Historical Cartography and GIS for the Analysis of Carbon Balance in Rural Environment: a Study Case in Southern Italy

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ABSTRACT

Human activities impose a transformation of the extra-urban land that may lead to the modification of the frail equilibrium of whole ecosystems. Sound planning strategies should be therefore pursued, employing a multidisciplinary approach that should take into account geographical, environmental and landscape factors as variables interacting among themselves and with the social and economic aspects. In order to simultaneously analyse all these properties, tools able to manage, interpret and integrate several data are necessary.

The present research has been developed using a geographical information system applied to historical maps in order to assess the environmental impact of land use transformation, with a special emphasis on the atmospheric carbon dioxide balance. The analysis was focused on the transformation of a rural area in Southern Italy along the last 138 years, due to the change of land use through the introduction of corn and fruit orchards increasingly substituting olive trees and forested surfaces.

The results showed that the cultivation conversion caused a loss of CO_2 fixation value, that was accompanied by heavy emission of greenhouse effect gas in the atmosphere by urban settlements too. A sound rural land management should efficiently balance environmental pollution determined by the economic development; the methodology employed in the present case study could properly be transported into other areas, and the resulting analysis extended to different rural context.

Keywords: Historical maps, GIS, landscape, environment, CO_2

1. INTRODUCTION

1.1 Foreword

Earth surface and the different forms of life on it were modelled by the planet evolution under the drive of natural forces. In the past two Centuries human activities have mixed with natural events, inducing profound modification causing in some cases severe changes in natural cycles due to the indiscriminate use of pollutant technologies. Moreover, the absence of adequate eco-compatible development programs and the research for maximum production, associated with the disappearance of large forested surfaces, were often observed. The alterations that were induced were so severe to modify in some cases the whole terrestrial ecosystem structure itself.

Among the major environmental consequences determinated by the land use modification driven by human activities, there is the variation of atmospheric carbon dioxide. Since the beginnings of the industrializion age, CO_2 concentration values increased by 37%, passing

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from 260-280 ppm in the Year 1880 to 360-380 ppm in 2001. According to the last 30 years trend, the actual gain ratio amounts to nearly 1,0 – 1,5 ppm per year. (Paci, 1997; Ministero dell'Ambiente, 1999). Heavy use of fossil fuels on one side and deforestation (and the consequent forestry soil erosion) on the other constitute the main cause of the actual severe quali-quantitative alteration of the atmospheric gases, especially CO_2, with a consequent global overheating phenomenon. This "greenhouse effect" of planetary dimension, is the result of the total amount of single local realities.

Real and useful tools for a sound planning of agricultural land by politicians and planners, that should take into account also environmental aspects, were only recently developed. The relationship among agriculture, ecosystems and environment were proposed by some Authors (Tassinari, P., 2006; Adinarayana, J., et al., 2006) as new contributions to turf and landscape design so as to land planning and management.

On the other hand, new systems for the rational collection and analysis of forestry and agricultural land data are now available. GIS-based techniques, Image Processing, remote sensing and other new technologies for the survey, planning and management of land evolution are now enabling (Capobianco et al., 2004; Massoud et al., 2004) a more accurate analysis of rural landscape and environment. When an historical support, like cadastral registers, old maps, etc. (Bender et al., 2005/a, 2005/b) could be available, an analysis of the evolution during time of rural landscape may be also possible.

1.2 New Technologies for Rural Land and Environment Analysis.

New more powerful technologies enabled the possibility to carry out more detailed analysis of rural ecosystem and landscape (Tortora et al., 2002). A specific ecosystem study has been held by Jansen & Di Gregorio (2002): through a systematic description of the environment, an indication useful to understand changes in land use and cover was obtained.

The application of a Geographical Information System (GIS) to planning strategies was utilized since its attitude in synthesising complex land relations (Toccolini, 1998). Ayala et al. (1999) examined the situation in Almeria, a semi-arid Spanish region, where the location of areas with best attitude for intensive agriculture in greenhouses was defined using a GIS, in relation to risks connected with aquifer salinization caused by an indiscriminate use of underground water.

