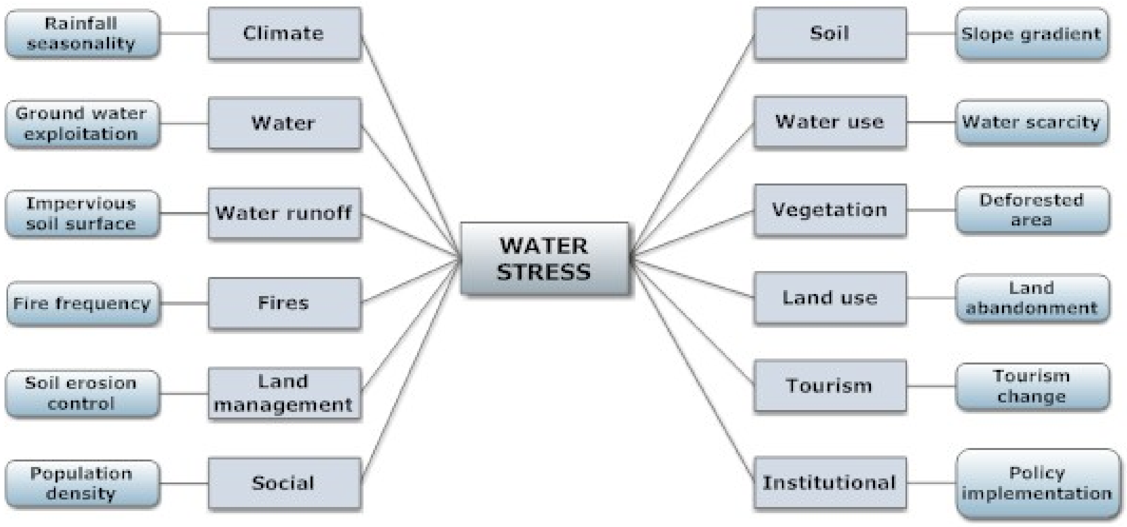

Fig. 6. Important indicators affecting water stress defined by the analysis of 203 field sites

The most important indicator related to soils affecting water stress and desertification risk is slope gradient. Under high slope gradients (greater than 25%), the growing plants are subjected to higher water stress since surface water runoff is expected to be higher.

The indicators rate of deforested area and fire frequency are negatively related to water stress. Under high rates of deforestation or fire frequency the growing plants are mainly removed reducing water demands and water stress risk.

Water stress is negatively related to soil erosion control measures. Field sites in which no or low soil erosion control measures are undertaken, water stress and desertification risk is high.

Tourism change is positively related to water stress. Areas under high tourism change (higher than 5% - number of overnight stays in a specific destination in one year averaged by overnight stays in the last 10 years) are more vulnerable to water stress since urban water consumption increases in charge of water used for plant growth. The same trends with tourism change are found for the indicator population density. Finally, if existing policies on environmental protection are implemented, water stress and desertification risk is diminished.

Interrelated indicators

The analysis of variance among indicators affecting desertification risk in areas where soil water stress is the most important land degradation process have shown the following interrelated pairs of indicators in the study field sites:

- Aridity index – drainage density (-)
- Aridity index – land abandonment (-)
- Aridity index – population growth rate (+)
- Air temperature – human poverty index(+)
- Rainfall seasonality – rate of deforested area (+)
- Rainfall seasonality – fire frequency (+)
- Rainfall seasonality – fire protection (-)
- Rainfall seasonality – tourism change (+)
- Rainfall seasonality – population growth rate (+)
- Rainfall seasonality – ground water exploitation (+)
- Water consumption/water demands – ground water exploitation (+)
- Water scarcity – water quality (+)
- Tourism change – ground water exploitation (+)
- Tourism change - fire frequency (+)
- Tourism change – population growth rate (+)
- Tourism change – policy implementation (-)
- Tourism intensity – exposure of rock outcrops (+)
- Population growth rate – rate of deforested area (+)
- Fire frequency – ground water exploitation (+)
- Fire frequency – fire protection (-)
- Rate of land abandonment – human poverty index (-)
- Old age index – human poverty index (-)
- Old age index – population growth rate (-).

The analysis of variance have shown that the climate indicators air temperature, aridity index, and rainfall seasonality are interrelated with many land management, and social indicators. Specifically, aridity index is negatively related to drainage density, and rate of land abandonment. Field sites with high drainage density have been mainly associated with high aridity indices. Also, the rate of land abandonment is mainly characterized as low (lower than 10 ha/10 years/10 km^2) in areas with high aridity index. Finally, aridity index is positively related with population growth rate. Areas of high aridity indices are usually characterized by high population growth rate. Furthermore, high average air temperature is usually associated with high poverty index.

Rainfall seasonality is interrelated with many indicators. Rate of deforested areas is positively related with rainfall seasonality. Field sites with long rainfall seasonality (greater than 0.6) have usually high rate of deforestation (greater than 2.5% per year). Fire frequency and fire protection are indicators related to rainfall seasonality. Under long rainfall seasonality, fire frequency is mainly high, while fire protection measures are highly limited. The indicators tourism change, population growth rate, and ground water exploitation are positively related to rainfall seasonality. Areas with long rainfall seasonality are mainly characterized with high tourism change rates (greater than 5%), high population growth rate (higher than 0.4% per year), and high ground water exploitation since water demands for irrigation and human consumption are increased.

