INVENTORY OF TREE HEDGEROWS IN AN ITALIAN AGROFORESTRY LANDSCAPE BY REMOTE SENSING AND GIS-BASED METHODS

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Abstract

Agroforestry denotes land use systems combining trees with agricultural crops and/or livestock. The woody component, consisting of scattered or linear trees, can be located either inside the field or along the field boundaries as tree hedgerows. Such land use approach aims to optimize both ecological interactions and economical revenue and offers a number of ecosystem services, environmental benefits, occurring over a range of spatial and temporal scales. The resulting complexity of the landscape patterns can be detected combining Remote Sensing, GIS spatial analysis and field surveying in order to understand the interactions between woody and crop components, and for assessing, mapping and quantifying the socio-economic values of the agroforestry systems services. In this study, we aimed to map and estimate the extent of Tree Hedge Rows (THR) in an Italian agroforestry landscape and to assess the influence of THRs on the yield of crops at the plot-farm scale.

Keywords: spatial analysis; ecosystem services; Sentinel-2; NDVI; hemispherical canopy photos

Introduction

Agroforestry systems have traditionally been used in different places of Europe employing several types of practices at different levels of intensity (Mosquera-Losada et al. 2009). Agroforestry denotes a land use system in which the woody component (trees/shrubs) is cultivated on the same land unit as agricultural crops and/or animals. Agroforestry is increasingly perceived as providing ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape (Jose 2009). These services and benefits occur over a range of spatial and temporal scales: from the farm/local scale, through the landscape/regional scale up to the global scale (Izac 2003). Thus, the use of GIS technology and the spatial analysis is of major importance for understanding the interactions between biological and physical components and for assessing, mapping and quantifying the socio-economic values of the agroforestry systems services (Mishra and Agarwal 2015).

uring the 20th century due to agricultural intensification, the European Common Agricultural Policy for Rural Development 2014-2020 is currently supporting the establishment of agroforestry systems, because of their high ecological and socio-economic value. Most of the Italian countryside is naturally suited for agroforestry due to its environmental setting, geomorphological and climatic conditions, as well as for historical and cultural traditions. This study focuses on an agroforestry landscape located in the *Umbria* region in central Italy, with a special focus on "marginal agroforestry systems". In these systems, trees grow only at the edges of fields, within hedgerows, or on scarps and drainage ditches between fields, and have positive effects on soil erosion, wind protection and ecological as well as aesthetic upgrading of landscapes.

The aims of this work are: i) to map and estimate the extent of Tree Hedge Rows in the study area; ii) to assess the influence of THRs on the yield of crops at the plot scale.

Materials and methods

The study area is located within the municipality of *Castel Giorgio* (TR) in the *Umbria* Region, on the *Vulsini* volcanic hills northeast of *Bolsena* Lake (central Italy). The average elevation is 500 m, average air temperature is 13°C and average annual precipitation is 706 mm. We investigated the farmland owned by the *Faina* Museum Foundation (FMF). This farm manages more than 600 ha of arable land and woods. The main land uses include herbaceous crops (wheat, barley, sunflower, rapeseed, grain legumes, clover and alfalfa), tree hedgerows, shelterbelts and forest belts.

In this study, we combined different methodologies comprising remote sensing, photo interpretation, GIS analyses and field surveys to analyze the spatial distribution of the land cover/use of the area and the spatial interaction between the crop and tree components of the system.

We digitized the land property map from the cadastral map and aerial imagery (Data source: AGEA 2011), then we classified the land use of the study area through photo interpretation.

Basing on the land use classification, we identified two experimental sites (ES) (Figure 1b) to study the continuous or discontinuous THRs along the margins of the cultivated fields. Each site contains a plot of annual crops and a THR along at least one of the borders consisting of oaks (mainly *Quercus pubescens* and *Quercus cerris).*

Basing on the aerial photos (2011) and the Google Earth satellite images (2017), we identified two test areas (TA) of 100 ha (1km x 1km squares) each one containing one of the two ES (Figure 1a).

We tested the following procedure for the GIS inventory of THR over the two TAs:

1) GPS field survey of THRs in the ES; measurement of height (H), diameter at breast height (DBH) for each tree of the THRs; measurement of the distance between adjacent individuals;

2) recognition of THRs by photo interpretation of aerial and satellite images;

3) estimation of the incidence of THRs per hectare of cultivated area over the two TAs and over the whole farmland.

The recognition of THRs was based on photo interpretation of high-resolution multispectral Sentinel-2 (HRS2) images. In particular, evaluating the NDVI (Normalized Difference Vegetation Index, NDVI = (NIR-VIS) / (NIR + VIS)), we could easily discriminate between areas with dense vegetation coverage (0.6 <NDVI <0.9, tree covered areas) and areas with low/zero vegetation cover (cultivated areas or bare soil areas). Starting from the HRS2 images and using the raster algebra of the Sentinel Application Platform (SNAP), the NDVI was derived and the corresponding raster file was generated for the TAs. The 10m spatial resolution of HRS2 scenes, allowed the identification of narrow and long polygons corresponding to the crowns of the tree rows. THRs were identified in the two TAs (Figure 1a) and appropriately validated by comparison with the GPS surveys. This procedure was then applied throughout the study area to estimate the incidence of THRs per hectare.

