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Volume 3

Earth Observation: current challenges and opportunities for environmental monitoring

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Earth Observation: current challenges and opportunities for environmental monitoring

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A GIS-BASED SPATIAL ANALYSIS FOR AGRICULTURAL PRUNING WASTE MANAGEMENT IN THE CIRCULAR ECONOMY PERSPECTIVE

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ABSTRACT:

Agricultural activities produce huge amounts of agro-residues usable as resources in the optic of the circular economy. Among these, those from pruning olive groves, vineyards and fruit plantations can be particularly relevant. Biomass residues from agricultural pruning represent a typical case of agro-residues yearly produced and hardly ever used. Mismanagement practices are very common and cause serious human and environmental health issues. It is necessary to overcome technical and logistic problems that farmers experience by developing a proper management system. This study aims to contribute to the design of an effective collection system for agricultural pruning biomass. Data from earth observations are precious to achieve this objective. In this study, the GIS tools were used to work on earth observation products and perform a territorial analysis. The attention was focused on an area particularly suited to agriculture in the Apulia Region (Italy). Land use maps derived from orthophotos were used to identify areas of pruning waste production. By defining and applying pruning indices for each crop, pruning residues were quantified and localized. Based on this, the suitable position of the collection centres was defined. The obtained maps can be easily used and continuously updated with remote sensing imagery. The study highlights the power of the methodology implying land use maps based on orthophotos and in turn on earth observations and GIS tools for this purpose. The results represent a first step towards the improvement of the agro-residues management system and can help policymakers and stakeholders to promote more sustainable actions.

1. INTRODUCTION

Over the last 20 years, the most spread economic model was the linear based on "take-make-use-dispose". This model unsustainably exploited huge quantities of readily available raw materials and non-renewable energy sources. As consequences, the linear model has led to rapid depletion of natural resources, progressive loss of biodiversity with dramatic impacts to the environmental system and pressures from climate change (European Commission, 2012).
After the energy sector (68.1%), agriculture is the second largest production sector with the highest environmental impacts in terms of greenhouse gases emissions (19.9%) (Lamb et al., 2021), and the first sector for environmental impacts due to land use (90%) (Kusumastuti et al., 2016). Furthermore, the world agricultural production system is responsible for a huge amount of solid waste (Kamusoko et al., 2021). Agricultural waste can be divided into two categories: inorganic and organic waste. The former includes plastic, chemical containers, and other materials used in farming activities. Agricultural organic waste is represented by biomass; it is estimated that 60% of the world's agricultural biomass comes from plant production (Sommer et al., 2015).
Biomass is the biodegradable fraction of product, industrial and municipal waste, and any residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, such as fisheries and aquaculture (European Parliament and Council, 2009)
These agro-residues represent a resource as they are a stored source of solar energy and fixed in the form of organic carbon (McKendry, 2002). This intrinsic value can be used prospectively in the circular economy and bioeconomy policy. The circular economy aims at making production processes sustainable by reducing the influx of resources and the production of waste, minimizing environmental impact.
In optics based on "reuse, recycle or biodegradation", biomass can be efficiently used as renewable energy source and as secondary raw material in other production processes (FAO, 1997). Today, energy obtained from biomass, through various physical and chemical processes, is considerable; in the world biomass is the fourth natural source of energy, after coal, oil, and natural gas (Tong, 2019).
Biomass is not only used as a source of energy to produce biofuel. Recent research is increasingly investigating possibilities to convert biomass waste in value-added products for diverse applications, such as construction materials, medicine, and food packaging (Zhou and Wang, 2020). Through different treatments and production methods, biomass waste is used to produce construction materials with good mechanical and thermo-hygrometric properties (Barbieri et al., 2019; Liuzzi et al., 2020; Ryłko-Polak et al., 2022), good performing materials to be used in agriculture (Babu et al., 2022; Vox et al., 2005), biosorbents (Anastopoulos et al., 2019; Nampeera et al., 2022), and many other products used for electronic components, coatings for packaging, in paper industry and in other industrial applications (Babu et al., 2022; Tripathi et al., 2019; Zhou and Wang, 2020).
In the Mediterranean basin, most of the agro-residues are represented by pruning waste from permanent crops typical of the local agrosystem, such as vineyards, olive groves, and almond trees (García-Galindo et al., 2016).
Over 13 million tons of pruning waste are produced in Europe but represent an unexploited resource. In fact, a large fraction of these agro-residues is left in the field to decompose naturally, or disposed of in dump, or in the worst cases burned. It is estimated that 25% of the produced agricultural waste is burned in the open field (Venkatramanan et al., 2021). Wrong management of agro-waste causes damage to human and environmental health, threatening food and energy security. The poor management of waste is due to a series of factors such as low awareness of the

