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An exploratory analysis of land abandonment drivers in areas prone to desertification

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ABSTRACT

The abandonment of land is a global problem with environmental and socioeconomic implications. An approach to assess the relationship between land abandonment and a large set of indicators was illustrated in the present study by using data collected in the framework of the European Union DESIRE research project from 808 field sites located in 10 study sites in the Mediterranean region, Eastern Europe, Latin America, Africa and Asia. A total of 48 indicators provided information for biophysical conditions and socioeconomic characteristics measured at the plot level. The selected indicators refer to farm characteristics (family status, land tenure, present and previous types of land-use, soil depth, slope gradient, tillage operations) and to site-specific characteristics including annual rainfall, rainfall seasonality and water availability. Classes were designated for each indicator and a sensitivity score was assigned to each class based on existing research or empirically assessing the importance of each indicator to the land abandonment issue. Questionnaires for each process of land degradation were prepared and data were collected at field site level in collaboration with land users. Based on correlation statistics and multivariate analyses more than ten indicators out of 48 resulted as significant in affecting land abandonment in the studied field sites. Among them, the most important were rainfall seasonality, elderly index, land fragmentation, farm size, selected soil properties, and the level of policy implementation. Results contribute to the development of appropriate tools for assessing the effectiveness of land management practices for contrasting land abandonment.

1. Introduction

Taken as a process active in both developed and emerging countries, land abandonment is a socioeconomic issue with environmental implications at both global, regional and local scales (Strijker, 2005). Land abandonment can be defined in various ways according to the territorial

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context and emphasis on environmental or agricultural issues. Rudel (2009) qualifies land abandonment as a change of land use to a lower economic state, which is per se not a worse situation as land can retain (at least partially) its functioning. Abandonment does not necessarily mean that land is no longer used, either by agriculture or any other rural economic activity. It means a change in land use from the traditional or recent pattern to another, less intensive pattern. As an example, the transition to a lower economic state from an intensive cropping to a less intensive land use could be more sustainable in the present socioeconomic context. By concentrating on agricultural systems, land abandonment means the (partial or complete) abandonment of agricultural activities and may reflect a transition into rural systems with possibly lower productivity (e.g. Koulouri and Giourga, 2007). Land abandonment occurs when the agricultural system is affected by external drivers or because of its own dynamics toward extensification or intensification.

Although studies were carried out to define causes and consequences of land abandonment at the local scale (Corbelle-Rico et al., 2012; Helming et al., 2011; Strijker, 2005), a comprehensive approach aimed at identifying regional-scale drivers using indicators deserves further investigation. The necessity of elaborating indicators is a research priority claimed by United Nations Convention to Combat Desertification (UNCCD) (COP, 2009). Many attempts have been made to assess land degradation processes, efficiency of land management practices and implementation of existing policies using indicators (EEA, 2005; Kosmas et al., 1999; Recatala et al., 2002; Rubio and Bochet, 1998; Salvati et al., 2008). Indicators generally simplify reality to make complex processes quantifiable so that the information obtained can be disseminated (EEA, 2005). The identification of reliable indicators will ensure the most effective use of restricted data provided by monitoring systems. The most useful indicators, however, are those which allow the identification of land abandonment drivers while there is still time and scope for remedial action (Sluiter and de Jong, 2007; Van Doorn and Bakker, 2007).

Various authors have simultaneously used the terms ‘abandoned land’ and ‘grazing land’, but grazing or hunting of an abandoned land may be considered as a traditional use (Baudry, 1991; Kosmas et al., 2000; López-Bermúdez et al., 1996; Martinez-Fernandez et al., 1995).

In the Mediterranean basin, abandoned agricultural land is generally found in unfavorable environmental conditions such as higher elevations, steep slopes, shallow soils, dry climatic conditions as well as marginal agricultural areas (MacDonald et al., 2000). Sloping croplands in semi-arid or dry sub-humid areas under intensive cultivation for a long period have been subjected to degradation due to soil erosion and shallow unproductive soils have been formed (Bakker et al., 2005; Kosmas et al., 2000). The analysis of land-use evolution in a Mediterranean area for the last 4000 years showed a drastic increase in agricultural land by replacing forested land (Marathianou et al., 2000). Many of the areas that once supported forests were cleared in order to sustain agriculture because of inadequate measures for environmental protection.

From the socioeconomic perspective, parallel employment of farmers or older landowners has a greater probability of abandoning agricultural land (Baudry, 1991; Van Doorn and Bakker, 2007). Land abandonment is also associated to depopulation due to out-migration of rural people (Christof et al., 2011). Although the European Union (EU) Common Agricultural Policy (CAP) supports economically less favorable areas for the local population in order to avoid abandonment of the land, the availability of better-paid jobs in neighboring urbanized areas stimulates agricultural abandonment (Gellrich et al., 2007; Kosmas et al., 2000).

Based on these premises, the aim of the present study is to propose an exploratory framework for the assessment of land abandonment drivers in a sample of vulnerable and non-vulnerable areas to desertification with different ecological and socioeconomic characteristics using a large set of indicators.