Indicators related to water and water use such as water consumption/water demands, ground water exploitation, and water quality are interrelated. Ground water exploitation is positively related to tourism change and water consumption/water demands. High ground water exploitation rates (recharge>exploitation> 0.8*recharge) are usually accompanied with high tourism change and high water consumption/water demands ratios.

Tourism change is positively interrelated with fire frequency and population growth rate, but negatively to policy implementation of existing regulations for environmental protection. Field sites located in areas of high tourism change (greater than 5%) are usually subjected to high fire frequency (greater than once every 15 years), and population growth rates are usually greater than 0.4% per year. The land in areas characterized by high tourism change is usually inadequately protected from degradation and desertification. Usually people leaving in such areas are seeking more and more to exploit the land without applying adequate measures for protection. In addition, this type of environmental management is associated with areas of high percentage of rock outcrops. High percentage of rock outcrops (greater than 10%) in sloping areas is usually characterized with high tourism intensity (greater than 0.04 - number of overnight stays /10 km^2).

Population growth rate is interrelated with rate of deforestation. Field sites located in areas of high population growth rate (greater than 0.4% per year) are usually subjected to high deforestation rates (greater than 2.5% per year).

Fire frequency is interrelated with the indicators ground water exploitation and fire protection. Field sites characterized by high fire frequency (less than once every 15 years) are subjected to low fire protection but high ground water exploitation rates.

The indicator human poverty index is related to rate of land abandonment and old age index. Field sites located in areas of high poverty index are usually characterized by low rates of land abandonment (less than 10 ha/10 years/10 km^2). Under high poverty index conditions, land is not abandoned but cultivated for satisfying food needs for the living people. Furthermore, field sites located in areas of high poverty index are usually characterized by moderate to low old age index (less than 10% of the population with age >65 / total population). In addition, the indicator old age index is negatively related to population growth rate.

5.5. Overgrazing

Overgrazing occurs when the number of animals grazing the land is more than its grazing capacity. Overgrazing is an important cause of land desertification affecting biodiversity, soil degradation, and soil erosion. Animals overgrazing the land eat parts of plants or whole plants removing selectively the most palatable species in favour of the less palatable species. Under such conditions, land is dominated by certain plant species (non-palatable species) and other species are disappeared (palatable species) greatly affecting biodiversity. Furthermore, as large number of animals walk over the land exert high pressure on the soil with their hooves causing soil compaction, and reduction of soil infiltration rate favouring higher surface water runoff.

Overgrazing is usually accompanied by fires which are deliberately ignited by farmers to eliminate unpalatable plant species. Under such conditions soils remain unprotected to raindrop splashing impacts resulting in accelerated soil erosion rates, causing severe problems of land degradation and desertification.

Overgrazing was identified as important process of land desertification in 140 field sites, corresponding to the following 3 study sites: Boteti Area-Botswana, Konya Karapinar plain-Turkey, and Djanybek-Russia. Of course in overgrazed areas the main process of land degradation and desertification is soil erosion due to surface water runoff.

Important indicators of overgrazing

The analysis of the data obtained in the study field sites of DESIRE project have shown that important indicators affecting land degradation in overgrazing areas are related to climate, soil, agriculture, land use, fires, water use, social, and institutional characteristics (Fig. 8). Field sites located in areas of low annual rainfall (lower than 650 mm per year) are characterized as moderately to severely eroded. Furthermore, field sites located in areas of high aridity index are subjected to moderate or low soil erosion since these areas receive low amounts of rain during the year to generate runoff and sediment loss even though they are overgrazed.

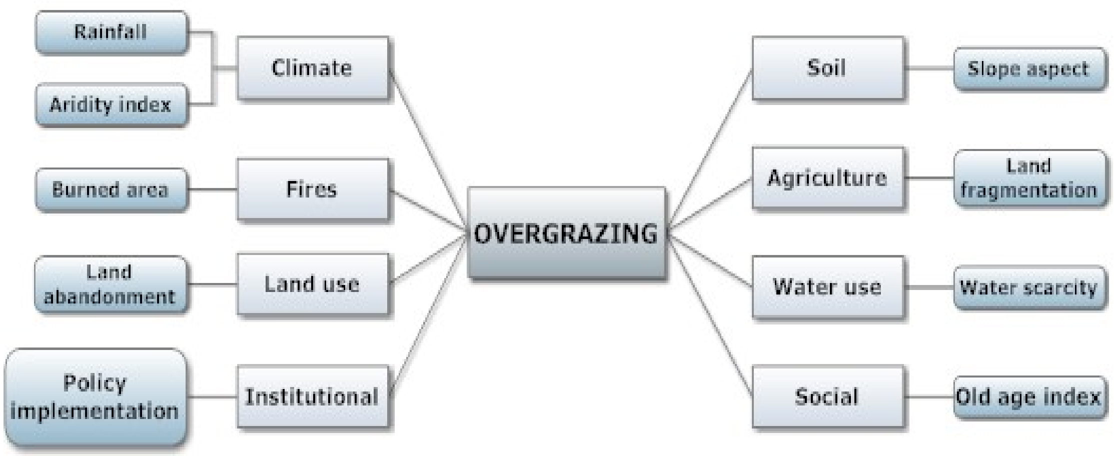

Fig. 8. Important indicators related to soil erosion in field sites subjected to overgrazing

Among the soil indicators only slope aspect is significantly related to soil erosion in overgrazed land in the study field sites. Field sites located in south-facing slopes are mainly subjected to moderate or severe erosion. In addition, such areas are characterized by adverse climatic conditions in arid or semi-arid climates. Higher air temperatures accompanied by high evapotranspiration rates in south-facing slopes reduce soil water availability and plant growth, aggravating overgrazing impacts.