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intrinsic value of the product, high costs for collection, logistical barriers due to the geographical dispersion of waste, seasonality, inhomogeneity of production between crops and production realities, and lack of localized collection centres on the territory (Velázquez-Martí et al., 2011).

Knowing the amount of residual biomass for each type of crop and its location in the territory allows the design and planning of a pruning residues management system. The matter is complex and data from earth observations are the key to start addressing it. Earth observation products and their application, involving the use of geographic information systems (GISs) tools are crucial to the study purpose and can lead to the development of a georeferenced database. GISs allow managing large amount of data, georeferencing, storing, analysing, and visualizing it (Hachem et al., 2023). Therefore, a GIS, implemented with earth observation data, can be very precious to perform territorial analyses, identify biomass production sites and design a management system. The resulting database can be continuously updated through the updating of land use base maps and remote sensing imagery (Lanorte et al., 2017).

The aim of this study is to apply the methodology based on earth observation products, GIS, and specific residues indices to quantify and localize biomass production from pruning activity in an agricultural area, as a first step towards the design of an appropriate management system. Moreover, suitable positions for biomass collection centres are identified. The study could be further developed by including other parameters relevant to the objective and with the support of remote imagery. The obtained georeferenced database can be a useful tool to improve the agricultural waste management system. The produced maps, easily updatable and manageable, can be used by planners and policymakers to promote sustainable approaches for the development of rural territory and landscape.

2. MATERIALS AND METHODS

The study focuses on an area particularly suited to agriculture in the Apulia Region (Southern Italy). The area has mean coordinates of latitude 40.962834° and longitude 17.207541° and the elevation ranges from 0 m asl to 408 m asl. It measures about 400 km^2 and consists of four municipalities. The four municipalities, Monopoli, Polignano a Mare, Conversano and Mola di Bari, are grouped since they represent a single optimal administrative collection area in the Province of Bari. Given the strong vocation for agriculture, the production of agro-residues in this area is abundant.

The attention was focused on the biomass waste coming from pruning activities. A GIS database was obtained and pruning residues were georeferenced on the territory.

The methodology implied the use of land use map files freely available thanks to the territorial information system of the Apulia Region (http://www.sit.puglia.it). Apulian land use map, available at scale 1:5000, derives from colour orthophotos with 0.50 m spatial resolution. These are digital true colour aerial data recorded by a digital mapping camera. Land use map was useful to identify the cultivated area and the crops distribution in the study area.

The free software QGIS (https://www.qgis.org) was used to perform the territorial analysis, starting from the land use map. By observing the crops distribution on the land use map and by calculating the area per feature through the specific QGIS geometry tool, three main crops emerged: olive groves (35%), orchards (20%) and vineyards (11%). Olive groves are mainly cultivated in the southern part of the study area, orchards essentially in the centre and vineyards mostly in the northern part (Figure 1).

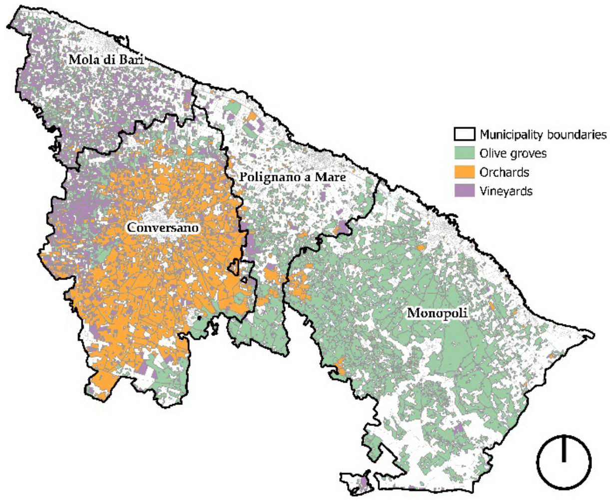

Figure 1. Land use map of the study area identifying the three most widespread crops: olive groves, orchards, and vineyards.