2. Methods

2.1. Description of the investigated field sites

A total of 10 study sites were selected in various places of the Mediterranean and Eastern Europe, Latin America, Africa and Asia for a total of 808 observation field sites (with an average of 80 sites per study area). The study sites were located in the following major land uses: 478 in cropland, 245 in pastures, and 85 in forested areas. This study is a part of the extensive fieldwork carried out in the framework of the DESIRE research project. More specifically, data were collected from the following study sites: (i) Crete island—Greece, (ii) Guadalentin basin—SE-Spain, (iii) Eskisehir plain—Turkey, (iv) Novij Saratov—Russia, (v) Zeuss Koutine—Tunisia, (vi) Boteti area—Botswana, (vii) Santiago island—Cape Verde, (viii) Mamora Sehoul—Morocco, (ix) Secano Interior—Chile, and (x) Cointzio catchment—Mexico. (See Fig. 1.)

Data were collected from a variety of environmental, social and economic conditions. 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, overgrazing and forest fires. The climatic conditions of the study sites are characterized as arid, semi-arid or dry sub-humid with rainfall ranging from 280 to 650 mm heterogeneously distributed along the year in the large majority of the cases.

The available soils are formed mainly on sedimentary and unconsolidated parent materials, free of rock fragments to moderately stony in 84% of the sites. Soil organic matter content in the soil surface has been identified as low to very low in 77% of the sites. Soils were moderately to severely eroded in 72% of the sites. Vegetation cover types include cereals (33%), olives (18%), vines (19%) and cotton (10%) generating a poor vegetation cover in the majority of the cases. The agricultural structure has been characterized as owner-farmed in 64% of the study field sites with variable farm size ranging from 2 to more than 100 ha.

Table 1
List of candidate indicators related to variables possibly affecting land abandonment in the investigated study sites.

Biophysical indicators	Socioeconomic indicators
Climate	Agriculture
Annual rainfall	Farm ownership
Annual potential evapotranspiration	Farm size
Rainfall seasonality	Land fragmentation
Rainfall erosivity	Net farm income
Soil	Parallel employment
Parent material	Cultivation practices and husbandry
Rock fragments on soil surface	Tillage operations
Slope aspect	Tillage depth
Slope gradient	Tillage direction
Soil depth	Frequency of tillage
Soil texture	Grazing control
Soil water storage capacity	Grazing intensity
Exposure of rock outcrops	Land management
Organic matter surface horizon	Fire protection
Degree of soil erosion	Sustainable farming
Vegetation	Reclamation of mining areas
Prevalent land cover	Soil erosion control measures
Vegetation cover type	Soil water conservation measures
Plant cover	Terracing (presence of)
Water runoff and fires	Land-use
Drainage density	Land use intensity
Impervious surface area	Period of existing land use
Burned area	Water use
Desertification risk	Irrigation percentage of arable land
	Runoff water storage
	Demography and tourism
	Elderly index
	Population density
	Population growth rate
	Tourism intensity
	Institutional
	Farm subsidies
	Policy implementation

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Table 2
List of indicators with distinct classes for each indicator and the related score.

Climate

Annual rainfall (mm)	<280	280–650	650 –1000	>1000
	2	1.6	1.3	1.0

Aridity index	<50	50–75	75–100	100–125	125–150	>150
	1.0	1.2	1.4	1.6	1.8	2.0

Annual potential evapotranspiration (mm)	<500	500–800	800–1200	1200–1500	>1500
	1.0	1.2	1.5	1.8	2.0

Rainfall seasonality	<0.19	0.20–0.39	0.40–0.59	0.60–0.79	0.80–0.99	1.00–1.19	>1.20
	1.0	1.2	1.4	1.6	1.8	1.9	2.0

Rainfall erosivity (mm/h)	<60	60 –90	91–120	121–160	>160
	1.0	1.2	1.5	1.8	2.0

Soil

Parent material	Limestone –marble	Acid igneous	Sandstone, flysh	Marl, clay, conglomerates	Basic igneous	Shale schist	Alluvium, colluvium
	2.0	1.8	1.6	1.3	1.4	1.2	1.0

Rock fragments on soil surface (%)	<15	15–40	40–80	>80
	2.0	1.0	1.6	1.8

Slope aspect	N, NW, NE	S, SW, SE	Plain
	1.0	2.0	1.0

Slope gradient (%)	<2	2 –6	6–12	12–18	18–25	25–35	35–60	>60
	1.0	1.2	1.4	1.6	1.7	1.8	1.9	2.0

Soil depth (cm)	<15	15–30	30–60	60–100	100–1500	>150
	2.0	1.8	1.6	1.4	1.2	1.0

Soil textural class	Very coarse	Coarse	Medium	Moderate fine	Fine	Very fine
	2.0	1.8	1.6	1.2	1.3	1.4

Soil water storage capacity (mm)	<50	50–100	100–200	200–300	>300
	2.0	1.8	1.5	1.3	1.0

Exposure of rock outcrops (%)	None	2–10	10 –30	30–60	>60
	1.0	1.3	1.5	1.8	2.0

Organic matter of surface horizon(%)	High >6.0	Medium 2.1–6.0	Low 2.0–1.1	Very low <1.0
	1.0	1.3	1.6	2.0