Langaas (1995) has consistently contributed to GIS analysis of agricultural-forestry land evolution phenomena and the related environmental impacts. Despite the well spread knowledge of several sustainable development indicators, an adequate consideration of their spatial connotation was not investigated before the advent of GIS user-friendly software.

Indicators of environmental sustainability, when combined with visualization, manipulation and analysis tools, constitute the essential components of the monitoring process itself. The output information, if managed with appropriate tools, enables decision makers to use spatial queries in order to obtain rural development data (Farrow & Winograd, 2001).

The use of a GIS for data cataloguing and inter-correlated analysis was recently introduced as a support for strong progress in the land use and attitude study field. Gardi (2001), using GIS techniques and crop simulation models, assessed at a basin scale the relation between rural system, land use, pedology and morphology features and the concentration of herbicides and nitrates in the water body. Ceballos-Silva & Lopez-Blanco (2003), using a multicriteria analysis approach in the framework of a GIS, identified appropriate areas for oat cropping in central Mexico through fuzzy analysis of variables related to weather, soil, topography at different spatial and time scales.

An interesting example of GIS methodology for the realization of a Decision Support System is that applied to AOP (Appelation d'Origine Protègèe) cheese production in the Massif Central area, France (Brunschwig, 2000). The study objective was the identification and characterization of several production areas of different cheese types typical of the Massif area, in order to improve their quality by addressing the production only to those sites found to be suitable by the analysis. The output data of this work enabled French authorities to screen several sites in the Massif Central area where some pasture typologies should be avoided, because it would be counterproductive to permit cheese production in areas not suitable due to the milk quality decrease and the consequent market price drop of the entire production system.

An other example of GIS methodology application was carried out by Giorgi (2001) who, comparing historical and updated maps, through appropriate georeferencing and warping methodologies, obtained an information about landscape evolution history. When the detail scale was accurate enough, he was also able to collect data about environmental transformation and historical settlement dynamics, recovering in some occasion rural buildings dated early '800 and nowadays still preserved.

Historical documents were recovered and employed, in more recent years, with the aim to analyse the time evolution of extra-urban land, environment and landscape. Pärtel et al. (1999) obtained a description of the landscape history of the largest calcareous semi-natural site in Estonia, resulting in a decrease in species richness more dramatic in forests of age 20-40 years, if compared to open grassland. Jordan et al. (2005) investigated the impact of historical land use change on soil erosion and sediment transport in the Kali basin (Lake Balaton, Hungary) by means of historical maps dated starting from year 1784, so evaluating land use and agricultural changes introduced by land ownership.

Moreover, Bender et al. (2005/a) analysed changes in the landscape of a sector of Upper Franconia (Germany) by comparing land use change over four time periods (1850, 1900, 1960 and 2000), entering the information into various temporal layers of a land register-based vector GIS. The same Authors (Bender et al., 2005/b) examined two study cases in order to develop appropriate techniques for quantifying and analysing the landscape changes since 1850; based on cadastral maps and land registers, results were rendered at a land plot level by the use of a diachronic GIS, that provided valuable indication relevant for planning processes and nature conservation in changing cultural landscapes.

The object of the present work is the analysis of land use change over more than a century in a study area by a comparative examination of historical cartographic supports with more recent maps, using GIS and image processing techniques. The elaboration was then used to assess and quantify CO_2 variation through a comparison of chronologically different land cover maps.

2. MATERIALS AND METHODS

2.1 Study Area

The study area has been chosen, among other ecosystemically homogeneous regions, due to the availability of historical cartography starting from Year 1859, in order to assess land use change among a temporally long enough period.

This area, covering about 1500 ha, is located in Southern Italy, mainly in Bernalda e Pisticci municipalities of the Basilicata Region, nearby the Ionian Sea coastline (fig.1). The thermoregulation effect of the sea, the aspect, the soil structure and the socio-economic context determined and still are determining the vegetation species pattern of this area.

Figure1. Study Area

The morphology is mainly constituted by low hills, suitable for corn and olive production. The spread of mechanization technology for crop cultivation and harvesting together with, especially in the late ‘800, the development of industrial wheat transformation techniques serving the pasta and bakery products industry (Dal Sasso & Picuno, 1996), caused remarkable changes in the whole land asset.

