GeoInformation in Europe, M.A. Gomarsca (ed.)

Remote sensing evaluation of afforestation versus natural revegetation on abandoned croplands in central Spain

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Keywords: land use, change detection, object-oriented classification, afforestation

ABSTRACT: Land abandonment is an outcome of a wider process of cropland marginalization. It leads to an increase of biomass and naturalness of the vegetation, but also to increased risks of wildfires, erosion, and to loss of habitats for species that are characteristic of agro-ecosystems. This process is addressed in Spain, where the Afforestation Programme of Cropland has converted a total of 801693 ha.

This study focuses on the evaluation of the afforestation process in Central Spain. Remote Sensing is used to register cropland abandonment, natural re-vegetation on abandoned croplands, and afforestation over the last four decades. Both object-oriented classification technique on LANDSAT (TM, 1991 & ETM+, 2002) imageries and photo-interpretation of aerial imagery (1957, 1957 & 2002) were utilized for detecting changes over time. Present status is validated with the on-line database SIG-PAC of the Spanish Ministry of Agriculture, Fisheries and Food.

The positive and negative effects of land use change are identified by incorporating NDVI and indicators produced by spectral mixture analysis into the object-oriented classification procedure for the imageries of 1991 and 2002. Results indicate that the rate of vegetation recovery is higher for the recently abandoned land, whereas the afforestation performs better in longer term.

1 INTRODUCTION

Land abandonment is an outcome of a wider process of marginalization of extensive and traditional cropland cultivations. In Mediterranean Spain, cropland abandonment has been successfully refrained during the last decade, through various CAP-related policies. Nevertheless, the marginalization of less productive lands continues. This has lead to the application of several alternative land-uses, among which, the afforestation of agricultural lands transformed entire landscapes. Such rapid land-use changes might be viewed as timely and smart measures to keep an area economically viable, but the consequent environmental changes are mostly detrimental to the biodiversity characteristic for agro-ecosystems. Another impact is the loss of cultural values established through traditional cultivations in the landscape.

A programme for afforestation of agricultural lands has been going on in Spain since 1993. Its main objective was to convert the use of croplands from agricultural production to forestry. This objective was envisaged to provide alternative income from less productive croplands, and at the same time to curb the excessive food production (in addition to the land set-aside measures of the CAP). It was also intended as a restoration measure for lands suffering degradation, highlighting several functions of the forest, especially for soil protection and water regime regulation. Change to forestry use is also preferred, because of the established certainty of the existing practices and benefits (both economical and environmental). Moreover, it is proved that trees planted on former arable land have growth rates that are higher than expected from the parent material (Vesterdal *et al.* 2006). However, plantations in improper conditions may result also in impoverished ecosystem, and possibly cause land degradation in longer term.

Leaving the abandoned lands up to the forces of secondary succession is referred to as passive restoration. Relatively inexpensive, passive restoration techniques are preferable, where ecosystem structural and functional damage is relatively limited and resilience is high. It leads on one hand to an increase of biomass and naturalness of the vegetation while erosion risk decreases, but on the other hand to a raise of the risk of wildfires due to the establishment of a dense cover of highly combustible shrubs and herbs, and to a loss of habitats for species that are characteristic of agro-ecosystems in the long term. Typical succession vegetation stages in the semi-arid Mediterranean conditions of Central Spain involve rapid colonization by annual herbaceous species. Studies of García Ruiz & Lasanta (1994) point out an establishment of average cover of about 60% on northern expositions and about 40% on southern. Then gradually these are displaced by perennials and woody species and within 10–20 years shrubland communities get established if no preventative measures are applied. Forest, comprised of stone oak and juniper associations could be established in the best case within 40–50 years.

In most cases, however, abandoned croplands do not stay completely out of use and the new disturbance regime (after cease of arable cultivation) is of primary importance. It may involve overgrazing, as in feed lots (a major degradation factor). Under intensive grazing, grasslands are formed, rich in *hemicryptophytes*. Undergrazing results in growth of coarse vegetation and increases the potential for fire, as well as causes a decline in biological diversity (Gonzalez Bernaldez 1991).

Land management in Mediterranean semi-arid conditions is a rather complicated issue, where rational choice of single and best land use is very difficult to determine. Planting trees on croplands, switch to animal husbandry or leaving the lands out of human touch may be viewed as contrasting land management strategies, all with both negative and positive consequences which are yet hard to predict beforehand. This study demonstrates a remote sensing approach for quantifying and evaluating the changes following cropland abandonment in Central Spain. It allows the monitoring of the habitat diversity and biomass recovery progress over large areas. In addition it can be utilized as a decision support for land-use optimization i.e. to determine the areas, where current actions perform badly and alternatives would be necessary.

