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Revitalizing Marginal Areas of Basilicata (Southern Italy) with Saffron: A Strategy Approach Mixing Alternative Cultivation System and Land Suitability Analysis

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Abstract: The abandonment of farmland in Europe is a significant issue due to its environmental, socio-economic, and landscape consequences. This tendency mainly impacts marginal and inner areas, located far from large urban districts, because of biophysical and/or socio-economic factors. Although European and national regulations try to turn the fragility of these territories into an opportunity for sustainable development, many of these areas, especially in southern Europe, continue to suffer socio-economic disparities. For this reason, it is necessary to consider regional and district-wide initiatives that can economically revitalize marginal areas while safeguarding their natural capital. Alternative cropping systems, capable of optimizing the quality of some food crops, can play an essential role in the economic development of populations living in marginal areas. These areas, represented by inland zones often abandoned due to the difficulty of applying mechanized agriculture, can represent an opportunity to rediscover sustainable and profitable practices. Among the high-value crops, saffron (*Crocus sativus* L.), "red gold" and "king of spices", stands out for its potential. Indeed, thanks to the use of tuff tubs, a more eco-sustainable choice compared to the plastic pots already mentioned in the literature, it is possible to improve the quality of this spice. Furthermore, *Crocus sativus* L. not only lends itself to multiple uses but also represents a valid opportunity to supplement agricultural income. This is made possible by its high profitability and beneficial properties for human health, offering a way to diversify agricultural production with positive economic and social impacts. It is known that the saffron market in Italy suffers from competition from developing countries (Iran, Morocco, India) capable of producing saffron at lower costs than European countries, thanks to the lower cost of labor. Therefore, this study seeks to identify marginal areas that can be recovered and valorized through an eco-sustainable cultivation system with the potential to enhance the quality of this spice, making it unique and resilient to competition. Specifically, this paper is organized on a dual scale of investigation: (a) at the local level to demonstrate the economic-ecological feasibility of saffron cultivation through the adoption of an alternative farming technique on an experimental site located in Tricarico (Basilicata—Southern Italy, 40°37′ N, 16°09′ E; 472 m. a.s.l.) that, although fertile, is not suitable for mechanized cropping systems; (b) at the regional level through a

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spatially explicit land suitability analysis to indicate the possible location where to export saffron cultivation. The final map, obtained by combining geo-environmental variables, can be considered a precious tool to support policymakers and farmers to foster a broad agricultural strategy founded on new crop management systems. The adoption of this alternative agroecological system could optimize the use of land resources in the perspective of increasing crop productivity and profitability in marginal agricultural areas.

Keywords: inner areas; saffron; land abandonment; land suitability; economic revitalization; cropping systems; Mediterranean areas

1. Introduction

The abandonment of agricultural land is the result of the effect of different drivers encompassing natural, socio-economic, and institutional factors [1]. Among the natural factors, the main ones are represented by topography, climate, and soil fertility [2,3]. For example, rugged mountainous and hilly areas with steep slopes are those with a greater probability of abandonment, unlike flat areas [4]. Among the socio-economic and institutional factors, depopulation, increase in labor costs, and lack of suitable policies meeting the needs of farmers are those most implicated in land abandonment [5–7].

The reduction or interruption of agricultural activities inevitably determines changes in the quality and quantity of agricultural land, with enormous repercussions on the environment, economy, and society [8]. Liu et al. (2020) [9] highlight the negative effects on soil features due to the abandonment of agricultural lands, such as increased erosion rates and adverse changes in microbial communities as well as the overall degradation of agricultural landscapes.

These issues affect mainly marginal inner areas placed far from major metropolitan/urban areas and thus forced to exist on the edge of development trajectories. These areas suffer from an infrastructural and service gap that reverberates on economic assets causing depopulation and regional development imbalances [10–13]. However, they can represent, at the same time, a potential opportunity for environmental and productive resources that are largely underused and which should be exploited within a unified policy for development and cohesion [14].

Recent European policies (EU's Green Deal, Farm to Fork Strategy, Common Agricultural Policy 2023–2027) are focusing on the revitalization of inner areas. They aim to balance economic development, socio-ecological sustainability, and habitat preservation. The goal is to avoid poverty and depopulation from a social perspective and to prevent increased pollution levels and ecosystem alterations from an environmental standpoint. The issue of marginal areas in Europe fits into a broader theoretical framework that has gained significant attention among scientists and policymakers, particularly in the run-up to the release of the EU Green Deal and the Farm to Fork Strategy. The debate has primarily focused on how to establish sustainable food systems that ensure environmentally friendly agricultural production through proper land use [15–18] while also addressing issues related to the progressive degradation and potential restoration of vast areas.

In this context—shaped by global phenomena such as climate change and biodiversity loss, as well as highly localized socio-economic factors (e.g., markets, depopulation)—the discussion has been further intensified by debates on how to align the Common Agricultural Policy (CAP) with the Green Deal [19]. Within these discussions, marginal areas have been considered a potential solution.

Specifically, Italy has established an ad hoc policy instrument, the so-called National Strategy for Inner Areas (SNAI), to enhance territorial cohesion. It functions as a policy laboratory (see https://opencoesione.gov.it/en/SNAI/, last accessed on 10 April 2025), experimenting with measures to counteract the decline affecting the inner regions of Italy [20,21]. To address marginalization and depopulation, SNAI outlines two main action plans. The first aims to strengthen essential public services and create the necessary conditions for socio-economic growth. The second focuses on promoting local development projects to revitalize these areas. Additionally, the SNAI emphasizes the importance of long-term structural measures to optimize local resources [22]. Effective development policies must be based on a comprehensive understanding of heritage and available resources, followed by agricultural planning to safeguard the land and enhance local supply chains for food, non-food products, and biomass for energy [23]. In fact, at the regional/local level, public administrations' lack of knowledge on this issue prevents them from outlining policy guidelines that favor local entrepreneurs in focusing their investments on activities with secure economic returns in fragile, still predominantly agricultural areas.

As entrepreneurs' investment decisions are linked to the profitability of agricultural products [24], at regional/district level, plant cultivation may play a pivotal role in the development of the economic conditions of resident people since they can be used for different purposes (foodstuff, fuel, and medicine, [25]). Specifically, people have used and continue to use a huge number of plant species to cure different diseases along time because they are rich sources of valuable molecules with different positive biological effects [26]. This means that some plants could turn out to be profitable due mainly to their metabolic profile [25]. In particular, medical plants have been considered the most suitable for the recovery of marginal areas, such as those falling in less-favored Mediterranean districts, where degradation occurs due to the intrinsic soil vulnerability (low levels of soil organic matter, rugged morphology, etc., see e.g., [27,28], improper management practices [29], and impacts of climate change and market globalization [30,31].

A large part of Basilicata, a Mediterranean region of Southern Italy, is prone to land abandonment due to its peripherality with respect to the most urbanized/developed areas of Italy, a relentless depopulation trend and the predominant hilly and mountainous nature of its land [32–34]. In addition, the topographic features make it difficult to practice mechanized agriculture. Therefore, most of these zones, despite their fertility, have been relegated to grazing activities or left abandoned [35,36].