The rate of burned area is the most important indicator related to fires affecting soil erosion. Rate of burned area is a regional indicator negatively affecting soil erosion. Field sites located in areas of high rates of burned area (greater than 26 ha per year per 10 km^2 territorial surface) are subjected to moderate or slight erosion. This trend can be attributed to the existing regulations for burned areas in which grazing animals are excluded for a certain period for rehabilitation of the land. In addition, field sites located in areas with high rates of land abandonment (greater than 26 ha per 10 years per10 km^2) are subjected to moderate or severe erosion. It seems under such conditions animals are removed from areas affected from fire to abandoned areas for grazing. Furthermore, recently abandoned agricultural areas are mainly covered by palatable annual plant species quickly overgrazed by a large animal population.

Among the indicators related to agriculture, land fragmentation is significantly related to degree of soil erosion. Field sites belonging to a highly fragmented farm (number of parcels greater than 10) are mainly subjected to moderate or severe soil erosion. Furthermore, field sites belonging to old-aged farmer are also characterized as moderate or severe eroded, since old people are usually not able to apply measures for controlling grazing and soil erosion.

Field sites located in areas of high water scarcity (higher than R=0.5, water available supply per capita/water consumption per capita during the last 10 years) are mainly characterized as subjected to moderate or severe erosion. Finally, field sites in which the existing regulations on environmental protection are applied, the degree of soil erosion is mainly characterized as moderate to slight.

Interrelated indicators

The analysis of variance has shown several pairs of interrelated indicators. Several interrelations have been assigned to indicators referring to climate and land management. The following interrelated pairs of indicators have been distinguished for the field sites subjected to overgrazing:

- Potential evapotranspiration – period of existing land use (-)
- Potential evapotranspiration – soil water conservation (+)
- Potential evapotranspiration – grazing intensity (+)
- Potential evapotranspiration - population growth rate (+)
- Aridity index - land fragmentation (-)
- Rain seasonality – parallel employment (-)
- Fire protection – fire frequency (-)

- Fire protection – fire risk (-)
- Fire risk – rate of burned area (+)
- Fire risk – fire frequency (+)
- Population growth rate – period of exiting land use (-)
- Population growth rate – soil water conservation measures (+)
- Grazing intensity – period of existing land use (-).

Period of existing land use, soil water conservation measures, grazing intensity, and population growth rate are related to annual potential evapotranspiration. Under high potential evapotranspiration rates the period of existing land uses are longer and water conservation measures are usually absent. Furthermore, grazing intensity and population growth rate are usually characterized as high under high potential evapotranspiration rates.

The climate indices of aridity index and rain seasonally are negatively related to land fragmentation and parallel employment of the farmer. Farms located in areas characterized by dry climatic conditions (high aridity index and long rain seasonality) are usually highly fragmented with the farmer mainly working on the farm.

Fire protection measures are negatively related to fire risk and fire frequency. Fire protection measures are usually characterized as low to moderate in areas with vegetation of high fire risk subjected to frequent fires. Furthermore, rate of burned area and fire frequency are negatively related to the indicator fire risk. F ield sites covered with vegetation characterized by high fire risk such as shrubs or pines fire are mainly subjected to high fire frequency and high rate of burned area.

Population growth rate is closely related to land management indicators period of existing land use and soil water conservation measures. Under high population growth rates (greater than 0.4%), period of existing land use is mainly long (longer than 10 years). In addition, under high population growth rate, soil water conservation measures are mainly absent.

Grazing intensity in overgrazed field sites is closely related to period of exiting land use. Grazing intensity is mainly characterized as high (stock rate over grazing capacity greater than 1.5) in field sites with long period of existence of the present land use.

5.6 Forest fires

As it has been recognized by the UNCCD, dry sub-humid to semi-arid regions are especially prone to large wildfires. In contrast, drier areas do not support adequate vegetation, restricting fires propagation. In the last fifty years there has been a great socio-economic transformation from rural to urban in many areas of the world. As a consequence there has been a reduction of grazing animals, firewood exploitation, and land abandonment resulting in a dramatic increase in the availability of vegetation fuel. Furthermore, forest fire frequency has increased in the last decades due to various economic interests of people such as changing land use, generating new vegetation for grazing animals. All these transformations have led to an increase of fire-prone ecosystems in the various landscapes and rate of burned areas where the study field sites are located.

Forest fires are identified as the main cause of land degradation and desertification in 85 field sites, corresponding mainly to Mação-Portugal, Cointzio catchment-Mexico, Gois-Portugal and in few cases in the Boteti Area-Botswana study sites. Soil erosion becomes a crucial issue for land degradation after the occurrence of a fire.

Important indicators of forest fires

Desertification risk due to soil erosion in the study field sites is affected by indicators related to climate, soil, vegetation, husbandry, land use, fires and social characteristics (Fig. 9). Field sites located in areas of relatively low annual rainfall (less than 650 mm) have been subjected to moderate or sever erosion. In the opposite, field sites located in areas of high rain seasonality are characterized with moderate to low degree of soil erosion.