2 MATERIALS AND METHODS

The study area covered one LANDSAT TM scene, which covers the Western part of the region (Autonomous Community) of Castile La-Mancha, most of the area of the provinces of Toledo, Ciudad Real, and small parts of the regions of Andalusia (to the south) and Extremadura (to the west). The region occupies a part of the southern Spanish meseta, geologically characterized with heavily weathered limestone based on sedimentary rocks. It has a continental Mediterranean climate with low rainfall and a sharp contrast between cold winters and hot summers.

The following datasets were used:

- LANDSAT ETM+ image from the 12th of August, 2002
- LANDSAT TM image from the 8th of August, 1991
- Aerial photos from 1957 (for six subsets of the whole LANDSAT imaged area)
- The SIG-PAC database (MAPYA, Ministerio de Agricultura, Pesca y Alimentación, Spain), containing aerial photos of August 2002, and cadastral properties of each parcel.

Main objectives were to map the areas of land-use change: from cropland cultivation to forestry, extensive grazing or nature; and perform evaluation of the vegetation recovery using LANDSAT derived indices.

The six subset areas were selected in order to map the areas of naturally re-vegetated, and the areas of afforested abandoned croplands over the last four decades. Those correspond to the topographic maps (scale 1:50000) of Spain, sheets No: 601, 631, 685, 736, 835, 812. They were selected on the basis of having large extents of afforested and abandoned areas.

Multi-temporal remote sensing analysis products are suitable datasets for monitoring biomass and habitats related with land-use change. In the current application the two LANDSAT scenes were automatically registered, then radiometrically calibrated, and normalized on the basis of pseudo-invariant features (PIFs) with ENVI software (version 4.3, Research Systems Inc.). Three PIFs were selected: rocks, water and dark vegetation. They were identified and extracted through overlay of the two images in eCognition software (version 4.0, Definiens Imaging), after segmenting with scale-factor 3 (almost approximating pixel level), and after finding the object of the above PIFs with maximum homogeneity (or minimum standard deviation of the pixel values in the 6 bands, the thermal band was excluded) within the object.

Broadband vegetation indices were used to quantitatively and qualitatively evaluate (a) the abundance of biomass, correlated with the inverse reflectance of LANDSAT band 5 (EON2000 2000), (b) green vegetation vigour, correlated with NDVI (Rouse *et al.* 1973), and (c) vegetation water content, correlated with NDWI (Gao 1996). In addition, spectral unmixing procedure (SMA) was performed to derive a fraction reflectance of green vegetation, which is asserted to reflect vegetation variability with higher precision (Elmore *et al.* 2000).

The radiometrically normalized scenes were imported in eCognition. Segments were produced with scale 5 (and shape 0) using bands 1 to 6 TM and ETM+, all with equal weight. Object-oriented classification was performed on both scenes to distinguish the

areas of cropland cultivations (harvested, ploughed, standing crops, according to cultivation signs), shrublands, and other (not clear croplands/ designation as pasture, unproductive surface or forestry use in SIG-PAC in 2002). The lands abandoned after 1991 were mapped as result of change detection, from croplands in 1991 to shrublands or other in 2002. All changes were registered as such after validation with the SIG-PAC database. Lands mapped as abandoned or afforested before 1991 were first recognized as croplands on the aerial imagery of 1957 through analogue visual photo-interpretation. The photo-interpretation allowed also to distinguish 4 vegetation types established on abandoned croplands: grassland, scrubland (mostly occupied by small shrubs), garrigue (open shrubland), maquis (dense shrubland). In this way totally 10 vegetation classes were mapped, 5 resulting from short-time (up to 11 years) and 5 resulting from long-time (max. 46 years) establishment after afforestation or natural re-vegetation. Finally, the land-use change types were categorised into 3 groups, namely from cropland cultivations to:

- forestry, including the abandoned parcels, which were afforested;
- animal husbandry, including the areas, where grasslands were established after abandonment, which may still be referred as agricultural lands, but with no sign of crop production;
- (semi) natural land, including the areas where shrublands, garrigues and maquis, established after abandonment, which may also be used for grazing or game breeding, but less intensively, generally allowing for the appearance of a natural and semi-natural character of the landscape.

The forestry designations were directly derived from SIG-PAC; the second category was determined on the basis of the observed traces of grazing and mowing; and the third, where no such signs were observed.

In the next step the vegetation indices were calculated, as mean and standard deviation within each homogeneous object, for the two years (1991 and 2002) as well as their difference (increase or decrease in the 11 year interval). The object-oriented analysis with eCognition proved especially useful for fast processing of large dataset and for construction of integrated spatial data-base. It also facilitated the exploration and analysis of the vegetation indices.