In this study, saffron (*Crocus sativus* L.), namely the plant used to produce the king of spices [37], was used as a model system to recover and valorize typical abandoned areas of the Mediterranean region. Saffron is a spice derived from drying the dark red stigmas of the flowers of *Crocus sativus* L., a geophyte from the Iridaceae family [38]. *Crocus sativus* L. blooms in the autumn, displaying delicate and attractive flowers, with a perigonium made up of six tepals, typically violet or purple in color, and featuring darker veins [37–39]. The androecium consists of three stamens with yellow anthers, which derive their color from the pollen. The gynoecium, or pistil, is made up of an inferior ovary that extends into a style. The style then passes through the entire tube of the perigonium and splits into three parts to form the stigmas, which are the most valuable part of the flower [38,40]. Saffron is a triploid and sterile plant that propagates through corms, which naturally originate from the mother corm. These corms play a crucial role in the saffron life cycle, as they provide the photosynthetic material for the plant, both after the dormant period and during the early stages of growth [41]. Typically, the number of daughter corms increases with the size of the mother corm. Moreover, larger daughter corms are more significant than smaller ones, as they contribute to higher flower production, ultimately boosting stigma yield [42].

Saffron cultivation is prevalent in various regions around the world, including Iran, India, China, and California, as well as several Mediterranean countries such as France, Spain, Italy, Greece, Morocco, and Tunisia [41]. The ideal climate for saffron cultivation is the Mediterranean climate, characterized by warm, dry summers [39].

Saffron is one of the most valued spices, prized for its bitter flavor, coloring properties, attributed to picrocrocin, safranal, and crocins, respectively, as well as its nutraceutical benefits [43–45]. Indeed, saffron is renowned for its culinary qualities and health benefits, which are attributed to its bioactive components [37]. Additionally, saffron has long been referred to as "red gold" due to its status as the most expensive spice on the global market. This high cost is primarily a result of the intensive manual labor required throughout the entire process, from corm planting and weeding to flower picking, stigma separation, drying, and packaging. In particular, the flower harvesting and stigma separating (or "mondatura") phases have the greatest impact on the final price, as they involve meticulous, labor-intensive, and time-consuming manual work.

The choice of saffron is mainly due to its greater profitability among the medical plants [46]. Moreover, it is also attracting attention from consumers thanks to its beneficial properties for human health [37,47]. The economic motivation for the choice to grow saffron is mainly due to the real potential to increase its quality through the use of the alternative cultivation system proposed in this work for this medicinal plant. In fact, "cultivation tuff tubs", in addition to being a more eco-sustainable system than that of big plastic pots [48], offers the same excellent conditions to ensure the maintenance of the integrity of the floral tissues. This way, the flower can thus be collected from the stem without touching the soil and damaging tepals and stamens that can contaminate the spice. However, the cultivation system of terraces with dry made-tuff tubs does not exclude the possibility of growing other high-value crops such as lavender and rosemary to recover an unused territory, enhancing it. On this basis, saffron can represent an income supplement, allowing the diversification of production, the multifunctionality of farms, and the promotion of gastronomic tourism in sustainable agricultural systems [37,49]. Furthermore, a systematic incentive for saffron (or other high-value crops) cultivation in marginal areas could be a viable solution, not only to provide farmers with additional income but also to mitigate land degradation in sloping areas at high risk of abandonment [50].

Specifically, this paper is organized on a dual scale of investigation: (a) at local level where an experimental site is used as a pilot case to demonstrate the economic and environmental feasibility of the saffron cultivation conducted by adopting an alternative farming technique specific for marginal areas characterized by steep slope and poorly suited to mechanized agriculture; (b) at the regional level where, through a spatially explicit land suitability analysis, we want to indicate the possible location in which to expand saffron cultivation within Basilicata.

With respect to point (a), this work, inspired by a previous paper [48], proposes alternative solutions through the introduction of "tuff tubs" for saffron cultivation. This choice serves to solve some critical issues that sometimes make saffron cultivation very difficult [51], discouraging young agricultural entrepreneurs from investing in this crop, thus representing an important barrier for its spread.

With respect to point (b), Basilicata has a clear vocation for saffron production both for pedoclimatic and socio-cultural aspects, connected to the historically predominant peasant culture, which should be considered a decisive strong point for an alternative development of the region [52].

From this perspective, a land suitability analysis can represent a useful tool to address questions such as "where", "why", and "when" a specific crop is suitable for a given area [53]. In our case, we used different geospatial thematic maps in a GIS environment to identify areas with specific geo-environmental features, most likely abandoned or poorly exploited, that are suitable for saffron cultivation. The final goal is to provide policymakers with a suitability gradient of saffron vocation through the identification of potential productive soils considered as marginal. Here, it will be possible to activate incentive policies to push farmers to explore a new economically viable agricultural asset.

2. Materials and Methods

2.1. Study Area

2.1.1. Regional Scale

Basilicata, located in Southern Italy, features Mediterranean eco-mosaics with a mix of mountainous and hilly areas, influenced by both continental and Mediterranean climates [54]. The region has little plain area (8% of its total surface), with forests and pastures at higher altitudes, mostly in the Apennines, and large conservation zones belonging to the Natura 2000 Network [55]. The central-eastern part is more arid, with degraded areas and a loss of landscape value [56,57]. Agricultural areas, covering over half of the region, face both local threats, like depopulation [34,58], and global challenges, such as climate change (see e.g., [59,60]).

Key agricultural practices in the Vulture-Melfese district (northern part of the region) include cereal crops, olive growing, and viticulture (PDO—Protected Designation Origin) [61].

According to the Bank of Italy's annual report on regional economies (2023), the incidence of agriculture on added value in Basilicata reached 5.8% in 2021 (against 3.9% and 2.2% in Southern Italy and Italy, respectively). The industrial development is polycentric and anchored in a few sectors localized in specialized districts: oil exploitation in the Agri Valley, automotive in the Vulture-Melfese, and cultural industry in Matera, already the 2019 European capital of culture, tourism, and agro-industries in the Metapontum Plain [62] (https://www.bancaditalia.it/pubblicazioni/economie-regionali/2024/2024-0039/index.html, last accessed on 10 April 2015). The huge forest heritage is not adequately exploited by a few companies involved in the wood-furniture supply chain [63].

2.1.2. Experimental Site

An explorative trial was conducted during the 2021–2022 growing season in an experimental field located in the municipality of Tricarico (40°37′ N, 15°39′ E; 723 m. a.s.l., see Figure 1), a small and characteristic Arab-Norman village of Basilicata (Southern Italy).

Tricarico is known not only for its important medieval old town but also for its characteristic Saracen garden terraces (Figure 2). These represent an ancient system of vegetable cultivation that consisted of creating terraces with stone walls laid dry on sloping sites connected by stairs, also made of stone. Originally, they were also exploited to collect rainwater.