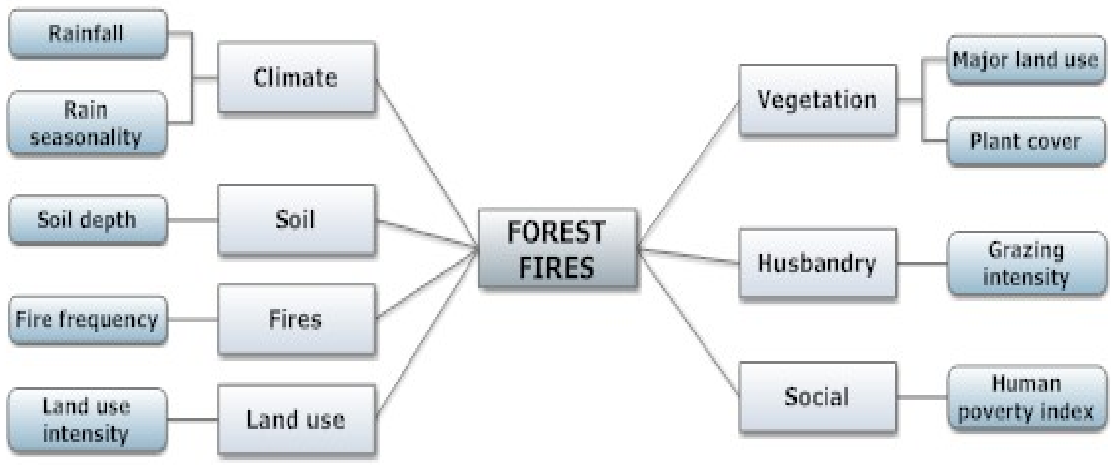

Fig. 9. Important indicators related to soil erosion in field sites subjected to forest fires

Type of vegetation has also affected degree of erosion. Field sites located in areas used as pastures and characterized as shrubland have been subjected to higher soil erosion. In the opposite, field sites covered with pine or deciduous forests or areas used for recreation are characterized by slight degree of soil erosion. Furthermore, as it is expected field sites with plant cover less than 50% are mainly subjected to moderate or severe erosion.

Among the most important soil indicators affecting soil erosion is soil depth. Field sites with soil depth less than 30 cm are characterized with severe or very severe erosion since such soils have limited soil water storage capacity generating higher surface water runoff. Furthermore, land use intensity is negatively related to degree of soil erosion. Forested areas under low land use intensity are usually covered with high amount of flammable biomass favouring forest fires and therefore higher soil erosion. This trend is further explained by the fire frequency indicator. Field sites located in areas with higher fire frequencies (once every 25 years or lees) are mainly characterized as subjected to moderate or severe soil erosion. In addition, field sites subjected to low grazing intensity (sustainable rate lower than grazing capacity) are mainly characterized by moderate to severe soil erosion.

Among the social indicators, human poverty index is more significantly related to degree of soil erosion. Field sites located in areas with high poverty index are subjected to moderate or slight soil erosion.

Interrelated indicators
The analysis of variance of the various indicators has shown the following important sets of interrelated indicators in the study field sites:

- Fire frequency – fire risk of the existing vegetation (+)
- Fire frequency – rate of burned area (+)
- Grazing intensity – rate of burned area (-).

Fire frequency is positively related to fire risk of the existing vegetation and rate of burned area. Areas in which the risk of fire of the existing vegetation is high (pine forests, Macchia, etc.) the fire frequency is mainly characterized as moderate to high (once every 25 years or less) accompanied by high rate of burned area (greater than 25 ha burned/10 years/10 km^2 of territorial).

Grazing intensity is related to the rate of burned area. When an area is subjected to high grazing intensity, an adequate amount of flammable biomass is removed by the animals, usually reducing the rate of burned areas in values less than 10 ha burned/10 years/10 km^2 of territorial.

5.7 Effective land management indicators

Effective land desertification protection requires both appropriate land management practices and macro policy approaches that promote sustainability of ecosystem services. It is preferable actions for combating land desertification to focus on protection or prevention than on rehabilitation of desertified areas since such areas are usually at high stage of land degradation and the expected profitability of applying measures is low. Of course it is recommended in desertified areas to apply measures for protection against active processes or causes of land degradation. The priority is to apply the appropriate land management practices to protect the productivity of sensitive areas to desertification than to allow active degradation processes to convert in critical areas of low economical importance for the local population.

As was mentioned in the previous discussion, a number of indicators have been defined as importantly affecting the various land degradation processes or causes. Many of the defined indicators can not easily altered at farm level such as soil depth, slope gradient, rainfall seasonality, etc. However, indicators related to land management such as no tillage, storage of water runoff, grazing control can change by the farmer. In the following paragraphs have been summarized the most effective land management indicators highly related to measures against desertification. These indicators are classified according to land degradation process or cause.

Water erosion
The most effective land management indicators for reducing land desertification risk related to soil erosion due to surface water runoff in agricultural areas are runoff water storage, sustainable farming, and land terracing (Fig .10). These land management practices become

more effective under low land use intensity and implementation of existing regulations for environmental protection.