3 RESULTS

The mapping revealed a total of 7455.19 ha naturally re-vegetated and 3145.16 ha afforestated former croplands. 3265.75 ha of change were mapped within the subset areas, and additionally 7334.58 ha out of them (over the rest of the LANDSAT imaged area).

3.1 *Areas of land use change after cropland abandonment*

Rates of land-use change were compared between the two periods 1957–1991, and 1991–2002, within the 6 subset areas.

In the earlier period, 1957–1991, the shares of these categories show 10% conversion to forestry, 11% to animal husbandry and 78% to natural land out of total area of change 1543.2 ha. In the recent period, 1991–2002, those shares were respectively: 78% to forestry, 13% to animal husbandry and 9% to natural land out of total mapped area of change 1722.5 ha. Outside the subset areas, total areas of change were classified as well. They demonstrated 22% conversion to forestry, 47% to animal husbandry and 30% to natural land out of a total area 7334.6 ha.

In accordance with the previously mentioned stages of the secondary succession (García Ruiz & Lasanta 1994) under the 3 types of land-use regime (see introduction chapter), on recently abandoned lands mostly grasslands are recorded in 2002 (their share ranges from 85.7% in subset 835, to 30% in subset 685), followed by scrublands (their share ranges from 49% in subset 631, to 4% in subset 835). In subset 685 mostly garrigue was recorded i.e. 54% and mostly on former cultivations under dehesa. Over the rest of the study area (out of the sample subsets) grasslands were established on 47% and scrublands on 29% of the respective mapped area.

On the long-time abandoned lands, natural re-vegetation established mostly scrublands (70% in subset 835 to 17% in 736), followed by garrigues and maquis.

3.2 *Evaluation of vegetation recovery*

The evaluation procedure started by comparing the mean values of the vegetation indices (NDVI & NDWI) and fraction reflectance of green vegetation estimated between the years 2002 and 1991, which were averaged for each of the 10 classes of vegetation established on old and recently abandoned lands. The green vegetation fraction showed very high positive correlation with NDVI exceeding 90% for all classes. Therefore, it was not further considered, because of contributing almost no extra information at the current stage of the analysis. The NDWI showed strong correlation with both NDVI and the green vegetation fraction (over 70%) for all classes of natural vegetation, and very low correlation for the classes that were harvested or ploughed croplands in 1991. This complication needs further investigation. The current paper presents an evaluation based on the means of NDVI, as presented in Table 2.

Table 1. Proportions of vegetation types established on recently and old abandoned lands.

Within subset areas						Outside subset areas		
Croplands in 1957	Area (ha)	%	Croplands in 1991	Area (ha)	%	Croplands in 1991	Area (ha)	%
Afforested ′91	161.14	10	Afforested ′02	1337.18	78	Afforested	1646.86	22
Garrigue ′91	358.59	23	Garrigue ′02	90.05	5	Garrigue	54.45	1
Grassland ′91	176.14	11	Grassland ′02	229.6	13	Grassland	3468.7	47
Maquis ′91	119.93	8	Maquis ′02	0	0	Maquis	33.41	0
Scrubland ′91	727.43	47	Scrubland ′02	65.69	4	Scrubland	2141.47	29
Total area	1543.23		Total area	1722.52		Total area	7334.58	

Table 2. Mean NDVI values of the 10 classes of re-vegetation types.

Re-vegetation type	Old abandoned lands			Recently abandoned lands		
	2002 NDVI	1991 NDVI	NDVI change	2002 NDVI	1991 NDVI	NDVI change
Afforested	0.455	0.467	−0.012	0.248	0.218	0.030
Garrigue	0.354	0.313	0.041	0.295	0.213	0.081
Grassland	0.247	0.239	0.008	0.256	0.220	0.037
Maquis	0.406	0.362	0.045	–	–	–
Scrubland	0.247	0.249	−0.001	0.242	0.213	0.030
Average	0.342	0.326	0.016	0.260	0.216	0.045

Highest means in both years were recorded for the early afforested areas (which were croplands in 1957), followed by the maquis and garrigue vegetation. The recent afforestations display very low mean of NDVI, nearly as low as that of the scrublands. Looking at the means of NDVI for the different classes does not allow for contrasting positive and negative consequences of natural re-vegetation versus afforestation, although all classes show higher positive difference on the recently abandoned lands.

Therefore, the magnitude of NDVI change was used for calculating the percentage areas of increase and decrease of NDVI from the total area of the class.