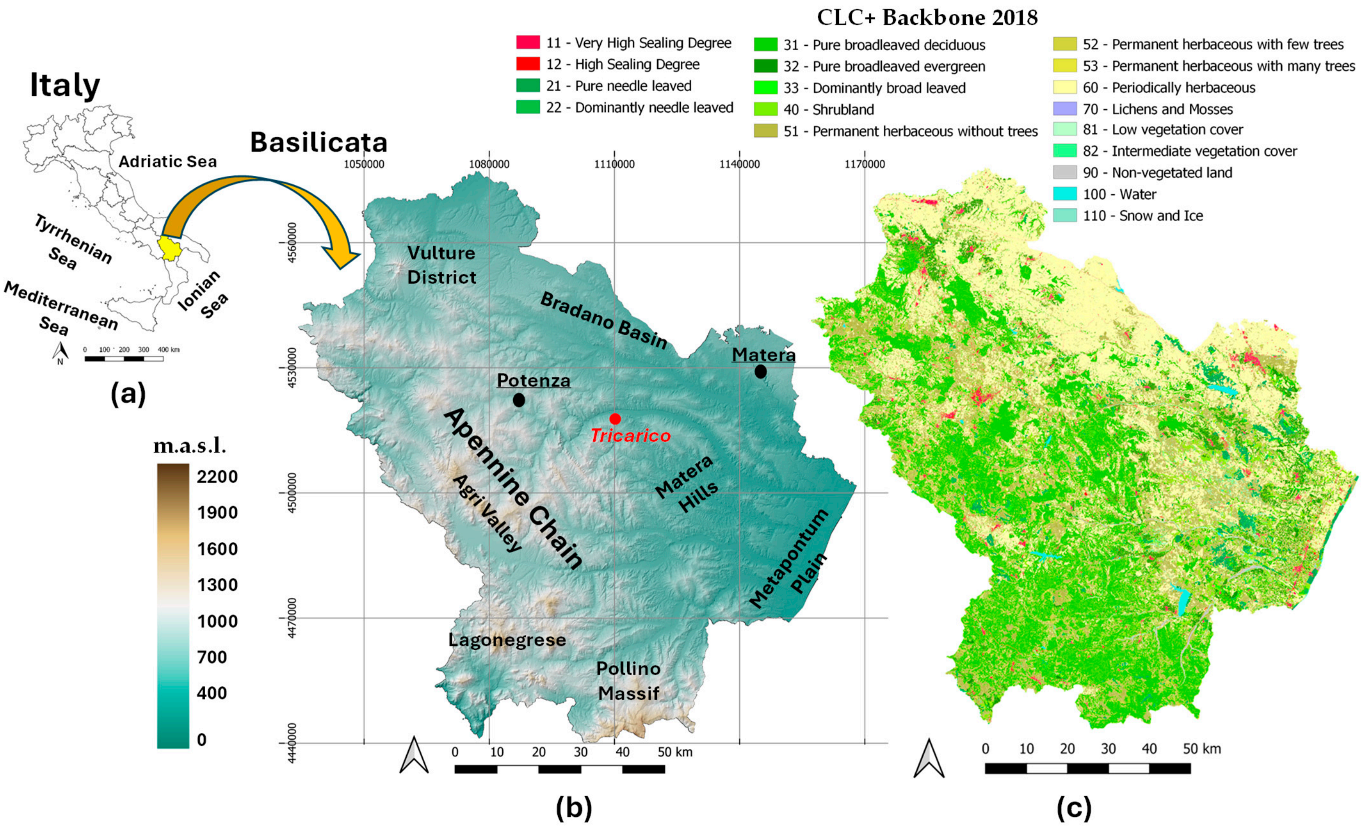

Figure 1. (**a**) Italy subdivided into homogeneous administrative units (regions corresponding to NUTS2—Nomenclature of Territorial Units for Statistics); (**b**) DEM of the region with the location of the experimental field of Tricarico; (**c**) land cover of the study area from CLC+ Backbone vector 2018.

(**a**) (**b**)

Figure 2. Saracen garden terraces in Tricarico; front view (**a**) and side view (**b**) (picture source: (**a**) photo taken by authors; (**b**) https://consiglio.basilicata.it/archivio-news/files/docs/48/90/04/DOCUMENT_FILE_489004.pdf, accessed on 10 January 2025).

2.2. Input Data for Local and Regional Analysis

The geospatial data used to elaborate the saffron suitability map are reported below:

1. Meteorological data of the Tricarico station (from the Decentralized Functional Center of Civil Protection of Basilicata Region, see http://www.centrofunzionalebasilicata.it, last accessed on 10 April 2025) were acquired and collected to characterize the environmental conditions of the experimental area. These meteorological data include monthly precipitation and mean, maximum, and minimum air temperature collected during the vegetative period of saffron (September 2021–May 2022);
2. Regional and municipal boundary of Basilicata (from the ISTAT-Italian National Institute of Statistics [64], see https://www.istat.it/notizia/confini-delle-unita-amministrative-a-fini-statistici-al-1-gennaio-2018-2/, last accessed on 10 April 2025);
3. The territorial database of CLC+ Backbone 2018 (available as a vector) [65–67];

4. Tinitaly DEM (digital elevation model) at 10 m of spatial resolution (https://doi.org/10.13127/tinitaly/1.1, last accessed on 10 April 2025, [68]);
5. Regional space data infrastructure of the Basilicata region (RSDI-Basilicata, see https://rsdi.regione.basilicata.it, last accessed on 10 April 2025);
    (a) 2013, 2017 and 2020 orthophotos, provided by AGEA (Italian Agency for the Delivery in Agriculture) and available as WMS layers [69];
    (b) Inventory of landslide areas of Basilicata, available as shapefile [70];
    (c) Grain size of the eco-pedological regions of Basilicata, available as shapefile [71].

2.3. Methodology

2.3.1. Local Scale: Construction of Terracing on the Sloping Experimental Field Using Dry-Laid Tuff Brick Walls

In this study, the experimental analysis was conducted in a sloping and abandoned marginal area of about 100 m^2 (size = 15 m × 6.0 m and slope ≈ 33%) located in the Tricarico countryside (Basilicata), taking advantage of a cropping system similar to the Saracen gardens.

In fact, recalling this traditional cultivation method, small terraces were built with dry-laid tuff bricks walls, henceforth referred to as "cultivation tuff tubs" since they delineate tuff semi-tanks resting on the ground and include areas for growing plants (Figure 3). Each cultivation system was made with 74 or 36 tuff blocks (50 × 25 × 15 cm) to obtain a "tuff tub" with a length of 11 m or 8 m, a depth of 0.75 m or 0.5 m, and a width of about 0.5 m. The dimensions of the dry-made tuff tubs were carefully designed, finding the right balance between height (depth) and length, thus ensuring the stability of the walls and preventing bulging in the event of frequent and intense rainfall. In order to resist hydrostatic thrusts, generally proportional to the depth of soil impregnation, some criteria were adopted, such as (a) the inclination of the tuff blocks at the base towards the land side (3–4%); and (b) the staggered arrangement of the tuff blocks for the upper layers (Figure 3).

Figure 3. Terraces with "cultivation tuff tubs" in the experimental site of Tricarico (Southern Italy). Photos taken by authors from different views.

Moreover, thanks to the different levels of the terraces, obtained by means of an excavator on the slope of the experimental marginal area, it was possible to create large tubs (4–5.5 m^2) by exploiting the side of the land for one of the long sides of the tank. In this way, approximately half the number of tuff blocks that would have been needed to create tuff tubs of the same surface on flat ground were used. Furthermore, the creation of tuff tubs is not only more environmentally sustainable but also cheaper than large plastic pots (with a capacity of 350 L and a cultivation surface of approximately 0.6 m^2), which cost 38 euros.

Although the experimental area is considered not suitable for mechanized agriculture, it is fertile and consists of medium-textured soil and is thus suitable for the cultivation of some profitable medicinal plants, such as saffron. It is known that saffron can be grown in soils ranging from sandy to well-drained loamy texture [72,73] with a neutral or slightly alkaline pH [74] and in a Mediterranean climate with hot, dry summers [48], making it a resilient crop for sustainable agriculture, especially in the era of climate change [75].