2.2 Cartography

Land use change in the study area was examined over four different time periods: Years 1859, 1873, 1957 and 1997. The geographical information dated Year 1873 and 1957 was collected, in a 1:50.000 and 1:25.000 scale, using the historical maps of the Italian Geographic Military Institute (IGMI). Digital orthophotos - dated 1997 - were used together with a 1:5.000 scale technical map of Bernalda area obtained from a recent aerial photogrammetric survey.

The older time level (Year 1859) has been analyzed using an antique map created on Marquis Peres de Navarrete’s demand (fig.2). This map represents most of Bernalda municipality land, especially the northern zone above the built-up area, within the borders of adjacent communal areas, describing the rural landscape of that time. It constitutes a complete and consistent cartographic support, endowed with planimetric coordinates and enriched with thematic information about the land use at that time.

Figure 2. Historical Cartography (Year 1859) of the Study Area

Land use maps, chronologically based on different periods, have been obtained by the interpretation of the different cartographic supports recovered; every layer has been then classified in 9 classes: woodland, shrubland, arable land, orchards, olive groves, vineyard, meadows, urban, wasteland.

1997 land use classification was based on the interpretation of recent photographs (fig. 3); field data were collected, in order to obtain more accurate results and to localize the coordinates of control points, with the use of a GPS Mod. Garmin IIIplus. Data retrieved have been implemented in a land information database and processed in a multi-temporal GIS (GeoMedia - Intergaph) where each Year has been considered as an homogenous chronological layer. In this way, all the information about land orography and use were organized on four different layers (corresponding to Years 1859, 1873, 1957 and 1997), constitued by data characterized by the same time level.

Figure 3. Different Land use typologies in the Study Area

Then, through spatial overlay, the processed input layers sequence resulted in output vegetation temporal dynamism data.

Finally, two temporally different maps, one dated 1879 and the other being the contemporaneous one, have been also 3-D digitalized and processed, in order to analyse the different elevation attributes and vegetation cover condition between the two considered periods: morphological changes are strictly connected to the evolution of vegetation covers and, consequently, to different soil protection.

2.3 Image Processing

In order to input the historical cartography, the maps were geo-referenced through a sequence of rectification and referencing procedures; especially for the iconographic map dated 1859, control points on the map at known locations were located and projected on the modern overlaid maps (Capobianco et al., 2004). The geographic framework has been achieved using georeferencing and pixel resampling tools through an affine transformation six-parameter dependent (Della Maggiore et al., 2002). Using spatial analysis functions the map of Year 1859 was appropriately correlated to altimetry (DEM) of Year 1873; therefore, the land use here reported was associated with the visualization of land use as in the present orto-photos, so obtaining the historic reconstruction of Year 1859 landscape. This enabled an evaluation of the aesthetic changes of the study area in terms of both morphologic and vegetation variation of the agro-forestry landscape. Figure 4 shows three-dimensional reconstruction of 1859 landscape compared with the actual situation.