Figure 1 shows the percentages of areas of change in NDVI, i.e. increase and decrease for each re-vegetation type, respectively for recent and old abandoned areas. The difference to 100% percent includes the areas of no change or very small change (determined as the NDVI value change from −0.01 to +0.01). The 10 classes display both areas of increase and decrease of NDVI, but of varying magnitude. The classes reflecting natural re-vegetation patterns i.e. maquis, garrigue and scrubland show highest rates of increase (95 to 87% of the total areas) on recently abandoned lands with negligible areas

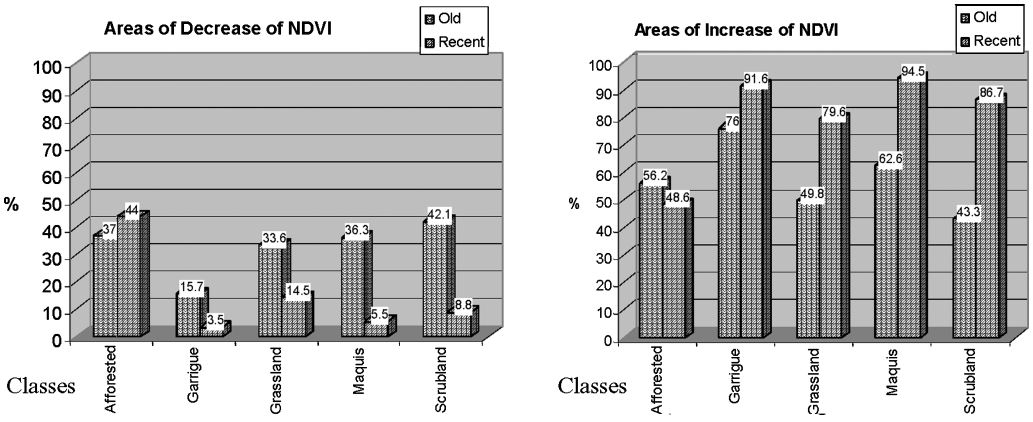

Figure 1. Areas and increase and decrease of NDVI changes following cropland abandonment.

of decrease (4 to 9%). These proportions are notably diminished on long-abandoned lands; with the scrublands showing almost equal areas of increase and decrease. This indicates that nearly half of the old abandoned areas, occupied by scrublands suffer degradation processes. About a third of the rest, except the garrigues, also display similar fate. The afforestations perform worst on recently abandoned lands, but in longer terms it is the only class which larger percentage of areas of NDVI increase with time (from 49 to 56%) and respectively smaller percentage of the areas of NDVI decrease (from 44 to 37%). This indicates that the afforestations are the land-management type capable to recover vegetation in longer run, compared to the rest, but the afforestation techniques need much improvement to prevent the degradation processes on recent afforestations.

4 DISCUSSION AND CONCLUSIONS

Both the mapping and the contrasting of vegetation index (VI) response of the classes of natural re-vegetation and afforestation of former croplands was a cumbersome task. This is because of the impossibility to clearly distinguish the vegetation types, and additionally complicated by the inherent heterogeneity of the Mediterranean environment. The automatic change detection served just as basis for the mapping purposes, i.e. delimiting the areas of change. Unsupervised classification of the land-cover/land-use types of interest was impossible due to the hardship to distinguish the recently abandoned and afforested croplands. In addition, it is hard to determine if the parcels are permanently abandoned, fallow lands (which in the semi-arid conditions of Central Spain may stay bare for a period between 1 and 10 years, or more, (Gonzalez Bernaldez 1991)) or lands set aside from production, in accordance to the rules of the CAP regulation (EC) No 2704/1999.

The generally slow rates of establishment of woody vegetation in Mediterranean conditions, as well as the higher frequency of environmental and anthropic impacts (as droughts, fires and overgrazing) makes the use of multitemporal LANDSAT VI-means hardly applicable both for long- and short-periods of time. The differences in the average mean NDVI values were negligible, apart of the areas of intensive vegetation growth, as in the ecotone (borders with forest). Therefore to complete the comparative assessment of natural re-vegetation versus afforestation on former croplands the effects of both factors (different period of establishment and different type of revegetation) are compared as reflected in the magnitude (percentage of areas) of NDVI change between 1991 and 2002.

It can be concluded that the afforestation performs better in longer-term, compared to natural re-vegetations, but with high risks of land degradation on recent plantations (nearly half of their total area decreased in NDVI, unlike the naturally re-vegetated classes, with 4–9% decrease). Therefore afforestation techniques need optimizations, closely resembling the secondary succession patterns in semi-arid Mediterranean environment.

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