To implement this terraced cultivation system, an excavator was used to obtain three levels on the entire slope of the experimental area. The terracing system, obtained by means of tuff walls, was designed with two main considerations in mind: on the one hand, the minimum width (1 m) to allow walking alongside the “tuff walls” at different height levels during planting, manual weeding, and flower harvesting; and second, a minimum height of the “cultivation tuff tubs” that would enable work to be carried out in an upright or at least in a more comfortable position compared to that required by the traditional cultivation system (Figure 4).

Figure 4. Possible positions taken by operators during the saffron flower harvesting stage in the traditional cultivation system (trunk flexed or knees crouched) (https://www.lecodelsud.it/zafferano-rosso-lagricoltura-giovane-salvera-leconomia#google_vignette and https://www.sativus.com/pages/growing-instructions/?srsltid=AfmBOoq-8SqOnnxw6H7gYe9v4DHsTQ2z_eDqZ_MLazhZUEzV5AFk3ZiT, accessed on 10 January 2025).

In addition, next to the walkway, a space of about 2 m was deemed large enough to make additional “cultivation tuff tubs”, albeit smaller than those nearby, below and above. This space also allowed for the transit of a tiller, the use of which was necessary to till the soil to a depth of 0.2–0.4 m [76].

2.3.2. Local Scale: Planting Scheme, Flowers, Leaves, Daughter Corms, and Spice Yield

Planting was carried out by hand obtaining a density of 90 corm per m^2 in accordance with the specialized literature [76,77]. We selected 1350 corms of *Crocus sativus* L. coming from Sardinia (Italy) with an average horizontal diameter of 0.03–0.035 m. They were dipped in a 1% fungicide water solution of copper oxychloride (Sumitomo Chemical Italia S.r.l., Milano, Italy) for 2 min to minimize fungal diseases (e.g., *Fusarium oxisporum f. sp. Gladioli*, see [77]). Then, they were drained and left to dry in a cool and ventilated place overnight. The next day, corms were planted in “cultivation tuff tubs” in 5 rows about 0.1 m apart, with a distance of 0.07–0.08 m between the corms within the rows, and covered with a 13 cm layer of the same field soil (Figure 5).

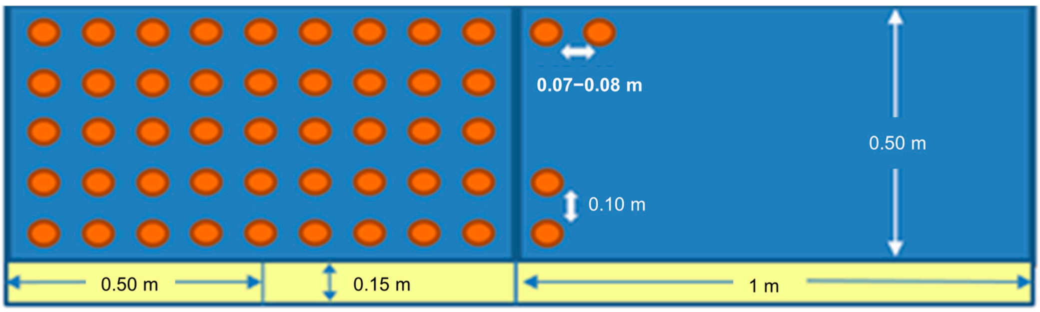

Figure 5. Planting scheme (average distances between corms (orange circles) and total width of planting pattern: white lettering; length and thickness of tuffs: black lettering).

Weed control was performed manually, and no irrigation was applied during the crop cycle except on the day of planting. During the flowering period between October and

November, the flowers were picked by hand in the early hours of each day. The harvested flowers were then taken to the laboratory where the stigmas were manually separated from the rest of the flower, placed on a glass plate, and dried for one hour in a yogurt maker (Girmi, Rimini, Italy) with a perforated lid on top at an operating temperature of about 40 °C. The dried stigmas were weighed and stored in a glass jar at room temperature (20 ± 2 °C) in the dark until qualitative analysis was performed. During the growing season, some plants were labeled (marked) randomly: on average one plant per linear meter. To evaluate the effectiveness of the proposed cultivation system, a main morphological trait of these plants was also considered: during the period of maximum photosynthetic activity, the average leaf length per plant was recorded. At the end of the crop cycle, during the senescence phase, the same plants were lifted from the ground (1 May 2022). Specifically, 11 plants from the larger "cultivation tuff tubs" and 8 plants from the smaller tuff tubs were transferred to the laboratory, where the daughter corms were detached from the mother corm remnant to be later calibrated. The number of daughter corms per mother corm, expressed as ICMI (Initial Corm Multiplication 361 Index), was recorded. The total number of daughter corms were recorded, as well as the number of daughter corms with horizontal diameters in the different size classes from less than 2 cm to more than 4 cm. A handmade wooden gauge was used to classify the size class of the corms.

2.3.3. Local Scale: Spectrophotometric Analysis of Saffron Extract

To determine the saffron quality, samples of spice produced in 2022 were analyzed using a UV–Vis spectrophotometer (Ultrospec 4000, Amersham Pharmacia Biotech, Milan, Italy) and quartz cuvettes with a path length of 1 cm according to the International Standardization Organization 3632 normative [78]. Briefly, 500 mg of powdered samples were passed through a 0.5 mm sieve, transferred into a 1000 mL volumetric flask with 900 mL of distilled water (ultra plus distilled water purchased by Carlo Erba). The obtained aqueous solutions were stirred for 1 h in the dark and then brought to 1000 mL with distilled water. Extracts were diluted (1:10 v/v) with distilled water and filtrated with polytetrafluoroethylene (PTFE) filters (15 mm diameter and 0.45 μm pore size). The qualitative main features of saffron samples were expressed as absorbance values at 257, 330, and 440 nm corresponding to the λmax of picrocrocin, safranal, and crocins, respectively. They represent flavor strength, aroma strength, and coloring strength, respectively, according to the following equation:

$$A_{1\ \mathrm{cm}}^{1\%}(\lambda \mathrm{max}) = (D * 20{,}000)\ (100 - H) \tag{1}$$

where $A_{1\ \mathrm{cm}}^{1\%}$ is the maximum absorbance of a 1% solution over a 1 cm path length measured via spectroscopy. D is the specific absorbance; 20,000 is the dilution factor of the total extract considering the amount of saffron sample; and H is the moisture and volatile matter content, expressed as a percentage mass fraction.

H was determined by placing 2.5 ± 0.001 g of each saffron sample in an oven from 103 ± 2 °C for 16 h and it was calculated as the percentage of the initial weight of the sample according to the following formula:

$$\mathrm{H}(\%) = (m0 - m1)\ (100/m0) \tag{2}$$

where $m0$ is the mass of the saffron portion before drying (grams) and $m1$ is the mass of the dry residue (grams).

2.3.4. Regional Scale: Land Suitability Mapping

Today, geographical information systems (GISs) play a crucial role in land suitability analysis, enabling the investigation of various geospatial data. In this work, we carried out an assessment of saffron land suitability for Basilicata by considering several layers related to altitude, slope, land cover, and hydrogeological risk.

To build the saffron suitability map, areas considered optimal to this cultivation should be located at an altitude ranging between 300 m and 1000 m above sea level in Mediterranean regions (accidentally coinciding with the Castanetum phytoclimatic zone, see [79]), following the indications included in the Saffron project [76].