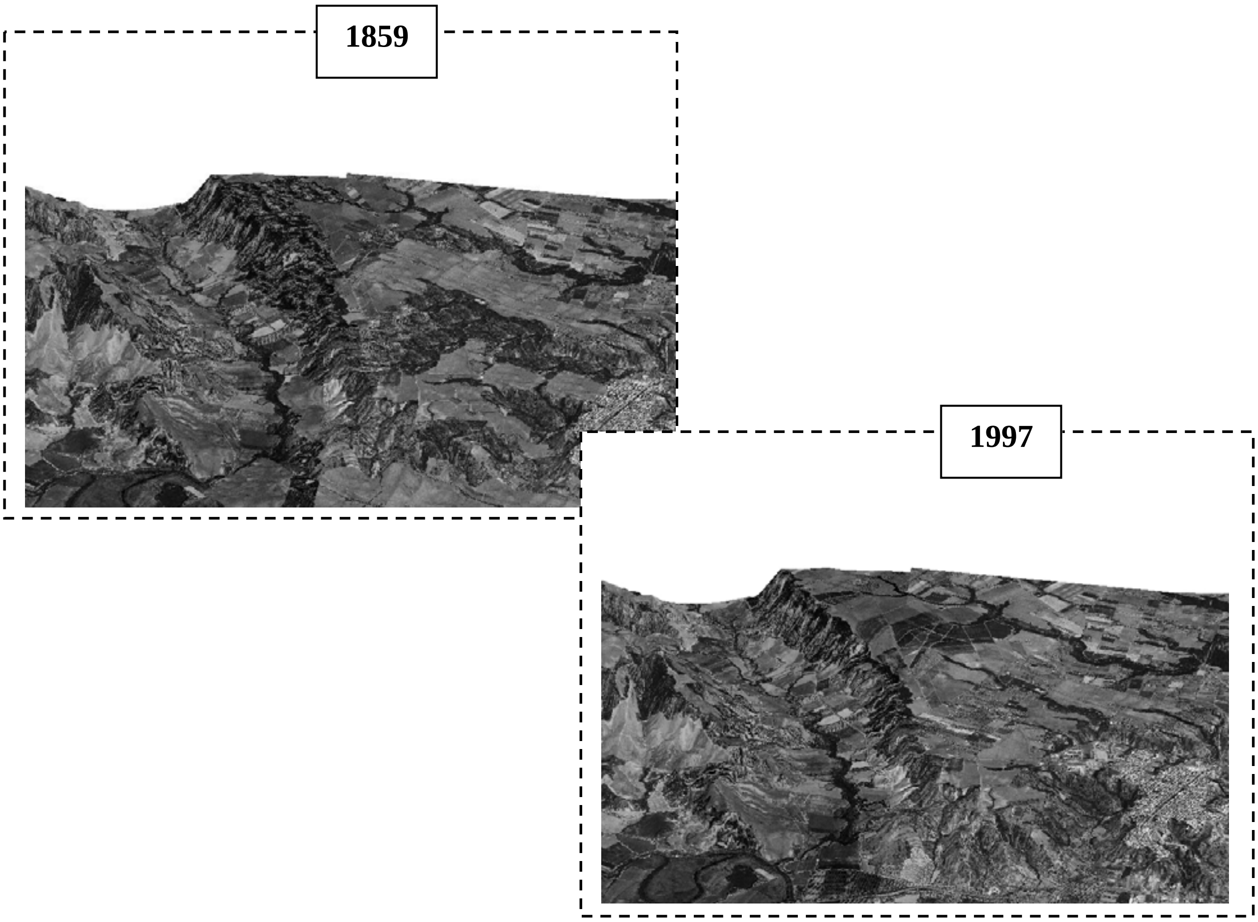

Figure 4. Comparison of three-dimensionally reconstructed landscape (1859 – 1997)

3. RESULTS AND DISCUSSION

3.1 Land Use

Figure 5 represents land use maps obtained for the four time periods produced on the basis of the thematic information contained in the historical maps that were retrieved. Based on polygonal topology, these maps represent for each data the state of landscape; the comparison obtained through a crossed over interpretation of the output maps has enabled the analysis of land changes from 1859 to present days, covering a time period of 138 years, giving information on historic persistence of soil use typologies along with their time-driven modifications. Dominant soil use typologies of the site have been grouped in order to better compare output data through a more evident highlighting of variations in time.