Degree of soil erosion	None	Slight	Moderate	Severe	Very severe
	1.0	1.2	1.5	1.8	2.0

Vegetation

Prevalent land use	Agriculture	Pasture	Shrubland	Forest	Mining	Recreation
	1.5	1.6	1.4	1.0	2.0	1.2

Plant cover (%)	<10	10-25	25-50	50-75	>75
	2.0	1.8	1.5	1.3	1.0

(continued on next page)

Table 2 (*continued*)

Water runoff

Drainage density (km of channels per km²)	Coarse <5km	Medium 5–10km	Fine 10–20km	Very fine >20km
	1.0	1.3	1.7	2.0

Impervious surface area (ha/ 10km² of territory/10 years)	Low <10ha	Moderate 10–25ha	High 26–50ha	Very high >50ha
	1.0	1.3	1.7	2.0

Burned area (ha burned/10 years/10km² of territory)	Low (<10ha)	Moderate (10–25ha)	High (26–50ha)	Very high (>50ha)
	1.0	1.3	1.7	2.0

Desertification risk	Very high	High	Moderate	Low	No risk
	2.0	1.8	1.5	1.3	1.0

Agriculture

Farm ownership	Owner-farmed	Tenant-farmed	Shared-farmed	State-farmed
	1.0	2.0	1.5	1.7

Farm size (ha)	<2	2 –5	5 –10	10 –30	30 –50	50 –100	>100
	2.0	1.8	1.6	1.5	1.3	1..1	1.0

Land fragmentation (no of parcels)	1–3	4–6	7–9	10–12	13–15	16–19	>19
	1.0	1.2	1.4	1.6	1.8	1.9	2.0

Net farm income	Low (<local mean–st. dev.)	Moderate (>local mean– st. dev.<local mean)	High (>local mean< local mean+st. dev.)	Very high (>local mean + st. dev.)
	2.0	1.7	1.3	1.0

Parallel employment	NO	Industry	Tourism	State	Municipality
	1.0	2.0	1.4	1.7	1.5

Cultivation practices and husbandry

Tillage operations	No	Plowing	Disking, harrowing	Cultivator
	1.0	2.0	1.7	1.4

Frequency of tillage (number)	No	1	2	3	4
	1.0	1.2	1.4	1.7	2.0

Tillage depth (cm)	No	<20	20–30	30–40	>40
	1.0	1.1	1.3	1.7	2.0

Tillage direction	Down–slope	Up–slope	Parallel to contour up–slope furrow	Parallel to contour down–slope furrow	Down–slope oblique	Up–slope oblique	Other (no tillage)
	2.0	1.4	1.2	1.5	1.8	1.3	1.0

Grazing control	No	Sustainable number of animal	Fencing	Avoidance of soil compaction (very wet soil)	Fire protection
	2.0	1.0	1.2	1.4	1.3

Grazing intensity	Low (SR<GC)	Moderate SR=GC to 1.5GC)	High (SR>1.5GC)
	1.0	1.5	2.0

Land management

Fire protection (Protected/total area %)	No	Low <25%	Moderate 25–50%	High 50–75%	Very high >75%
	2.0	1.8	1.6	1.3	1.0

Sustainable farming	No sustainable farming	No tillage	Minimum tillage	Inducing plant cover	Up-slope tillage	Minimum ploughing depth
	2.0	1.0	1.3	1.1	1.4	1.5

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Table 2 (*continued*)

Reclamation of mining areas (area protected/ total area, %)	No	Low <25% protected	Moderate 25–75% protected	Adequate >75% protected
	2.0	1.7	1.3	1.0

Soil erosion control measures (area protected/total area, %)	No	Low <25% protected	Moderate 25–75% protected	Adequate >75% protected
	2.0	1.7	1.4	1.0

Soil water conservation measures	Weed control	Mulching	Temporary storage of water runoff	Inducing vapour adsorption	No
	1.0	1.0	1.0	1.2	2.0

Terracing (presence of) (area protected/total area (%)	No	Low <25%	Moderate 25–50%	High 50–75%	Very high >75%
	2.0	1.7	1.5	1.2	1.0

Land use

Land use intensity	Low	Medium	High
	1.0	1.5	2.0

(Period) of existing land use	<1 year	1–5 years	5–10 years	10–20 years	30–50 years	>50 years
	2.0	1.8	1.6	1.4	1.2	1.0

Water use

Irrigation percentage of arable land	<5	5–10	10–25	25–50	>50
	2.0	1.8	1.6	1.3	1.0

Runoff water storage	No	Low	Moderate	Adequate
	2.0	1.8	1.4	1.0

Demography and tourism

Elderly index (population >65/total population =R, %)	Low R<5	Moderate R=5–10	High R=10–20	Very high R>20
	1.0	1.3	1.7	2.0

Population density (inhabitants/km2)	Low <50	Moderate 50–100	High 100–300	Very high >300
	1.0	1.3	1.7	2.0

Population growth rate (% per year)	Low <0.2	Moderate 0.2–0.4	High 0.4–0.6	Very high >0.6
	1.0	1.3	1.7	2.0

Tourism intensity (number of overnight stays/10 km^2 =R)	Low R<0.01	Moderate R=0.01–0.04	High R=0.04–0.08	Very high R>0.08
	1.0	1.3	1.7	2.0

Institutional

Subsidies	No	Subs/environ. protection	Subs/area	Subs/animal	Sub/kg
	1.2	1.0	2.0	2.0	2.0

Policy implementation	Adequate >75% of the area	Moderate (25–75% of the area)	Low (<25% of the area)	No
	1.0	1.4	1.7	2.0

Land has been subjected to high fragmentation with more than 7 parcels in 58% of the cases. Farmer's income has been assessed as moderate in 71% of the study field sites, while farmers are mainly working in the agriculture sector in 60% of the cases.