The attention was then focused on the identified predominant crops. To quantify and localize the pruning residues from these cultivations, pruning indices were defined and calculated per crop. Indices were derived based on data available in the literature concerning: the crops distribution on the cultivated area and the related quantity of pruning residues per crop, which strongly depends on the specific pruning methods in the area (ISPRA, 2010). Specifically, data in Table 1, deriving from a report of the Italian Institute for Environmental Protection and Research (ISPRA, 2010) were used for indices calculation. This data, resulting from a detailed estimation approach, was considered reliable for the purpose of the present study. The estimates are mainly based on three parameters: statistical data on the total production per each crop (retrieved from the Italian National Institute of Statistics, ISTAT, database); ratio of main by-product to product; fraction or percentage of the waste or by-product already recycled or reused. The combination of these three parameters led to the provincial estimates of the agro-residues.

Crop type	**Surface [ha]**	**Residues [kt/yr of dry matter]**
Olive groves	129450	115.4
Vineyards	37595	116.62
Almond trees	20850	27.08
Cherry trees	16700	1.71
Peach trees	830	2.35
Apple trees	100	0.14
Apricot trees	40	0.04
Kiwi trees	20	0.03
Citrus	14	0.05
Pear trees	12	0.01
Plum trees	8	0.01

Table 1. Distribution of the agricultural surface per crop type in the province of Bari and related pruning residues (ISPRA, 2010).

The pruning residues indices (*PRIs*) to be applied in the study area were calculated based on Table 1 as:

$$PRI_{crop} = R_{crop}/S_{crop} \quad (1)$$

where PRI_{crop} = pruning residues index per crop [t ha^{-1} yr^{-1}]
R_{crop} = amount of pruning residues per crop [t yr^{-1} of dry matter]
S_{crop} = cultivated surface per crop [ha]

PRIs were obtained for each of the three crops. Concerning orchards, the weighted mean was considered in order to proper take into account all the species cultivated in the area as well as their spread.
The land use map with the selected crops was then integrated by adding the new field of the PRIs in the attribute table, reporting the specific index per crop. The amount of pruning residues per crop (PR_{crop}, t yr^{-1}) was obtained based on PRI_{crop} and on the area of each feature (S_i, ha) as:

$$PR_{crop} = PRI_{crop} \cdot S_i \qquad (2)$$

The pruning waste was quantified and localized on the map of the area.
Suitable positions of collection centres were then assessed, also considering different management approaches. To this end, the coordinates of the features centroids weighted by the specific PRI_{crop} were evaluated as well as the mean coordinates of the centroids distinguished per crop, per municipality and for the whole area. This was made possible by using the "mean coordinates" vector analysis tool available in QGIS. This tool calculates a point layer (collection centres location) with the centre of mass of the geometries contained in an input layer (centroids of features polygons obtained through the "centroids" geometry tool). Moreover, an attribute of the layer attribute table can be specified as a weight to be applied to each element when calculating the centre of mass. In this case, the weighting factor was the amount of pruning residues calculated per each feature.

3. RESULTS AND DISCUSSION

The application of the PRIs on the land use map resulted in the spatial distribution of pruning waste, which is actually a by-product, in the study area (Figure 2). The highest production of biomass from pruning is localized in the municipality of Conversano (13115.6 t yr^{-1}) followed by Monopoli (7709.6 t yr^{-1}), Mola di Bari (5628.3 t yr^{-1}) and Polignano a Mare (3330.7 t yr^{-1}).