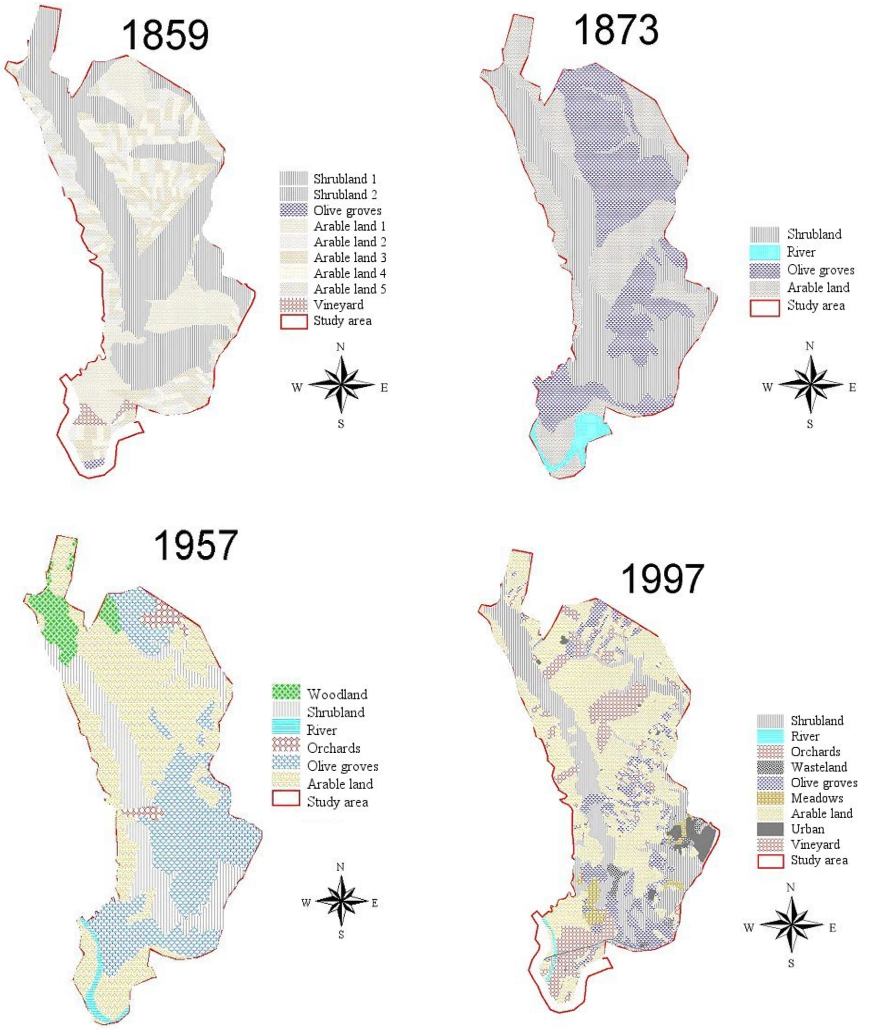

Figure 5. Thematical land use maps for the four different time periods

Visualizing data in graphs (Fig.6) we can observe an increase of crop growing and a reduction of forested surfaces, that have now almost disappeared leaving their place to urban areas and fruit orchards.

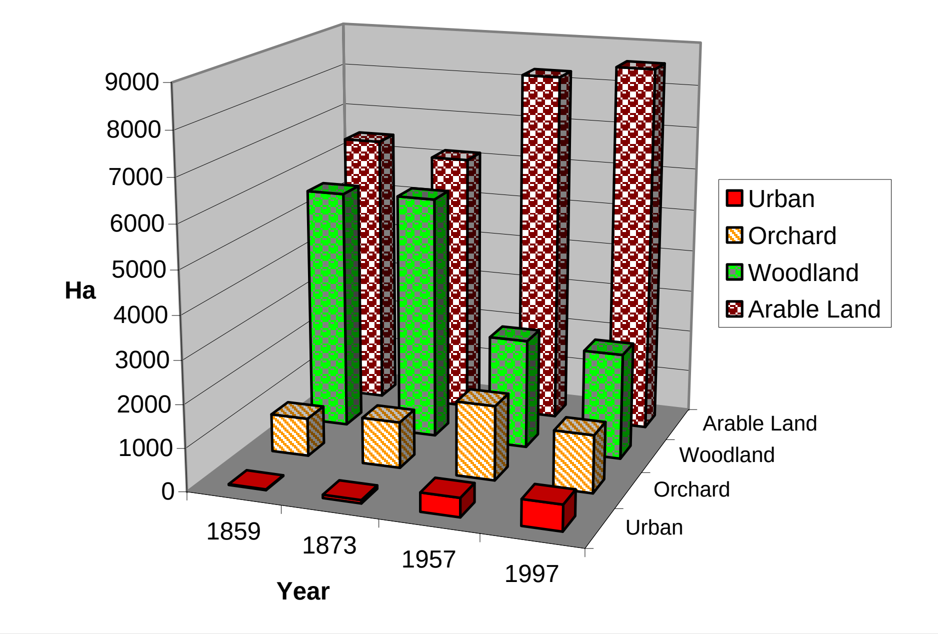

Figure 6: Evolution of principal land use over the four time periods

Historic dynamism of vegetation and morphology has evolved together with the effects of technology on cartographic production quality; this aspect is testified by the characteristics of the historical planimetric cartography of Year 1859, almost an iconography with very low metric precision, arriving to modern cartography, in paper or digital format, that has greater metric precision together with more accurate information.