Land abandonment has been defined as low (less than 10 ha/10 years/10 km^2) in 53% of the study fields sites, while moderate to high rate of land abandonment (10–50 ha/10 years/10 km^2) has been identified in 45% of the cases. Elderly index has been characterized as high in 64% of the field sites. Population density was basically low in 66% of the cases (less than 50 inhabitants/km^2) and population growth rate has been characterized as low (0.2–0.4% per year) in 73% of the sites.

2.2. Environmental indicators

An integrated approach incorporating indicators from various sources and used for assessing the degree of land abandonment and the drivers involved in this process in areas classified at different proneness to desertification has been developed within the framework of DESIRE project (Kosmas et al., 2013). The indicator system developed in the DESIRE project represents a proposal for standard collection and analysis of key environmental and socioeconomic variables at the local scale with practical impact for policy implementation.

The provided list of indicator (Table 1) has been formulated by: (i) reviewing existing literature (Enne and Zucca, 2000; Kosmas et al., 1999; Liniger et al., 2007; OECD, 2004; Wascher, 2000), (ii) consulting with stakeholders including land users, land managers and research groups working on land degradation and desertification issues both internationally and in each case-study area, and (iii) using previous research carried out in research projects on land degradation and desertification (e.g. MEDALUS III, MEDRAP, DESERTLINKS). Questionnaires on candidate indicators related to biophysical environment and socioeconomic characteristics have been prepared and were administered to various stakeholders including farmers, local administrators, planners and scientists. The developed list of candidate indicators is the result of combining scientific indicators with indicators that stakeholders evaluate as relevant.

The progressive abandonment of agricultural land, expressed as the hectares of cultivated land lost in the last ten years across a surface area of 10 km^2 centered in the studied farm, was specifically assessed in each field site based on expert opinion. The main drivers of land abandonment identified in each study sites were classified in eleven variable's classes (four representing biophysical factors, the remaining seven describing socioeconomic processes) including: (a) climate, (b) soil, (c) vegetation, (d) water runoff and fires, (e) agriculture, (f) cultivation practices and husbandry, (g) land management, (h) land use, (i) water use, (l) demography and tourism and finally, (m) institutional factors.

The analysis included (1) 'state' indicators allowing monitoring of the environmental and socioeconomic context; these need to be tailored for maximum sensitivity to each particular technique, (2) 'pressure' indicators focusing on conditions where remedial intervention may be needed to prevent land degradation and desertification, and (3) 'response' indicators relaying actions undertaken for land protection and the effectiveness of mitigation measures. The analysis included indicators related to local (farm) level, such as land-use type, farm size, tillage operations, or regional conditions such as subsidies allocated, or rainfall seasonality.

Using expert opinion, each indicator was described by defining distinct classes (Table 2) using existing classification systems such as the European geo-referenced soil database (Finke et al., 1998; Kosmas et al., 1999; Liniger et al., 2007; Van Engelen et al., 2005), and existing research data (Brandt and Geeson, 2005; Kosmas et al., 1999, 2000). Scores in the range from 1 to 2 were assigned to the various classes of the indicators based on existing research data or on the importance to land degradation and desertification. The methodologies for constructing the indicator system and deriving the coefficients assigned to each indicator are fully described in Kosmas et al. (2013). Definition of class boundaries introduces a level of subjectivity, which is considered justifiable for application to a wide range of environments and socioeconomic conditions. Besides, it scales the values of the different indicators to comparable ranges (between 1 and 2). Additionally, it allows comparison between different regions and a similar weighting system was successfully used in the definition of environmentally sensitive areas to desertification (ESA) that has been widely applied in the Mediterranean region, middle East, and northern Africa (Benabderrahmane and Chenchouni, 2010; Parvari et al., 2011; Salvati et al., 2008).

In order to compare land abandonment with desertification risk, the latter variable has been assessed using an empirical approach. The Environmentally Sensitive Area (ESA) index, based on the joint evaluation of climate, soil and vegetation quality (see Kosmas et al., 1999) has been combined with the processes or indicators triggering land degradation such as degree of soil erosion, water storage capacity and soil electrical conductivity (Kosmas et al., 2013). 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 degradation was soil salinization. Soil water storage capacity was considered for hilly or plain areas where water stress was defined as the major process of land degradation. Five categories of desertification risk were

Table 3
Pair-wise Spearman rank correlation analysis between land abandonment and selected biophysical and socioeconomic drivers (bold indicates significant correlation at $p < 0.001$ after Bonferroni's correction for multiple comparisons).