We collected samples for yield estimations of crops adjacent to the THR, along four transects (25m long) for each ES, two of which being under the influence of tree crowns, at increasing distances from the tree rows. During the summer 2017, we collected five wheat samples from each transect, for 20 plots (each one of 1 m^2) per site (Figure 1b). To assess the shading effect of trees on crops, we used the hemispherical canopy photography technique: 24 hemispherical photos were taken along the four transects of each ES. Using the Gap Light Analyzer software (Frazer et al. 1999), we estimated the light transmission during the growing season in relation to the canopy structure of the tree rows, indirectly evaluating the effect of the trees' shade on crops.

Figure 1: a) Detection of vegetated area and of tree hedgerows in the two test areas. b) Experimental sites with tree codes (Tx) along field margin and sampling transects (orange squares).

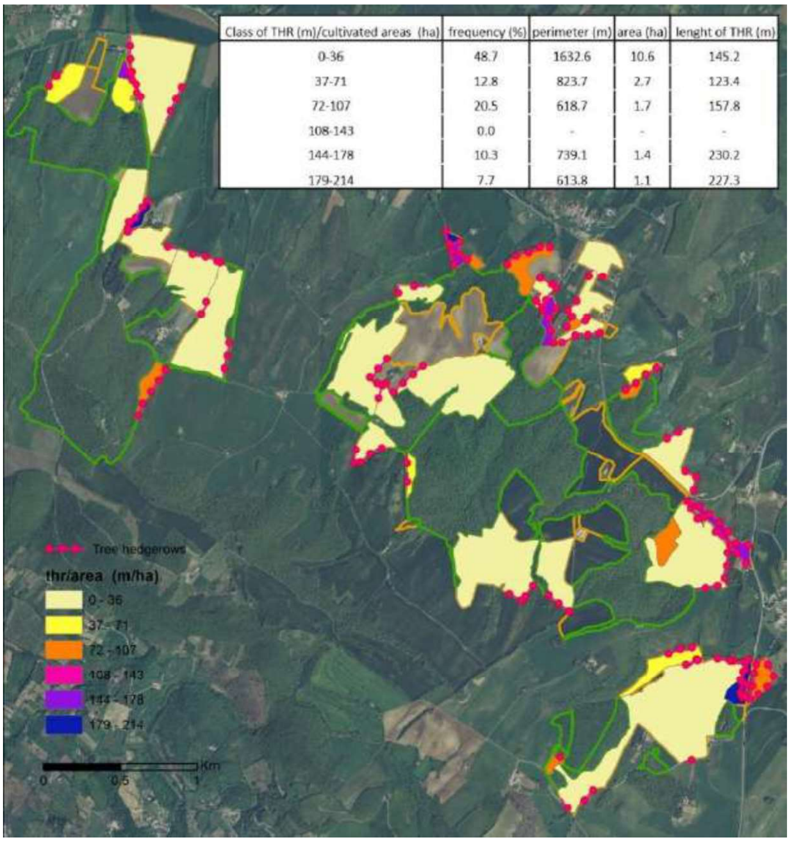
Results

We classified about 330ha of arable land out of 628ha of the total surface managed by the farm. Woodlands cover the remaining 298ha of surface with prevalence of mixed broad-leaved woods.

The first ES (Figure 1b) has a surface of 17.8 ha of arable land, and a perimeter of 1992 m. Fifteen oak trees make up a THR oriented N/NE–S/SW, with an average H of 14 m, an average DBH of 50 cm and an average distance between individuals of about 36 m. The second ES (Figure 1b) covers an area of 1.98 ha of arable land, with a perimeter of 791 m. The THR of site 2 is oriented E/NE–W/SW and consists of nine oak trees having an H of 20 m, a DBH of 62 cm and an average distance between individuals of about 15 m.

Through photo interpretation of HRS2 images, we derived polygonal features classified according to the NDVI values. Among these polygons, we selected those with NDVI values between 0.6 and 0.9, corresponding to areas with high density of vegetation coverage (Figure 1a). We estimated 827 m of THR over 5235 m of perimeter of cultivated plots over the TA1. 14% of the margins' length are made up by THRs. For each hectare of cultivated land in TA1, an average of 56m of THRs was found. We estimated that, in TA2, THRs were 16% of the margins length, corresponding to 1273 m out of 9076 m of total perimeter. For each hectare of cultivated land in TA2, an average of 58 m of THRs was found.

A total length of 6241 m of THRs was identified throughout the study area, with respect to a total perimeter of 44885 m of the cultivated plots. These results indicate that THRs correspond to 14% of the total perimeter of the cultivated areas and that for each hectare of cultivated land, there are, on average, 67 m of linear tree rows, along the corresponding boundary (Figure 2). Moreover, the THRs are located mainly along the margins of the cultivations oriented in the direction N-NE/S-SW and NE/SW. The existing THRs along the field boundaries have also an important ecological function, acting as ecological corridors to link fragmented forest patches, thus enhancing connectivity at the landscape level.