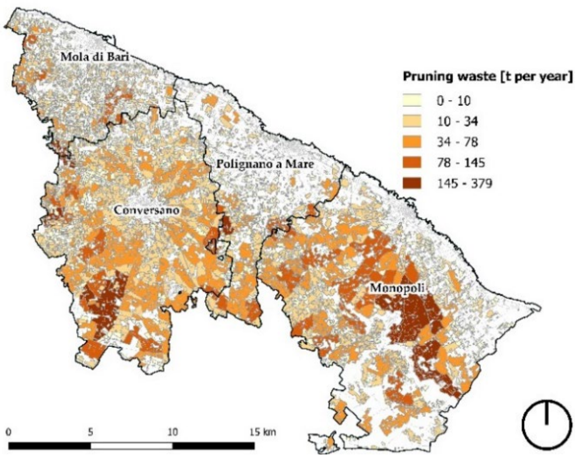

Figure 2. Distribution of the pruning waste from olive groves, orchards, and vineyards in the study area.

Concerning the management system for these pruning residues, it is important to identify the most suitable position of collection centres. In this regard, different approaches were investigated. It is possible to define different collection centres, distinguished per crop type and per municipality. This would lead to three collection centres for each municipality (Figure 3). According to the most widespread cultivations in each of the municipalities, the dimensions of the three collection centres could be set. As shown in Figure 3, the biggest collection centre should be the one for olive groves residues in Monopoli, where this crop is widely cultivated. This centre should be almost barycentrically located. The biggest centres for orchards and vineyards residues should be in Conversano, coherently with the land use map. The one for vineyards in a decentralised position towards the border with Mola di Bari, while the one for orchards more central.

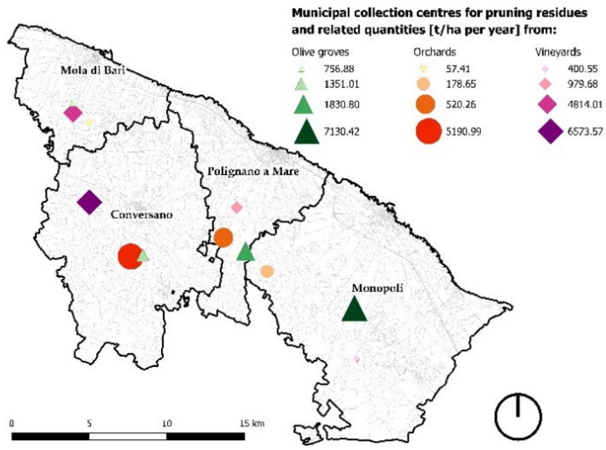

Figure 3. Suitable locations of municipal collection centres and related quantities of pruning waste per crop type in the study area.

This system based on different municipal centres could be optimized by considering the possibility to have three intermunicipal collection centres in total, one for each crop residues (Figure 4). As expected, the collection centres should be placed in Monopoli and Conversano. The intermunicipal centre for olive groves pruning residues should be in Monopoli, but moved towards the border with Polignano a Mare, to serve the whole area. The ones for orchards and vineyards should be placed in Conversano in barycentric positions considering the localization of these crops in the area. The biggest collection centre should be for vineyards pruning residues, followed by the ones for olive groves and orchards (Figure 5).

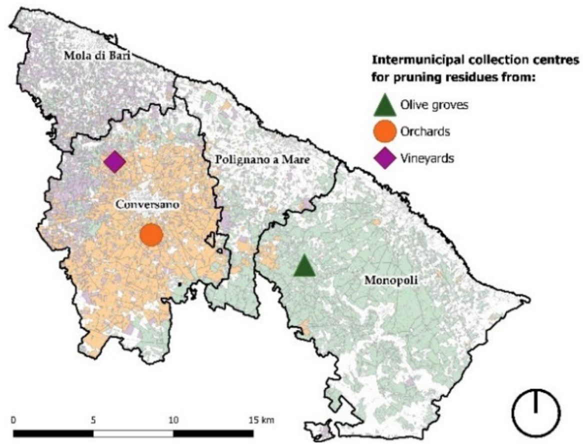

Figure 4. Suitable locations of intermunicipal collection centres for pruning waste per crop type in the study area.