Variable	Spearman ρ	Variable	Spearman ρ
Land fragmentation	**0.55**	Population growth	−0.01
Runoff water storage	**0.47**	Parent material	−0.02
Elderly index	**0.45**	Aridity index	−0.02
Parallel employment	**0.44**	Frequency of tillage	−0.06
Sustainable farming	**0.44**	Rock fragments	−0.07
Drainage density	**0.43**	Organic matter surface horizon	−0.10
Farm subsidies	**0.34**	Irrigation percentage of arable land	−0.11
Land use intensity	0.28	Soil water storage capacity	−0.12
Tillage depth	0.28	Desertification risk	−0.14
Policy implementation	0.23	Burned area	−0.16
Period of existing land use	0.21	Soil water conservation measures	−0.18
Tillage operations	0.20	Net farm income	−0.20
Tillage direction	0.20	Terracing	−0.21
Degree of erosion	0.19	Fire protection	−0.21
Plant cover	0.17	Farm ownership	−0.22
Soil erosion control measures	0.16	Soil texture	−0.25
Impervious surface area	0.11	Slope gradient	**−0.30**
Slope aspect	0.10	Grazing control	**−0.32**
Annual rainfall	0.10	Rainfall erosivity	**−0.34**
Annual potential evapotranspiration	0.09	Prevalent land use	**−0.38**
Exposure of rock outcrops	0.08	Grazing intensity	**−0.40**
Tourism intensity	0.05	Farm size	**−0.44**
Vegetation cover type	0.02	Population density	**−0.48**
Soil depth	0.01	Rainfall seasonality	**−0.66**

Table 4
Loadings to the four extracted factors of the PCA (bold indicates loadings >|0.6|).

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Degree of erosion	−0.22	−0.27	−0.12	**0.63**
Desertification risk	−0.28	−0.21	−0.20	0.12
Prevalent land use	−0.17	0.10	0.00	−0.08
Vegetation cover type	−0.37	−0.09	−0.59	0.28
Annual rainfall	−0.17	−0.35	0.51	−0.44
Aridity index	0.02	−0.31	0.51	−0.37
Annual potential evapotranspiration	0.18	0.13	**0.68**	0.34
Rainfall seasonality	−0.38	**0.75**	−0.32	−0.20
Rainfall erosivity	−0.22	0.52	−0.19	0.39
Parent material	−0.03	−0.08	0.38	0.33
Rock fragments	−0.11	−0.06	0.12	−0.16
Slope aspect	0.05	−0.05	−0.05	0.32
Slope gradient	−0.36	0.42	0.11	0.43
Soil depth	−0.59	−0.23	0.20	0.37
Soil texture	−0.53	−0.25	−0.02	−0.22
Soil water storage capacity	**−0.66**	−0.21	−0.03	0.01
Exposure of rock outcrops	−0.57	−0.20	0.09	0.37
Organic matter surface horizon	−0.46	−0.39	0.29	−0.21
Plant cover	−0.32	−0.41	0.11	0.22
Drainage density	−0.01	−0.51	0.21	0.42
Impervious surface area	0.11	0.39	0.16	0.40
Burned area	−0.02	0.35	0.08	0.19
Farm ownership	−0.40	0.36	−0.15	0.16
Farm size	−0.05	0.45	0.17	−0.17
Land fragmentation	0.54	−0.21	0.09	0.51
Net farm income	−0.25	−0.09	0.24	0.06
Parallel employment	0.02	**−0.71**	−0.04	0.10
Tillage operations	0.49	−0.17	−0.37	−0.40
Tillage depth	0.39	−0.08	**−0.62**	−0.13
Tillage direction	0.48	−0.16	−0.27	−0.28
Grazing control	−0.51	0.16	−0.58	0.06
Grazing intensity	−0.59	0.18	−0.38	−0.02
Fire protection	−0.55	−0.49	0.06	−0.19
Sustainable farming	0.45	−0.36	−0.50	0.17
Soil erosion control measures	−0.07	−0.26	−0.51	0.36
Soil water conservation measures	−0.30	−0.02	0.00	0.11
Terracing	−0.13	0.18	−0.37	0.03
Land use intensity	0.42	0.08	−0.35	0.08
Period of existing land use	0.41	−0.13	−0.37	−0.17
Irrigation percentage of arable land	−0.52	−0.34	0.24	0.09
Runoff water storage	−0.08	−0.46	−0.44	0.36
Tourism intensity	0.02	−0.01	−0.11	−0.10
Elderly index	**0.62**	0.23	0.02	0.56
Population density	−0.57	0.35	−0.09	0.04
Population growth	0.31	0.56	0.37	0.30
Farm subsidies	0.55	−0.13	0.25	0.24
Policy implementation	−0.11	−0.38	−0.55	0.03
Frequency of tillage	−0.03	−0.17	0.03	−0.26
Land abandonment	0.50	−0.58	0.06	0.33

distinguished: very high, high, moderate, low, and none. Coefficients were assigned for each category of desertification risk ranging from 1 (no risk) to 2 (very high risk). The description of each category of desertification risk is reported in Kosmas et al. (2013).