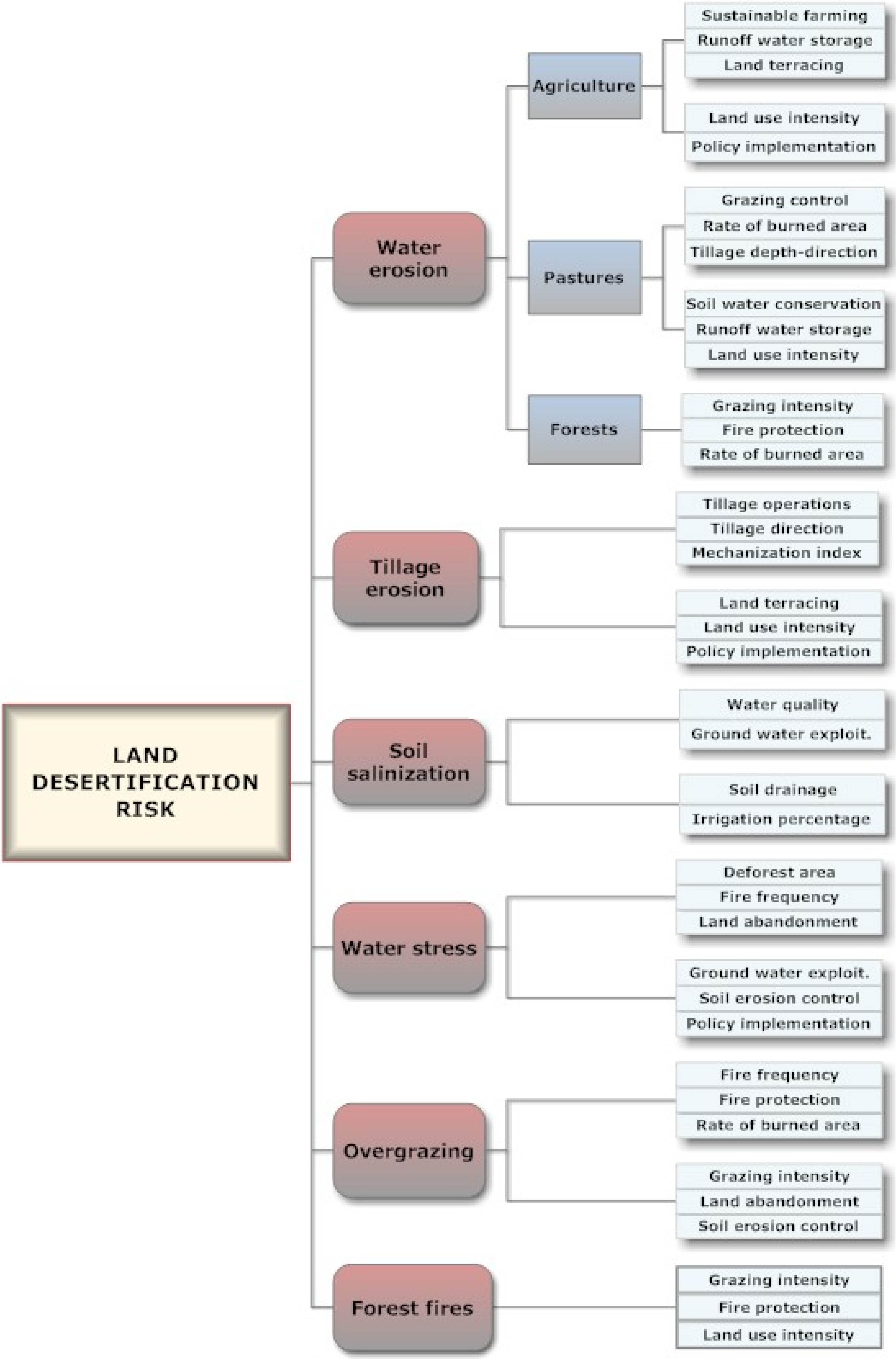

Fig. 10. Important land management indicators affecting desertification risk in various land uses, processes, and causes of land degradation

In pastures, the most important land management indicators affecting desertification risk due to soil erosion are grazing control, soil water conservation, runoff water storage. Tillage operations become especially important indicators in pastures cultivated for forage production. Of course reduction of the rate of burned area, and land use intensity are crucial indicators for reducing desertification risk in such areas.

Desertification risk in forested areas in which the main process of land degradation is soil erosion can be substantially reduced if fire protection measures are applied, and the land is subjected to low grazing intensity. Of course desertification risk is greatly reduced if the rate of burned area is minimized.

Tillage erosion

Desertification risk, in agricultural areas in which the main process of land degradation is tillage erosion, is greatly affected by tillage operations, tillage direction and mechanization index (Fig. 10). Sloping areas under high mechanization index in which soils are tilled by a moldboard perpendicular to the contour lines in the downslope direction are subjected to high desertification risk. Desertification risk is significantly reduced in sloping terraced areas, subjected to low land use intensity, and existing regulations on environmental protection are adequately implemented.

Soil salinization

Desertification risk due to soil salinization can be affected by the following indicators related to land management: water quality, rate of ground water exploitation, soil drainage, and irrigation percentage of arable land (Fig. 10). Areas with good quality of ground water in which exploitation is not higher to recharge rate are subjected to low desertification risk. Furthermore, the expansion of irrigated land using poor quality of water increases the risk of desertification especially in soils characterized with poor drainage conditions. The construction of drainage ditches in poorly drained soils for lowering ground water level or removing excess of irrigation water in areas with arid, semi-arid climatic or dry sub-humid climatic conditions is expected to reduce desertification risk.

Water stress

The most important land management indicators affecting desertification risk in areas in which water stress is the most important process of land degradation are: rate of deforested area, rate of land abandonment, fire frequency, rate of ground water exploitation, soil erosion control, and policy implementation (Fig. 10). The highest impact on desertification risk can be attributed to the rate of land abandonment and policy implementation. Under high rates of land abandonment, land desertification risk due to water stress is reduced. Of course the implementation of existing policy on e nvironmental protection and especially those regulations related to water resources management alleviates desertification risk.