With regard to slope (derived from the DEM), we restricted the suitable areas to those with values between 25% and 50%. This range was chosen to valorize agricultural and/or semi-natural areas characterized by a moderate to medium-high slope, which are therefore unsuitable for mechanized agriculture [80] and often affected by erosion phenomena [81]. Flat, sub-flat, or slightly sloping areas (slope < 25%) can be more profitably used for other agricultural purposes (permanent crops or cereals, [82]), while when the terrain is particularly rugged (slope > 50%), there are logistical conditions that could be unfavorable also for the saffron cultivation system reported in this paper.

The most delicate choice concerns the adoption of a suitable land cover map. The traditional CLC2018 land cover map, encompassing 44 different land cover classes with a minimum mapping unit (MMU) of 25 hectares [83], is too coarse for our applications based on layers having a finer spatial resolution (10 m for the adopted DEM) and finalized to identify areas suitable to saffron that can be rather limited in extension. In addition to this, the various heterogeneous agricultural classes included in the traditional CLC (classes 2.4.1, 2.4.2, 2.4.3, 2.4.4) are characterized by a mix of land uses including mosaics of permanent crops, arable land, meadows, and unused land, making it difficult to indicate the prevalent land cover. Differently, the recent pan-European CLC backbone vector (2018) [65] provides 18 basic land cover classes with a minimum mapping unit of 0.5 ha [67] (https://land.copernicus.eu/en/technical-library/clc-backbone-product-user-manual/@@download/file, last accessed on 10 April 2025), which is more suited because of a simpler labelling that makes it possible to identify for each polygon the dominant land cover with an appropriate spatial resolution. This enables us to capture areas that can be considered marginal in terms of agricultural vocation or those semi-natural zones having a low presence of trees and thus suitable for agricultural purposes. In light of this, among the 18 classes, we carried out analyses only on classes 51, 52, and 81, corresponding to "permanent herbaceous without trees", "permanent herbaceous with a few trees", and "low vegetation cover" after checking their land features using multitemporal high-resolution orthophotos from the RSDI geoportal (see Figure 1c).

Although the most suitable soils for saffron cultivation are those with a loamy clay texture; however, this crop also generally grows in soils with unfavorable characteristics as long as there is no waterlogging [76]. For this reason, we did not consider pedological constraints.

Once we defined the different suitable layers for saffron cultivation, the final suitability map was built by overlapping these strata (Figure 6). Lastly, by adopting municipal boundaries and the grain size layers, we obtained the extent of suitable areas at a municipal level and the subset of areas considered most suitable for saffron cultivation due to the optimal soil texture, respectively. The GIS environment adopted for the collection, management, and analysis of all the layers is Quantum GIS (QGIS) (3.28.5 version, available at http://qgis.osgeo.org, last accessed on 10 April 2025).

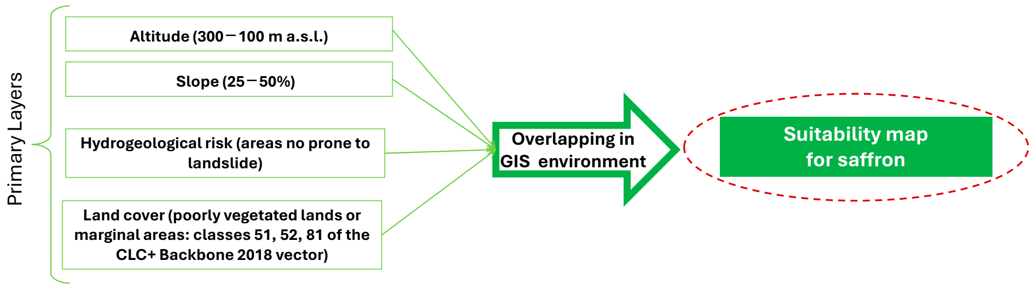

Figure 6. Scheme of land suitability analysis.

3. Results and Discussions

3.1. Local Scale

The traditional open-field cultivation of saffron presents significant challenges concerning production quality and worker posture. On the one hand, it is possible to harvest only the stigmas of saffron often contaminated from pollen while the remaining parts of the flower are discarded and thrown away (about 90% of the biomass); on the other hand, the non-ergonomic position of workers during various phases of plant growth hinders the hiring of a labor force at an acceptable cost [42].

The first noteworthy result of growing saffron in tuff tubs lies in facilitating and increasing the recovery of floral bioresidues, thus guaranteeing a better quali-quantitative production, according to the results obtained by Cicco [48], through the use of big plastic pots. At the same time, workers involved in agronomic practices can assume an ergonomic posture without jeopardizing the production of flowers and corms (Figure 7). In fact, saffron cultivation in tuff tubs offers the possibility of working both standing and seated. The collected data of the experimental area were compared with those reported in the literature [84].

(**a**) (**b**)

Figure 7. Terraces with "cultivation tuff tubs" that facilitate workers in the different agronomic phases (sowing, weeding and harvesting). Photos taken by authors: (**a**) during the peak flowering period showing the real possibility of sitting on the thickness of the tuff tubs to pick the flowers; (**b**) worker standing during harvesting phase.

3.1.1. Meteorological Data Elaboration

Values of monthly minimum, mean, and maximum air temperature and rainfall were reported in Figure 8 for the meteorological station of Tricarico (Southern Italy). Meteorological data were elaborated to assess the mean conditions over the growing period of saffron, from planting to the subsequent blooming (September–November) until the corm development period (December–May). During the 2021–2022 growing season, a higher rainfall amount was recorded in the flowering period (September—November) than in the vegetative one (December–May) in Tricarico. As for the temperature trend, it was in line with the typical seasonal trend because the flowering period (September–November) was warmer than the vegetative period (December–May), where average air temperature values increase only in early spring (late March–early April).

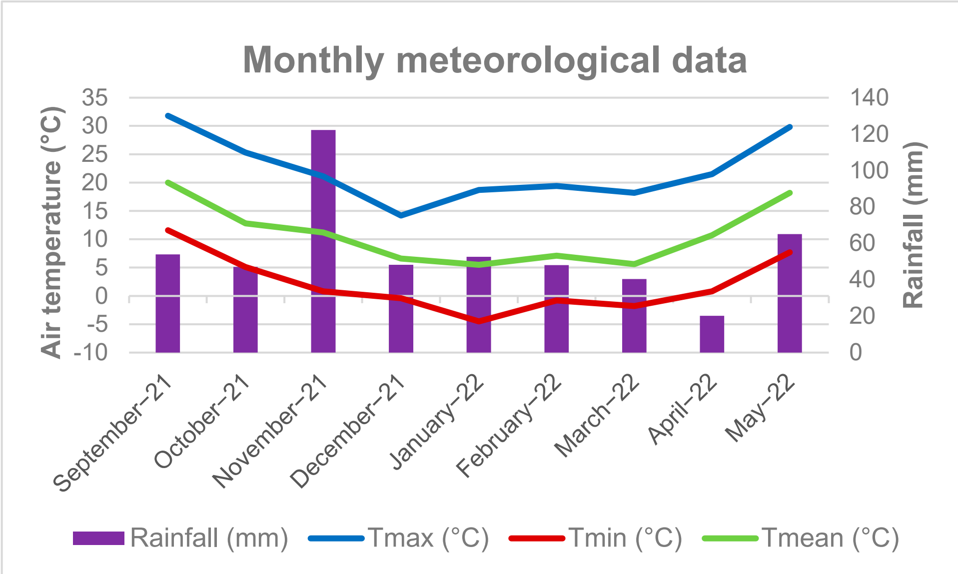

Figure 8. Meteorological data recorded at Tricarico station (Southern Italy) during the growing seasons 2021–2022.