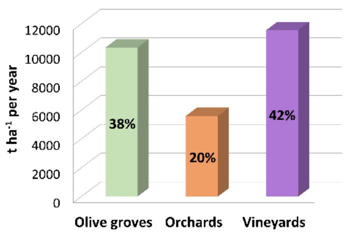

Figure 5. Amount of pruning waste per crop type and percentage distribution in the study area.

A further optimization could be to set a unique intermunicipal collection centre for all the crops (Figure 6). This should be in Monopoli but very close to the border with Polignano a Mare and here would converge the whole amount of biomass from pruning produced in the area.

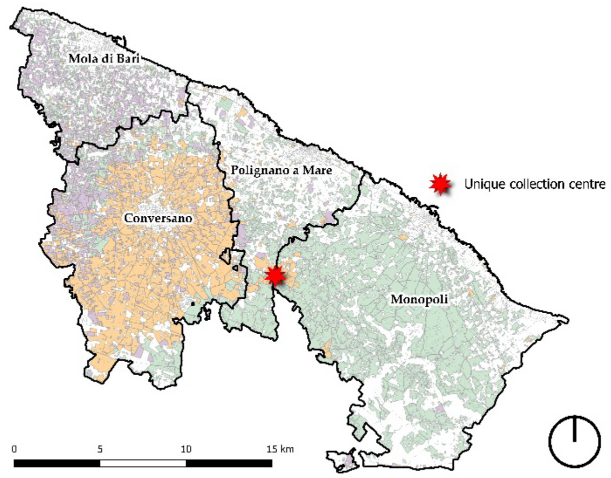

Figure 6. Suitable location of an intermunicipal collection centre for pruning waste in the study area.

Suitable locations of collection centres in the different analysed scenarios were mathematically obtained as weighted mean coordinates. In this very first study other parameters were not taken into account. The methodology proposed and in turn the results could be enhanced by considering other relevant aspects, specific of this issue, in the optic of designing an efficient biomass management system. It should be considered that pruning residues production is seasonally based and occurs in very limited time spans. The production of such by-product is very spotted on the territory, consequently there are relevant mechanization and transportation needs to be addressed. Finally, the management system should aim not only to the environmental sustainability, but it should also be technically and economically sustainable. Thus, it is crucial to have detailed and updated information on the pruning residues density and distribution on the territory. To include all these other aspects, the process of defining the most suitable location of collection centres and designing the whole management system should include the implementation of other data. It could be useful to implement data on environmental constraints, context favourable or unfavourable variables, the altimetry of the territory and the availability of infrastructures and transport facilities. Updated remote sensing data is fundamental to perform analyses and guide the whole process, from the actual quantification and distribution of the biomass production to the design of the management system, and for a continuous monitoring.

4. CONCLUSIONS

Agricultural activities are characterized by the production of considerable quantities of solid waste, some of which are actually by-products as in the case of the agro-residues deriving from pruning. These biomass residues are particularly precious and could become an important resource if considered and managed as such and not as a useless waste. To support the sustainable management of this biomass, a proper management system is mandatory. In this regard, earth observation products and their implementation in GIS environment can provide a fundamental support.

The study focuses on the production of agro-residues from pruning of olive groves, orchards and vineyards in four municipalities of Apulia Region. Thanks to land use map, derived from orthophotos and in turn from aerial photogrammetry, and by using GIS tools, the territorial analysis was performed. This allowed the quantification and localization of the biomass from pruning and the investigation of suitable positions of collection centres. The land use map was updated including information on pruning residues, resulting in a georeferenced database. Such database can be easily recreated and updated by using remote sensing imagery as well.

This study suggests that the proposed methodology, based on the use of earth observation data, and the obtained results could be precious tools for planners and policymakers for setting up a proper management system of this resource. Further studies aiming at designing the biomass management system should overcome the limitations of this first stage research by including other relevant parameters such as the presence of environmental constraints and infrastructures availability and accessibility. The use of remote sensing imagery can also be useful in the improvement phase of the study and for the monitoring stage.

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