Overgrazing

Overgrazing affects desertification risk by increasing the risk of soil erosion in sloping areas. The most important indicators related to land management affecting desertification risk in overgrazed areas are (Fig. 10): fire frequency, fire protection, rate of burned area, grazing intensity, rate of land abandonment, and soil erosion control. Fire protection and rate of land abandonment have the greatest contribution (higher linear coefficient) on c ombating desertification in overgrazed areas.

Forest fires

As it is expected fire protection and grazing intensity are two important management indicators affecting desertification risk in forested areas. Adequate measures on forest fire protection in forested areas subjected to low or moderate rate of grazing highly reduce significantly desertification risk. Another important indicator related to land management in forested areas is land use intensity. If the rate of extraction of wood is sustainable, then the land is adequate protected form desertification.

6. Application of indicator software

6.1 Description of software

The indicator software for assessing desertification risk is an expert system designed to provide an estimation of land desertification risk through the selection of appropriate degradation processes and corresponding indicators. The derived system can be used in a wide range of local physical and socio-economic conditions for assessing the effectiveness of the various land management practices in land uses and landscapes prone to desertification. Specifically, the developed tool can be used for:

- The analysis of a wide range of alternatives for land management practices for reducing land desertification risk.
- The evaluation and selection of the most important indicators through which desertification risk may be assessed in a variety of locales worldwide.
- The development of a consensus among various groups (politicians, managers, experts, etc.) in assessing desertification risks.

The expert system can be easily used in a variety of biophysical and socio-economic conditions for assessing the effectiveness of the various land management practices for combating land degradation and desertification. The architecture and the description of the knowledge based system are presented in the following discussion. The system is loaded in the website: http://www.desire-project.eu.

The main screen (Fig. 1) gives the opportunity to the user to select the following items: (a) introduction, (b) the work carried out in DESIRE project, (c) applicability of developed methodology, (d) description of important indicators affecting land desertification risk, (e) Processes and causes of land degradation and desertification, (f) application of indicator software.

Fig. 1. Main screen of the expert system for assessing desertification risk

By selecting the appropriate item, another page appears giving the opportunity to the user to go through details for each item mentioned above (Fig. 2). For example in the window of processes and causes, the user can select a specific process using the cursor and another page appears with the description of the corresponding process. Then by the command “back” the previous page appears.

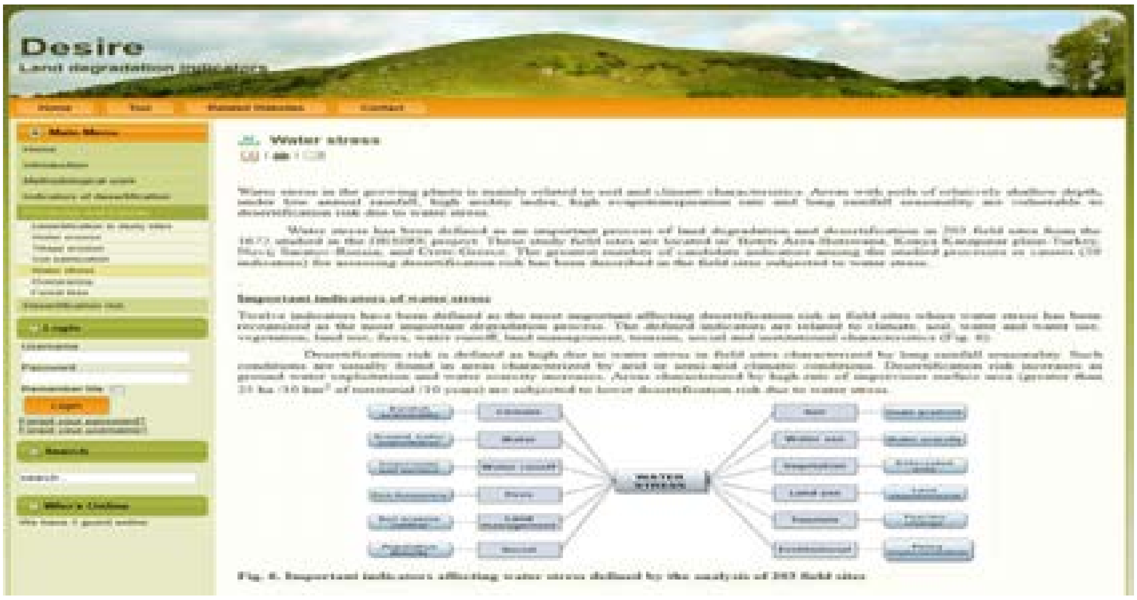

Fig. 2. A sequential screen showing the processes that a user can select to have the description

<u>Assessing desertification risk</u>

By choosing the item “assessing desertification risk” another screen appears with the various processes or causes of land degradation. After selecting the appropriate box with the desired process, the window “data” is selected and the screen with the list of important indicators appears (Fig. 2). The number of indicators appeared depends on the selected process or cause and may vary from 8 to over 17.

Fig. 3. Screen showing the list of indicators for the selected process or cause of degradation

The value for each indicator is selected by bring the cursor to the corresponding box in which a specific class can be selected. The same is reapeted for the whole list of indicators. In the list of classes of each indicator three colors appears, the red corresponding to the worst case, the green corresponding to the bast class, and a blue showing the selected class (Fig. 4).