3.1.2. Production of Flowers and Corms, Determination of Leaf Length and Spice Yield

To evaluate the effectiveness of the proposed cultivation system, the number of flowers, number of daughter corms per mother corm, and daughter corms with horizontal diameters belonging to different size classes, as well as the average leaf length per plant were recorded. Figure 9 shows the flowering period in 2021 in Tricarico and the most representative flowering data from the experimental trial. The parameters investigated are generally influenced by pedoclimatic conditions. However, values concerning the number of flowers per corm (diameter 3–3.5 cm) and flowers per square meter are fully within the average data reported in literature [84] for the traditional saffron cropping system.

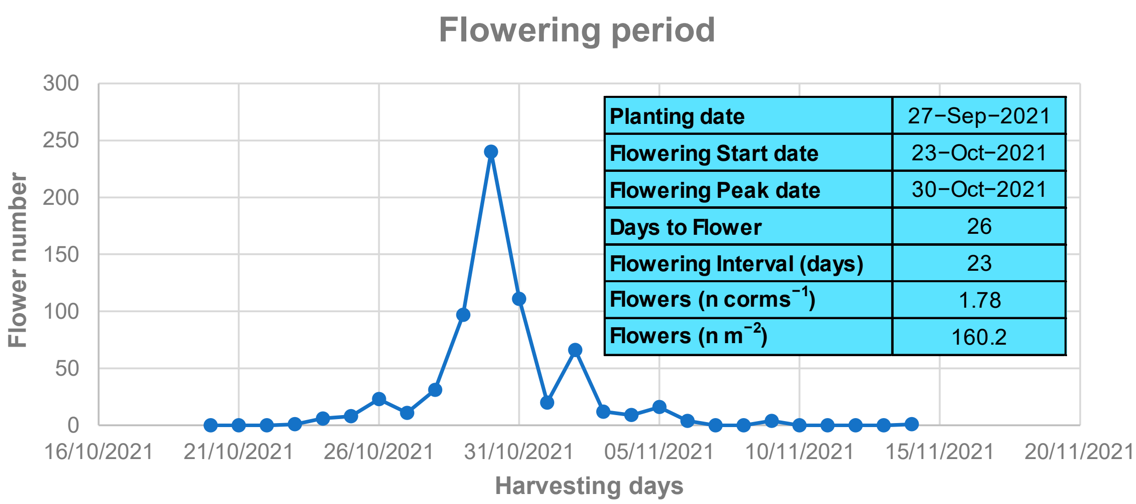

Figure 9. Flowering period and relative data obtained from the experimental site of Tricarico in 2021 by using "cultivation tuff tubs". Corm geographic origin: Sardinia (Italy).

In order to evaluate the efficiency of "cultivation tuff tubs", the leaf length of 30 labeled plants was determined, as this is the main morphological trait that can be measured in the open field during the growing season without causing damage to the plants. With the same objective, the spice yield was also determined. The value of leaf length was 63.1 $\pm$ 3.8 cm (mean value $\pm$ standard deviation). Regarding spice yield, the mean value of dried stigma weight was 0.00245, corresponding to a spice yield of about 0.4 grams per square meter.

This value is similar to the highest average value of dried stigma yield reported in the recent study by El Hajj et al. [85], obtained over five years (2016 to 2020) after triple application of 45 g m^{-2} of NPK in fall, winter, and spring, with a total application dose of 135 g m^{-2}. Remaining in Italy, the production values found are in line with what was reported by different works carried out in Italian saffron experimental fields, sometimes also with the support of agrochemicals.

Our yield (0.4 g/m^2) is higher than that (0.35 g/m^2) found by Mehmeti et al. [86] and the mean values reported for Italy by Shahnoushi [84] (0.20 g/m^2). This value represents the maximum of the range reported by Manzo et al. [87] for the 5-year yield of dried saffron stigmas. This is conservatively estimated at 700 grams per 500 square meters, starting at 70 grams (corresponding to 0.14 g/m^2) in the first year and increasing to 200 grams per year by the fifth year (corresponding to 0.4 g/m^2) [84,86,87]. Therefore, our annual experimental results showed that "cultivation tuff tubs" were very promising, taking into account that no treatment was applied. However, further investigations will be conducted in the near future to assess the possibility of extending this system regionally, taking advantage of the marginal areas identified through GIS analysis. The soil and climate conditions in different years, the geographic origin of the corms, as well as their size class and specific agronomic practices (biostimulants application) will be the focus of our future studies. Table 1 shows data on the daughter corms obtained from the 30 labeled plants, randomly chosen during the vegetative phase of the experimental trial, taken from the soil of the three "cultivation tuff tubs" (see Section 2.3). The mother corm progeny multiplication, expressed as ICMI, averaged approximately 1.83, which is remarkable considering the diameter of the mother corms, which, while having floral strength, were of medium size. In addition, a considerable percentage value of daughter corms in flower strength (i.e., diameter > 2.5 cm) was obtained. It amounted to about 70%, of which about 53% consisted of daughter corms with a size larger than that of the mother corm (i.e., diameter > 3.5 cm). Overall, these data ensure better flower production in the following year and a good reproductive capacity.

Table 1. Daughter corms belonging to different size classes recorded on 30 randomly selected plants.

	Daughter Corms						
Dimensional Class (cm)	<2.0	2.0–2.5	2.5–3	3–3.5	3.5–4.0	>4.0	Total
Daughter Corms (Number)	10	7	8	10	15	5	55
Daughter Corms (%)	18.2	12.7	14.5	18.2	27.3	9.1	100

3.1.3. Saffron Quality

Paying attention to the efficiency of the cultivation system, the quality of the spice was also determined. The results showed that the saffron obtained belongs to the first-quality category. In fact, the value of moisture content and volatile matter was 9.62% (reference value: <12%; see ISO 3632-1010, 2010). The obtained value was used in the equation mentioned in Section 2.3 to determine the main qualitative characteristics of saffron, taking into account the absorbances values at 257, 330, and 440 nm of the aqueous extract of the sample. The values of flavor strength (expressed as picrocrocin), aroma strength (expressed as safranal), and coloring strength (expressed as crocins) were equal to 86.08, 28.10, and

266.4, respectively. The ISO 3632 references used to assign the sample to the first qualitative category are reported: picrocrocin: A 1% 1 cm (257 nm) $\geq$ 70; safranal: values [min–max] (A 1% 1 cm (330 nm) 20–50; crocins: A 1% 1 cm (440 nm) $\geq$ 200. The value obtained was used in the equation shown in Section 2.3.3 to determine the main quality characteristics of saffron, taking into account the absorbance values at 257, 330, and 440 nm of the aqueous extract of the sample.