The methodology introduced here tries to capture regional variability in the observed indicators to achieve a possibly global evaluation. Of course, indicator systems and the associated coefficients may suffer from a level of subjectivity which depends e.g. on the degree of completeness and reliability of collected information. The reason to adopt a standard collection procedure with a unique questionnaire and full instructions to surveyors is to increase the representativeness of collected information. The high number of indicators derived from the elementary variables collected in the study may enhance the strength of the procedure.

2.3. Data collection

Questionnaires were prepared separately for each study site by including the indicators identified in Table 1. Questionnaires were completed by DESIRE partners in 808 field sites in the 10 study sites. To harmonize data collection among the study sites, a manual was compiled defining each indicator and describing the methodology or technique for measuring it (http://www.desire-his.eu). Data were collected at the scale of field site. Cultivated fields with an area usually ranging from 0.5 to 20 ha, and having uniform soil, topography, land use, and land management characteristics were considered as field sites (sees Kosmas et al., 2013). Some field sites were identified from topographic and ortho-photo maps in grids of 400 m by 400 m applying a systematic sampling design. However, this approach was not easily applied since the presence of the land owner was necessary for the collection of some data related to land management and social characteristics. Therefore, the majority of the field sites were described after contacting the owner of the land. The location of each field site was pin-pointed using a GPS. The dataset collected for the 48 indicators (with no missing values) was included in a harmonized database for further analysis.

2.4. Data analysis

An exploratory multivariate strategy including non-parametric Spearman correlations, Principal Components, non-hierarchical cluster analysis and linear discriminant analysis was developed in the present study using STATISTICA 8 package (Tulsa, Oklahoma). A Spearman rank co-graduation analysis was developed to correlate pair-wise each indicator to land abandonment. A total of 48 comparisons was run using the full sample size ($n = 808$ observations) and testing at $p < 0.001$ after Bonferroni's correction for multiple comparisons. Indicators were ranked according to the intensity of the Spearman coefficient. A Principal Components Analysis (PCA) was run on the matrix composed of 49 variables (the 48 selected indicators *plus* the land abandonment variable) by column and 808 field sites by row. The analysis was aimed at exploring the latent patterns and relationships among the selected indicators and the level of land abandonment in places affected by a different degree of desertification risk.

A linear discriminant analysis was then carried out on the matrix composed of the 48 selected indicators using a grouping variable modeling two conditions of land abandonment (0: no abandonment or low rate of abandonment <10 ha/10 years/10 km^2; 1: from moderate (10–25 ha) to very high abandonment rate (>50 ha/10 years/10 km^2: see below for land abandonment classes' explanation). The analysis was aimed at identifying (and rank the importance of) the most relevant indicators characterizing low and high land abandonment rates. The discriminant analysis was developed using a forward stepwise approach with F-to-remove and F-to enter set up at 10 and 5 respectively. Only significant variables entering the discriminant model based on the defined criterion were illustrated and discussed. Finally, a non-hierarchical classification tree analysis was run on the same data matrix in order to identify graphically the most relevant indicators associated to land abandonment processes.

3. Results and discussion

3.1. Non-parametric correlation analysis of land abandonment drivers

Results of the pair-wise non-parametric correlation between the degree of land abandonment and the selected indicators collected at the field plot level were illustrated in Table 3. Indicators were ranked according to the magnitude of the Spearman coefficient. A total of seven and eight variables correlated significantly with land abandonment with positive and negative signs, respectively. Land fragmentation, rainfall seasonality, population density, runoff water storage, elderly index and the farm size were the indicators mostly associated to land abandonment. Interestingly, both biophysical and socioeconomic indicators resulted significantly associated to land abandonment with the prevalence of socioeconomic indicators (12 out of 15 significant indicators).

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Table 5
Results of the stepwise discriminant analysis applied to classes of land abandonment (0: non-abandoned land; 1: from moderate to high abandonment rate).

Variable	Wilks λ	Partial λ	F-to-remove	p-Level	1-Tolerance
Rainfall seasonality	0.185	0.621	477,771	0.000	0.820
Tillage depth	0.118	0.974	20,713	0.000	0.573
Land fragmentation	0.118	0.975	19,747	0.000	0.568
Irrigation percentage of arable land	0.141	0.815	177,947	0.000	0.740
Runoff water storage	0.121	0.954	37,501	0.000	0.502
Farm size	0.123	0.937	52,486	0.000	0.528
Farm ownership	0.117	0.985	11,653	0.001	0.569
Soil texture	0.120	0.957	35,427	0.000	0.434
Policy implementation	0.121	0.954	38,052	0.000	0.564
Exposure of rock outcrops	0.121	0.947	43,892	0.000	0.564
Annual potential evapotranspiration	0.122	0.946	44,822	0.000	0.821
Fire protection	0.125	0.919	69,170	0.000	0.713
Population density	0.121	0.948	42,927	0.000	0.693
Impervious surface area	0.121	0.947	43,567	0.000	0.612
Elderly index	0.125	0.924	64,516	0.000	0.765
Grazing control	0.119	0.963	30,370	0.000	0.574
Land use intensity	0.120	0.956	35,817	0.000	0.444
Population growth	0.119	0.965	28,095	0.000	0.771
Plant cover	0.121	0.947	43,627	0.000	0.482
Desertification risk	0.117	0.987	10,504	0.001	0.407
Soil erosion control measures	0.118	0.972	22,690	0.000	0.357
Prevalent land use	0.118	0.978	17,597	0.000	0.235
Period of existing land use	0.117	0.986	11,151	0.001	0.629