3.2 Carbon Dioxide Balance

With the aim to quantify the effect of land use changes on the environment, with special emphasis on air quality, we estimated the CO_2 time variation connected with the use of the crops (Woodland, Shrubland, Arable land, Orchards, Olive groves and Urban) in the study area reported in the different chronological informative levels (Years 1859, 1873, 1957 and 1997).

CO_2 sequestration rates were calculated through adopting the user-friendly CO2FIX V.2 model (Masera O.R. et al., 2003), tool for the dynamic estimation of the carbon sequestration potential of forest management, agroforesty and afforestation projects. CO2FIX V.2 is a multi-cohort ecosystem-level model based on carbon accounting of forest stands, including forest biomass, soils and products. Carbon stored in living biomass is estimated with a forest cohort model that allows for competition, natural mortality, logging, and mortality due to logging damage. Soil carbon is modeled using five stock pools, three for litter and two for humus. The dynamics of carbon stored in wood products is simulated with a set of pools for short-, medium- and long-lived products, and includes processing efficiency, re-use of by-products, recycling, and disposal forms. The CO2FIX V.2 model estimates total carbon balance of alternative management regimes in both even and uneven-aged forests, and thus has a wide applicability for both temperate and tropical conditions. (Masera O.R. et al., 2003).

The CO2FIX model was developed as part of the “Carbon sequestration in afforestation and sustainable forest management” (CASFOR) project, which was funded by the European Union INCO-DC program. (Mohren et al., 1999).

CO2FIX V 2.0 is a carbon book-keeping model that simulates stocks and fluxes of carbon in (the trees of) a forest ecosystem, the soil, and (in case of a managed forest), the wood products. It simulates these stocks and fluxes at the hectare scale with time steps of one year. For an extensive description of carbon dynamics in forest ecosystems, and the role of forests in the global carbon cycle see Kauppi et al. (2001). Some of the results of CO2FIX have been used in the IPCC 1995 climate change assessment.

In order to initialise the model, different analysis parameters were used. The assumptions that were made were consistent with the software input characteristics (Mohren, G.M.J. et al., 1999) and the local area characteristics (Capobianco, R. et al., 2004). For forestry area the following characteristics were used: tree species, area, age, dominant height, standing volume, growth class and the coordinate of the stand.

Woodland in the study area is represented by highly degraded coppice forest with prevailing Quercus ilex. Rotation length is 30 years with maximum biomass in the stand equal to 130 Mg/ha. The allocation factor for foliage, branches and root production were copied from existing CO2FIX runs for comparable species. The turnover (annual rate of mortality of the biomass component) was evalutated in 0.3 for foliage, 0.06 for branches and 0.05 for roots. The soil organic matter compartment consists of dead wood, litter layers and stable humus in the soil. On the basis of this analysis, a total carbon stock ranging from 17 to 70 Mg/ha and an average atmospheric carbon sequestration approximately equal to 4.40 MgC/ha/yr were estimated.

In the study area, the orchard areas are generally orange groves with rare presence of apricot trees. For the purpose of CO_2 calculation, the orchard area was compared to coppice forest with a rotation of 20 years and periodical removal of organic matter through agronomic practices like pruning, comparable to a turnover (annual rate of mortality of the biomass component) of 0.3 for foliage, 0.07 for branches and 0.04 for roots. In an orchard, carbon balance depends on the intrinsic structural and morphological characteristics of each species and it is also influenced by population density, rearing system, and especially on the canopy and aboveground and underground woody organisms. Moreover, in the case of young plantation, canopy has to provide for a relatively small amount of branches and roots and, consequently, primary production is net and the surplus of organic matter increases every year up to maturity when dry matter increases over time and subsequently tends to zero (Xiloyannis et al., 2005). Based on such a principle, it is possible to estimate the average yearly sequestration of atmospheric carbon as being equal to 7.25 MgC/ha/yr for the orchards, to 2.75 MgC/ha/yr for shrubland and to 3.6 MgC/ha/yr for arable land.