3.1.4. Economic Advantages and Synthetic Analysis of Costs

The main aim of this work is to evaluate the possibility of recovering and enhancing abandoned, still fertile areas. However, a cost analysis of the proposed system is necessary to highlight its actual economic advantages. Some of these advantages are already inherent in the traditional method. In fact, both the systems (traditional and alternative) do not require large plots and particularly sophisticated machinery and equipment [84]. This makes saffron production possible even for those farmers who have low incomes and little financial capital. Instead, a specific advantage of the proposed alternative system is linked to the possibility of increasing the product quality, which can be obtained only if the integrity of the flower tissues is preserved already in the harvesting phase [48]. It is well known that, nowadays, the quality of food products—including spices—is increasingly valued by consumers, especially those with allergies [88]. The upright or more ergonomic posture of the workers, allowed by the alternative cultivation system, translates into a double economic advantage. The tuff terracing system, similarly to the cultivation system in large plastic pots, facilitates the supply of labor compared to the traditional method, as it requires less physical effort from workers, allowing them to work more comfortably and, consequently, with greater productivity. This can translate into reduced labor costs in the unit of time. Furthermore, the system offers the possibility of increasing the quality of the spice, thus allowing an increase in sales prices. In fact, being able to collect the flowers by the stem without touching the tepals helps to preserve the floral integrity, including that of the stamens located inside the flower calyx. This prevents contamination by pollen, which can easily disperse when the anthers of the stamens break. This eventuality can occur more frequently during the harvesting phase of the traditional method since the flower is collected from the upper part touching the tepals [48]. Conversely, during the harvesting phase of the traditional cultivation system, a specialized trolley and an innovative harvesting machine called "Saffron All In One" (SAIO) have been introduced to reduce physical strain and mechanical stress on workers' bodies. These tools enable workers to harvest saffron flowers while sitting or in a prone position, respectively. However, their implementation entails additional economic costs [89].

Based on these premises, a synthetic cost analysis of our cultivation system is reported here. It takes into account (a) the improvement in spice quality, which leads to an increase in selling price and (b) the cost for building the "cultivation tuff tubs", which are cheaper and more eco-sustainable than plastic pots and are the only additional cost with respect to the saffron traditional cultivation system. Table 2 shows the additional costs required, compared to the traditional system, for implementing the experimental field.

Table 2. Synthetic cost analysis for the setup of three "cultivation tuff tubs" in the Tricarico experimental field.

Materials/ Machinery	Tot. Time (min)	Tot. Time/Linear Meter	Tot. Cost/Linear Meter (EUR)	Tot. Cost (EUR)	Tot. Cost/m^2 (EUR)
Excavator	120	4	10	300	20
Labor	2160	72	15	450	30
Tuffs	-	-	8	240	16

It is very important to emphasize that the price of saffron varies between the different producing countries around the world and even within the same country [90]. In Italy, for example, saffron cultivated in the south is approximately 25% cheaper than saffron produced in the north [76]. The price of Italian saffron from the main producing regions (Sardinia, Toscana, and Abruzzo) ranges between EUR 20 and EUR 35 per gram, according to data collected by Giupponi et al. [91]. These authors accurately summarize recent sales prices of Italian saffron by distributing questionnaires to farms spread all over Italy that grew saffron. The 162 questionnaires received represent a robust statistical sample that confirms what was reported in our paper. Just 1% of respondents sell saffron for less than EUR 10 per gram. About half of them (51%) sell it for between EUR 20 and EUR 30 per gram, while 26.6 percent of saffron growers sell their product for more than EUR 30 per gram. As a result, the average price of saffron is EUR 23.68 $\pm$ EUR 6.95 per gram, with a minimum of EUR 5 per gram and a maximum of EUR 40 per gram. The high price is primarily due to higher labor costs compared to Iran (the world's largest producer), where saffron price ranges between EUR 1.4 and EUR 1.8 [92].

Generally, the choice to purchase saffron is influenced by lower prices, local origin, quality certifications, and organic farming practices [93]. Obviously, increases in saffron price can only be justified by the increasing quality of the spice. The alternative cultivation system proposed here, unlike the traditional cultivation one, allows us to preserve the integrity of all parts of the flower and to avoid contact of the workers' fingers with the soil, thus improving the quality of the spice [48] and, consequently, influencing its selling price. The price of saffron belonging to the first quality category (in terms of its main chemical and physical characteristics) could be estimated at about EUR 50 per gram. This price may seem high; however, it must be considered that food safety, which is increasingly demanded by consumers, leads to a price increase for foodstuffs with specific certificates [94]. The spice yield, obtained using the "cultivation tuff tub" system, is approximately 0.4 g m^{-2} and is within the average values reported in literature [74]. Our comparison was made solely with literature values, as it takes into account various parameters that may influence this production.

Considering that the costs linked to the building of "cultivation tuff tubs" is equal to EUR 66 m^{-2} and the best price obtained thanks to the superior quality of the spice (EUR 50 per gram), the return on investment is estimated at just over three years. It is to be hoped that this virtuous economic chain can promote the recovery and enhancement of those marginal, fertile areas, which are often subject to land abandonment [36]. In these areas, small landowners can form consortia aimed at enhancing the territory, thus promoting saffron in stigmas in both small shops and large-scale distribution markets, which are still rare today. This can be achieved through the promotion of regional/national policies that incentivize the use of this high-quality spice, also considering its well-known health benefits [95].

3.2. Regional Scale

Land Suitability Map

Figure 10a shows the suitability map for saffron cultivation in Basilicata. Areas potentially usable for introducing this crop amount to 31,053 hectares, i.e., more than 3% of the total area of Basilicata. With the exception of the Metapontum Plain and Vulture districts, almost the entire region is characterized by a more or less dense presence of areas suitable for this type of cultivation. Clusters of municipalities with a denser presence of suitable areas can be identified. The districts of the Matera hills and the low mountainous areas of the Apennines around the county seat of Potenza represent the relatively optimal areas for hosting this crop (compare with Figure 1). Figure 10b indicates the current mapping of inner areas according to the SNAI classification [96]. The vast majority of areas identified as suitable for saffron cultivation (about 70%) areas are located in zones recognized as marginal (peripheric and ultra-peripheric municipalities characterized by a significant distance from the main service provider centers), confirming the validity of our intuition to develop an innovative and unconventional agricultural supply chain specifically in areas suffering from infrastructural gaps and long-term economic stagnation. This feature is further supported by Table 3, which ranks the top-10 municipalities based on the extent of suitable areas for saffron cultivation. Apart from the county seat of Potenza and the municipalities of Tolve (Urban belts) and Tricarico (Intermediate), the other seven municipalities, hosting a considerable number of areas potentially suitable for this crop, are peripheric or ultra-peripheric. Furthermore, the first three municipalities, each with suitable areas exceeding 1000 hectares, belong to the most disadvantaged categories.