3.2. Principal Components Analysis

Preliminary analyses have shown that some indicators used in the present study are intrinsically correlated and that a single indicator analysis cannot effectively identify the most relevant variables influencing land abandonment processes. Moreover, the influence of these factors on land abandonment may be hardly predictable. Therefore, a combination of indicators is necessary to evaluate the joint impact of biophysical factors, socioeconomic conditions and land management practices. A multivariate framework was thus adopted in this study by considering together all the collected indicators in a PCA. The PCA extracted four factors explaining together more than 40% of the total matrix variance (Table 4). Land abandonment was primarily loaded to the first and second extracted axes (with a factor loading amounting to 0.50 and 0.58 respectively).

The first extracted factor, accounting for 13.8% of total variance, was associated to both biophysical and socioeconomic variables including elderly index and soil water storage capacity with intermediate loading scores observed for population density, grazing intensity, soil depth and exposure of rock outcrops. The second extracted factor accounted for 10.8% of total variance and was associated to rainfall seasonality and parallel employment with an intermediate loading score observed for population growth. In sum, results depict land abandonment as a process associated to defined socio-demographic characteristics of the study area (aging, population decline, low population density, absence of parallel employment), together with poor soil quality (e.g. soil water storage capacity) and climate regimes unfavorable to crop production (e.g. rainfall seasonality).

3.3. Discriminant analysis

After statistical analysis using non-parametric correlations and PCA, the number of indicators was substantially reduced by using a stepwise discriminant analysis aimed at identifying the most effective indicators discriminating field sites according to the observed level of land abandonment. A total of 23 indicators (among which 8 biophysical and 15 socioeconomic) entered the model (Wilks $\lambda = 0.115$, $F_{(23,784)} = 262.2$, $p < 0.0001$) and were ranked in Table 5 according to their contribution in the discrimination between no (or low) land abandonment conditions and moderate to high abandonment rate. The model correctly classified 799 out of 808 observations (98.9%).

Climate and soil properties unfavorable to crop production together with socioeconomic factors depicting specific characteristics of the agriculture at the local scale (namely rainfall seasonality, tillage depth, land

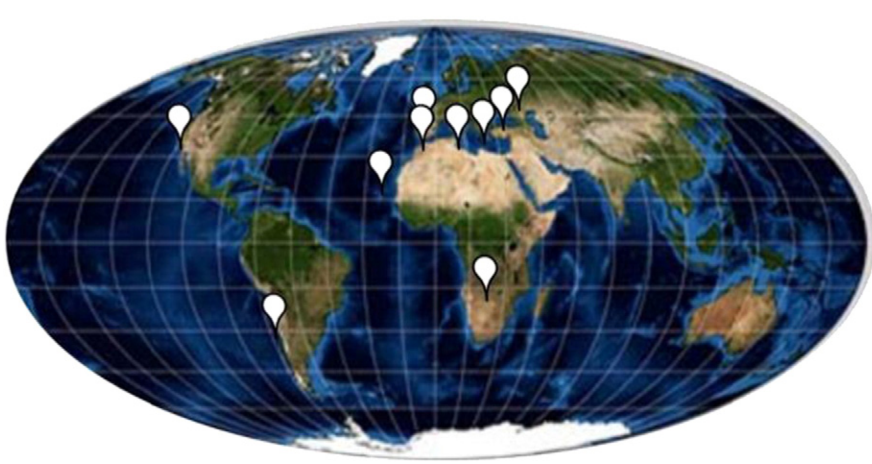

Fig. 1. Distribution of study sites for collecting data for indicators related to land abandonment.