On the other hand, urban areas represent a source of CO_2 emission from both municipal and industrial combustion; a yearly amount of 15.0 MgC/ha/yr of CO_2 release into the atmosphere was therefore estimated on the basis of a report on the environmental state of Basilicata Region (AA.VV., 2000).

All the above-mentioned values of average atmospheric carbon sequestration were adopted for each one of the four time periods (Years 1859, 1873, 1957 and 1997).

The data resulting from the implementation of the GIS gave the values reported in Table 1 expressed in terms of areas occupied by the different vegetation typologies and, applying their respective CO_2 sequestration rates, in terms of absolute values of annual sequestration of CO_2. The balance of CO_2 does not include the effects of the agricoltural machinery, supplies and transportation on CO_2: in woodland these factors are almost absent, while in case of orchard and arable land they depend strongly by crop techniques, and in some cases are negligible.

Table 1. Annual balance of CO_2 in the study area.

Year	Woodland		Orchard		Arable land		Urban		Total	
	Area [Ha]	Annual balance of CO_2 [MgC/ha/yr]	Area [Ha]	Annual balance of CO_2 [MgC/ha/yr]	Area [Ha]	Annual balance of CO_2 [MgC/ha/yr]	Area [Ha]	Annual balance of CO_2 [MgC/ha/yr]	Area [Ha]	Annual balance of CO_2 [MgC/ha/yr]
1859	5638	24807	890	6452	6440	23184	17	-255	12985	54188
1873	5691	25040	1080	7830	6153	22150	79	-1185	13003	53835
1957	2555	11242	1731	12549	8270	29772	438	-6570	12994	46993
1997	2474	10885	1339	9707	8582	30895	598	-8970	12993	42517

Examining Table 1, in the investigated scheme it is clear that the greatest changes in land use occurred after the establishment of large orchard grown areas and mainly consisting of orange tree plantations. The percentage rise in arable land was equally considerable with increases as high as 30-40 %, to the detriment of woodland and shrubland. Olive groove reached its peak in the late 19th century until after the First World War, since it was one of the early livelihood sources of farm families at that time. As a result of the different performance in terms of CO_2 fixation and relative to the investigated study area, all these land changes caused progressive decrease in carbon dioxide sequestered by biotic agents embedded in the soil. We can argue that the sequestration of land carbon in Year 1859 was higher than in more recent periods, and that during time the land carbon balance worsened: the cultivation conversion occured during time caused a constant loss of CO_2 fixation value (Mohren, G.M.J. et al., 1999), while heavy emission of greenhouse effect gas in the atmosphere by urban settlements were at the same time increasingly growing.

This pattern could be considered a typical situation also for many other areas located in Southern Italy or even elsewhere, and this approach seems that could be considered as a useful tool for the planning and management of rural landscape and environment: the study case showed that a sound planning in agricultural activities could significantly contrast the release in the atmosphere of CO_2 deriving from the diffusion of anthropic activities.

4. CONCLUSIONS

Extra-urban land planning must pursuit, as a main goal, environmental sustainability. A sustainable rural development, at least in European countries, has been perceived by social awareness and sensibility and is constantly been considered by new laws and regulations whose attempt is the natural resources protection.

In this scenario an accurate analysis of performing variations and a global monitoring of ecosystems seem necessary in order to propose environment protection politics, crucial element for a sound planning of extra-urban land and for a sustainable growth of the civilized World.

This analysis has shown how the results of the applied agronomic practises, in terms of CO_2 fixation, would be able to contrast heavy emissions of greenhouse effect gases in the atmosphere by urban settlements, demonstrating how a correct rural-site management could efficiently balance environmental pollution determined by the human development. The use of this approach for other environmental factors, such as water, soil etc., would lead to a more comprehensive understanding of landscape development dynamics through its principal environmental components, contributing to the proposal of production oriented politics that achieve compensation of natural balance alterations, and a real application of the concept of sustainable development.

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