Fig. 4. Screen showing the indicators after selecting the corresponding class with different colors red, green, and blue corresponding to the worst, the best and the selected class, respectively.

After selecting the classes for all indicators, the window 'claculate' is toughed and the desertification risk index (DRI), as well as the class of desertification risk with comments appears (Fig. 5). The sytem gives the possibility of the user to go back in the screen of used indicators and to change some values of indicators such as those related to land management or to land protection and to define a new DRI with the corresponding class. Therefore, the expert system gives the opportunity to the user to asses the effectivenes of various indicators for combating desertification.

Fig. 5. Screen showing the calculated desertification risk index and the corresponding class

6.2 Identifying best land managenet practice

The derived methodology is an important decision support tool to be used by various stakeholders for assessing land degradation and desertification risk under the existing physical environmental, economical and social conditions. It is a tool for selecting the appropriate land management practices and techniques for combating desertification. Two examples of application of the present methodology for assessing land management practices follows.

Example 1

A sloping land is given used for grazing under different grazing intensity. The land separated by a fence in Fig. 6 belongs to two farmers. The left part of the land is overgrazed, while the right part is sustainable grazed. Climate, topography, soil, and vegetation type characteristics are the same in both sites. By introducing all the appropriate indicators in the derived methodology for pastures the estimated defined desertification risk index (DRI) for the left part is 5.4 characterized as very high, while the DRI for the right part of the land is 4.4 characterized as high.

Fig. 6. Grazing land belonging to two farmers and subjected to different grazing intensity and land desertification risk

Example 2

An agricultural land cultivated with olives is given in Fig. 7 (field 1). The main process of land degradation is soil erosion caused by surface water runoff. Therefore, in the expert system the following items are selected "water erosion – agricultural areas". The system ask data for the indicators included in this process. Specifically, the data for the selected field are given in Table 1 (field 1). After introducing the corresponding classes of indicators, the system calculates a desertification risk index – DRI = 3.51 and the class of desertification risk is characterized as high. Then, the user has the opportunity to go through the list of indicators and to decide which indicators or land management practices can change. The hierarchy is to look over the indicators with red colors boxes. For example in the present case, indicators in red color are the following: sustainable farming, land terracing, land use intensity, runoff water storage, and subsidies. One first selection is the indicator "sustainable farming" since the land is tilled, a land management practice which can be change for olive groves. The possible changes of actions in this indicator are: (i) minimum tillage or non-tillage, (ii) enhancing vegetation cover, (iii) tillage of soil in the up-slope direction, (iv) minimum depth of ploughing. It is recommended for olive groves a minimum tillage (land is tilled once every 4-5 years). By selecting this land management practice, the following indicators land use intensity, runoff water storage, policy implementation have positively changed. By re-running the system and changing the corresponding indicators, the desertification risk is reduced to 2.72 which is characterized as moderate. An example with such a land management practice is given in Fig. 7 and Table 1 (field 2).

Table 1. List of indicators used to assess deseetrification risk under different land managenet practices

a/a	Indicators	Indicator characteristics

		Field 2	**Field 1**
1	Annual rainfall	570 mm	570 mm
2	Rain seasonality	Marked seasonal with a long dry season (1.8)	Marked seasonal with a long dry season
3	Soil depth	68 cm	75 cm
4	Slope aspect	North east	North east
5	Slope gradient	12.5%	12.5%
6	Organic matter content	1.8%	2.4%
7	Vehgetation cover type	Agriculture (olives)	Agriculture (olives)
8	Plant cover	75%	95%
9	Runof water storage	No actions	No actions
10	Sustanable farming	No	**Minimum tillage**
11	Presence of terracing	No	No
12	Rate of land abandonment	Low, less than 10 ha/10 years/10 km^2	Low, less than 10 ha/10 years/10 km^2
13	Tillage operantions	Disking twice per year	**No**
14	Land use intensity	High	**Low**
15	Parallel employment	No	No
16	Farm subsidies	Yes	Yes
17	Policy implementation	Low	**Adequate**
	Desertification risk	High, DRI = 3.51	Moderate DRI = 2.72

Fig. 7. Bordering field sites of olive groves under tillage (filed 1, right) and minimum tillage (filed 2, left) subjected to different desrtification risk.

The effectiveness of the various land management practices for combating desertification applied in a certain piece of land depends on its physical environment and social characteristics. For example in an agricultural area with shallow soils, the effectiveness of the land management of planting trees and applying minimum or no tillage will be less effective if the same practice is applied in another area with deep soils. Furthermore, the success of an applied management practice depends on the availability of human resources, the capital for operation and maintenance, the infrastructure development, the degree of dependence on external sources of technology, the cultural perceptions, etc.

6.3 Assessement of the derived methodology

The derived methodology was assessed using independent indicators measured in field sites located in other areas. The assessment was based in the comparison of the desertification risk index with the indicators: (a) measured soil erosion rate, and (b) soil organic matter content of the surface horizon. Soil erosion data were collected by the Agricultural University of Athens during the execution of the European Commission research projects: (a) Mediterranean Desertification and Land Use - MEDALUS I (Kosmas *et al*., 1993), (b) MEDALUS II (Kosmas *et al*., 1995; (Moustakas *et al*., 1995; Danalatos *et al*., 1995, Tsara *et al*., 2001), and (c) Tillage Erosion: Current State, Future Trends and Prevention – TERON (Kosmas *et al*., 2001; Gerontidis *et al.,* 2001). Soil erosion data were used from nine experimental field sites under various soil, topographic, land use and climatic conditions. The measured soil sediment losses in the various rainfall events were expressed on annual average basis for comparison with land desertification risk index defined by the derived methodology in this study.