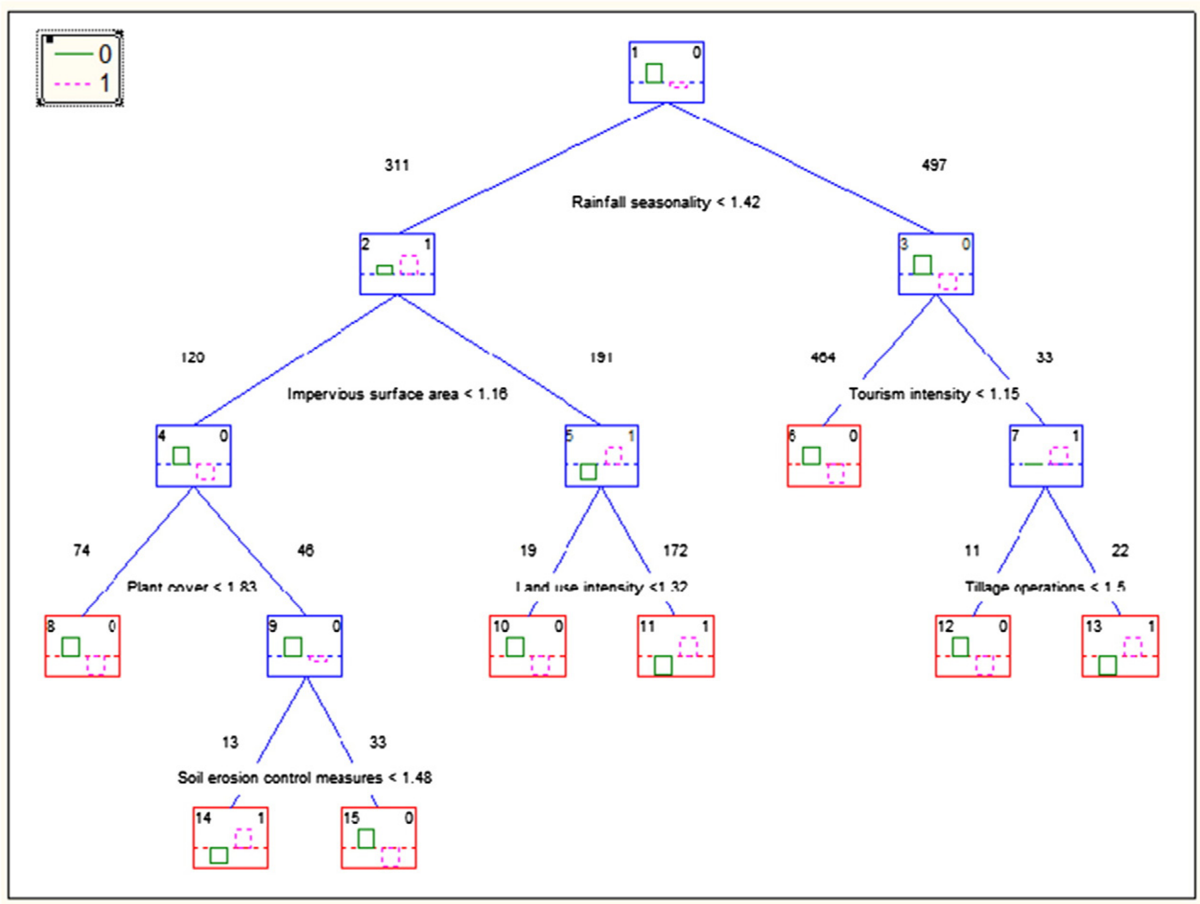

Fig. 2. Classification tree illustrating the most important drivers of land abandonment in the ten investigated study sites.

fragmentation, the percentage of irrigated land, runoff water storage and farm size) were identified as the most relevant indicators in the discrimination among the two groups of field sites. Farm ownership, soil texture, exposure of rock outcrops and annual potential evapotranspiration also entered the discriminant model with significant coefficients thus confirming previous results about the impact of factors limiting the agricultural production on land abandonment.

Interestingly, policy implementation was identified as a significant variable in the model indicating that environmental measures, if correctly applied at the farm or local level, exert a positive impact on land abandonment processes. Land-use and vegetation variables ranked bottom in the list of significant indicators, suggesting that land abandonment could be only moderately affected by land cover changes. However, this relationship should be better clarified using a diachronic assessment. Taken together, five variables resulted as significant in the three analyses developed in the present study (rainfall seasonality, elderly index, parallel employment, population density and grazing intensity/control) indicating a downward spiral driven by soil erosion and high-variability rainfall regimes coupled with depopulation processes and (possibly) unsustainable use of land.

Fig. 2 illustrates a classification tree splitting the examined field sites into homogeneous groups according to the indicators examined before. Results of this analysis partly confirm the outputs derived from the discriminant analysis which provided a partition of the investigated field sites in few homogeneous groups according to defined key indicators. The most important variable is rainfall seasonality, splitting the sample into two sub-samples respectively characterized by sites with negligible (n = 497) and intense (n = 211) processes of land abandonment. The left branch in Fig. 2 depicts the group of field sites with intense processes of land abandonment. This group was further partitioned into two sub-groups according to the imperviousness rate: in low imperviousness rate plots, plant cover and soil erosion control measures were the most important variables discriminating between the different observed levels of land abandonment. Taken together, results indicate that both biophysical and socioeconomic factors (mainly dealing with agriculture) can trigger land abandonment and indirect measures, including environmental policy implementation, soil erosion control and fire protection, can mitigate, at least partly, the phenomenon.

4. Conclusions

The derived methodology is a decision support tool to be used by various stakeholders for monitoring drivers of land abandonment in local contexts characterized by different environmental and socioeconomic contexts. The obtained results identify key indicators possibly affecting land abandonment processes. The novelty of the proposed approach is based on the exploratory analysis of a large number of candidate indicators collected in ten study sites and describing a variety of ecological and socioeconomic characteristics.

The present study demonstrates that a careful selection of indicators may be used to assess drivers of land abandonment in areas with different proneness degrees to desertification. Relatively few drivers of land abandonment, both related to natural conditions and to human actions, are demonstrated to be associated to the phenomenon and can represent the target of environmental measures aimed at containing the abandonment of land and desertification. Even though there were some simplifications in the assignment of scores to the various classes of selected indicators, the derived methodology can be considered as a worldwide valuable tool for assessing the efficacy of different land management practices and degradation monitoring techniques. The methodology can efficiently assess land abandonment in areas with varying degree of desertification risk and provides the pertinent information at both the local and regional scale.

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