Class of THR (m)/cultivated areas (ha)	frequency (%)	perimeter (m)	area (ha)	lenght of THR (m)
0-36	48.7	1632.6	10.6	145.2
37-71	12.8	823.7	2.7	123.4
72-107	20.5	618.7	1.7	157.8
108-143	0.0	-	-	-
144-178	10.3	739.1	1.4	230.2
179-214	7.7	613.8	1.1	227.3

Figure 2: THR incidence per hectare of cultivated land in the study area.

Wheat yields were estimated for ES1 and ES2. The results show average wheat yields of 2 Mg/ha and of 3.4 Mg/ha for ES1 and ES2, respectively (Figure **3**). On ES1, average yields estimated for the plots under tree influence are 1.5±0.2 Mg/ha, while the plots without the influence of trees produced 2.4±0.6 Mg/ha. On site 2, the yields on plots under tree influence are 3.6±0.6 Mg/ha while those on plots without tree influence are 3.1± 0.5 Mg/ha. Crop yield increased with the distance from THR at ES2, where the oak trees' shading affects the crop production. There is no significant relationship between wheat yield and distance from THR at ES1, where oak trees along THR are wider spaced than those of THR at ES2. Tree shading does not affect crop yield at ES1 (Figure 3).

Discussion

Combining methodologies such as remote sensing, photo interpretation, GIS analysis, field survey and hemispherical canopy photos, we quantified the extent of THRs and assessed the effect of THRs on the yield of annual crops at the farm scale in an Italian agroforestry landscape.

In the study area, the 14% of the total fields' perimeter is covered by THRs dominated by oaks, mostly adult trees with a high aesthetic value. The linear density of THRs is variable, amounting to an average value of 67 meters of THR per surrounded hectare. The effects of the trees on the yield of wheat as an adjacent crop were inconclusive, but they indicate that these effects were at least not entirely negative. To assess possible effects of THRs on crops in more detail, further studies with increased numbers of transects should be performed.

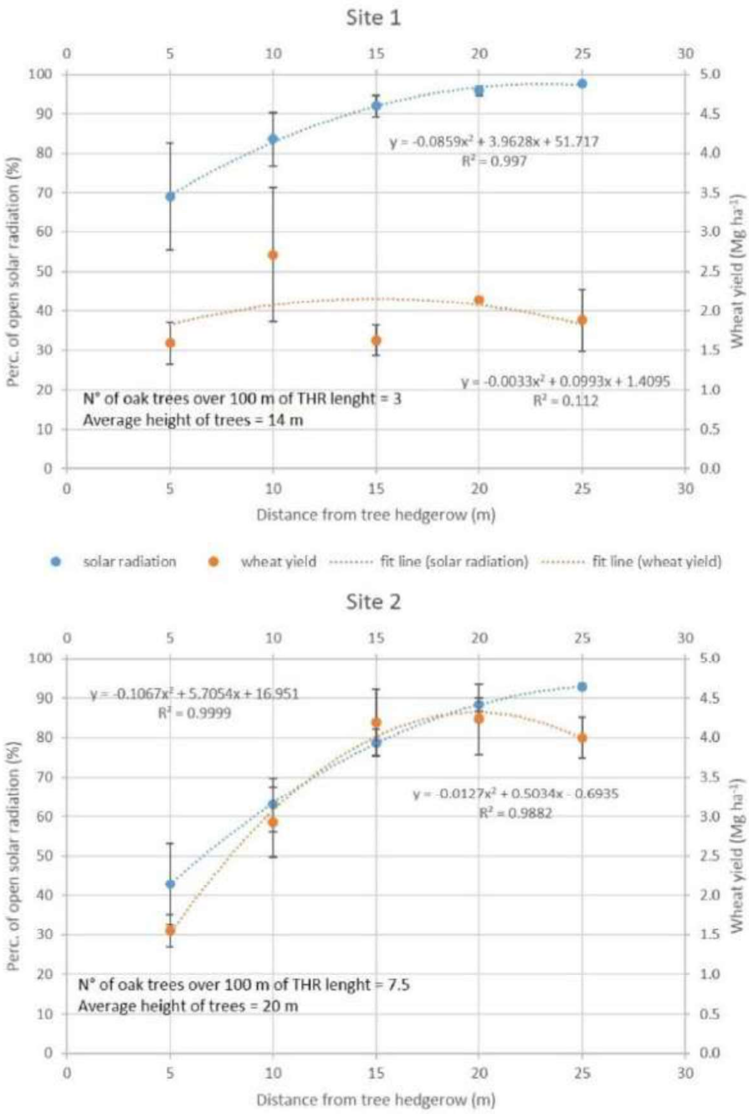


Figure 3: Crop yield and percentage of open solar radiation for Site 1 and Site 2 along sampling transects.

Acknowledgements

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