Concerning soil organic matter content, a number of 39 soil sites were selected in the study area of Crete. The selected sites were located in soils formed in various parent materials, under various climatic, topographic and land use characteristics. In each site, all the necessary indicators for defining desertification risk were measured. The selected soil samples were analyzed for particle-size distribution of the <2-mm fraction by the Bouyoucos hydrometer method (Gee and Bauder, 1986). The organic carbon content was measured using the modified Walkey-Black wet oxidation procedure (Nelson and Sommers, 1982).

As Fig. 8 shows, annual soil erosion rates are related with desertification risk index estimated by the corresponding algorithms developed in this study. Desertification risk index increases rapidly in low rates of soil erosion (up to 5 t ha^{-1} yr^{-1}) and then desertification risk index is increasing slowly while erosion rates are very high. This relation of desertification risk index and annual soil erosion rate can be attributed to the resilience of a system to withstand degradation. For example a relatively deep soil under certain climatic, vegetative and topographic conditions characterized with moderate desertification risk will remain in this class until soil depth reaches to a threshold value (less than 30 cm) where desertification risk is high with low potential of ecosystem to provide services.

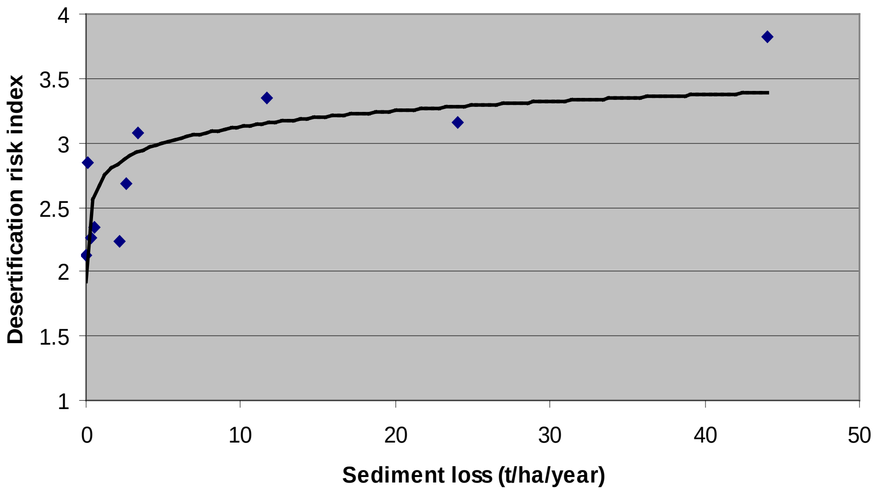

Fig. 8. Relation of desertification risk index estimated by the derived methodology and annual soil sediment loss measured for the same sites

Soil organic matter represents a key indicator for soil quality, both for agricultural and environmental functions. Soil organic matter is a major indicator influencing physical, chemical, and biological soil parameters. Aggregation and stability of soil structure increase with organic matter content. This in turn increases infiltration rate and available water capacity of the soil, as well as resistance against erosion by water and wind. Decrease of organic matter content is a key factor in accelerating soil erosion and thus for irreversible land degradation and desertification. As Fig. 9 shows, desertification risk index decreases as soil organic matter content in the surface horizon increases. Therefore, the development methodology on assessing desertification risk shows a satisfactory relationship with independent physical indicators such as soil erosion, and soil organic matter content.

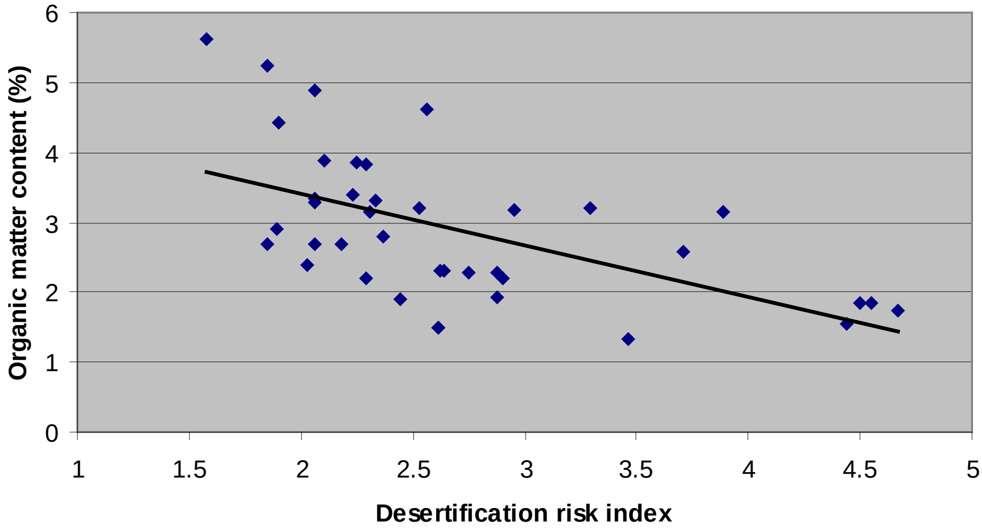

Fig. 9. Relation of desertification risk index estimated by the derived methodology and organic matter content of the surface horizon measured for the same sites

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