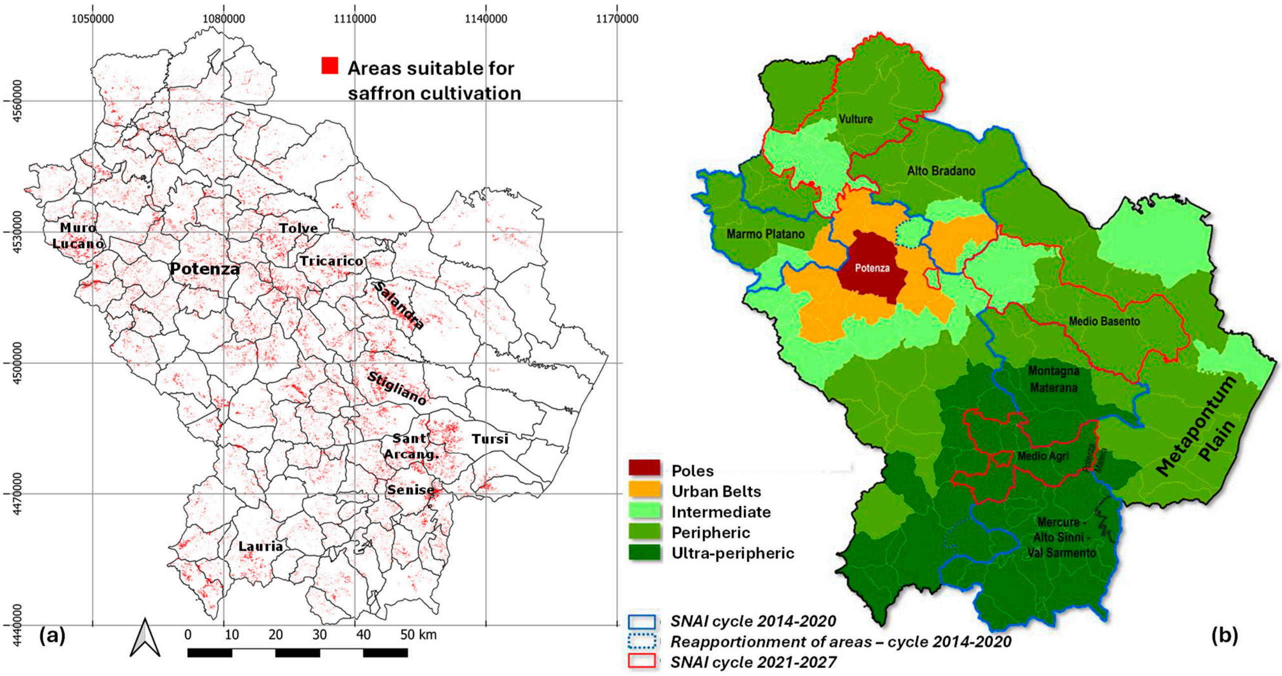

Figure 10. (**a**) Areas suitable for saffron cultivation (Basilicata–Southern Italy); (**b**) SNAI classification of municipalities of Basilicata (cycle 2021–2027).

Table 3. Top-10 municipalities of Basilicata ranked by the extent of areas suitable for saffron cultivation.

Municipality	Suitable Areas (ha)	SNAI Classification 2021–2027
Stigliano	1623.57	Ultra-peripheric
Muro Lucano	1044.21	Peripheric
Salandra	1035.23	Peripheric
Potenza	928.80	Hub
Tursi	866.38	Peripheric
Tricarico	852.05	Intermediate
Tolve	787.30	Urban belts
Senise	646.73	Ultra-peripheric
Sant'Arcangelo	625.53	Ultra-peripheric
Lauria	614.50	Ultra-peripheric

An additional element of land planning concerns the identification of the most suitable areas for saffron cultivation based on the grain size of the different eco-pedological regions of the study area. As specified earlier, although saffron grows in all soil types, the presence of loam and sandy-loam soil types (green pixels) favor productivity in terms of highest flower number, stigma yield, daughter corm, and horizontal diameter [97]. These areas represent about 42% of the total extent of suitable areas (Figure 11) and constitute priority zones in which to establish the first nuclei of saffron cultivation. Red pixels represent areas that are still suitable for saffron cultivation but to a lesser extent because they are located on soils with a different texture from the optimal one (58% of the total extent of suitable areas). This study, conducted at the regional level, could encourage the relevant local authorities (Basilicata Region) to implement specific policy measures within regional funding programs, such as the Rural Development Programme. These measures should incentivize the cultivation of areas unsuitable for mechanization but well suited for high-value crops like saffron.

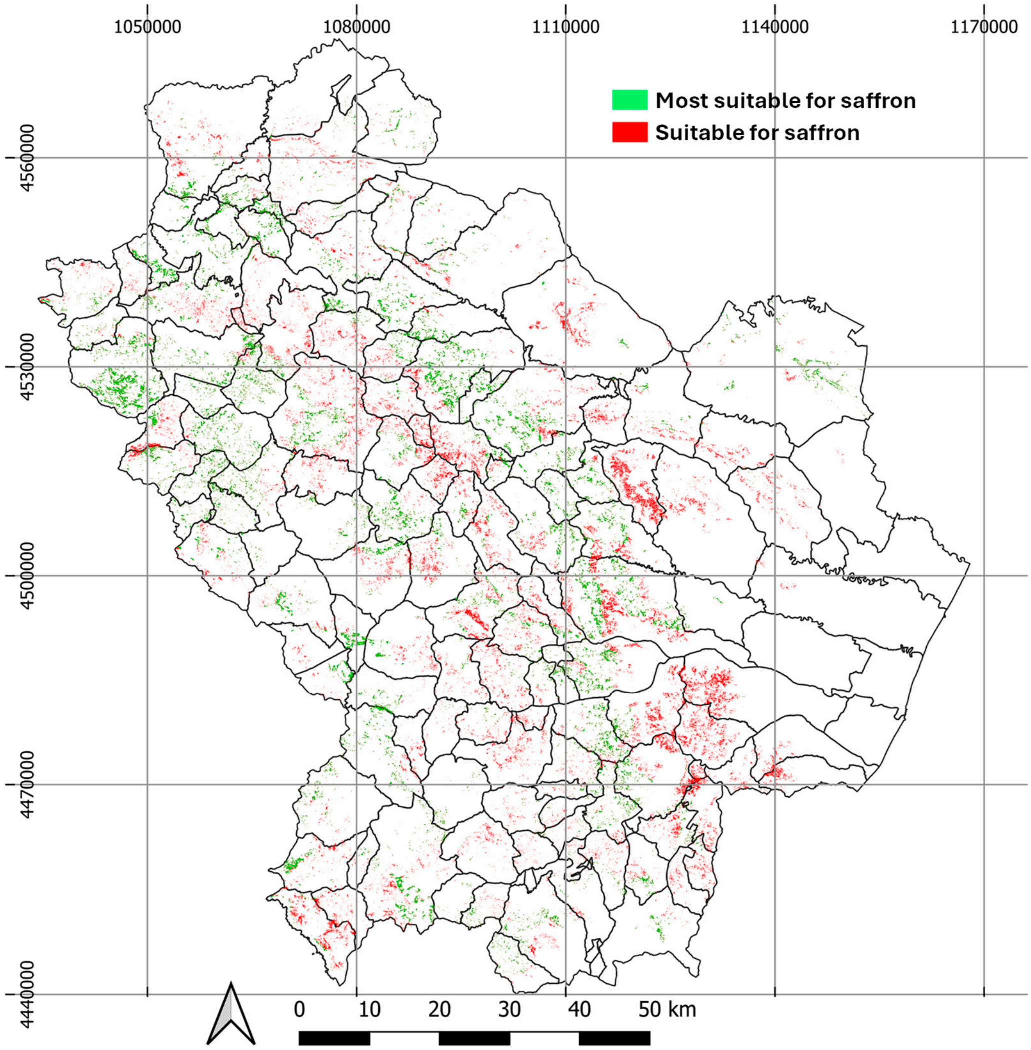

Figure 11. Areas most suitable (green colored) for saffron cultivation supported by a proper texture (loam and sandy-loam soil types), while red pixels identify areas suitable for saffron cultivation characterized by less appropriate textures.

Additionally, local authorities should promote farmer cooperation, as saffron production typically occurs on small to medium-sized plots [98]. Such cooperation would help farmers better withstand the impacts of international market fluctuations and climate change [91].

4. Conclusions

This article proposes the possibility of adopting an alternative saffron cultivation system at the local level with the aim at extending this practice over marginal areas of a Southern European region with a predominantly agricultural vocation (Basilicata—Southern Italy). Our alternative cultivation system involves the use of "cultivation tuff tubs". Similarly to the cultivation based on the use of big pots, the system reported here allows us to improve the posture of workers during the planting, weeding, and harvesting phases without affecting the production of flowers and corms [48]. The results achieved at the Tricarico experimental site (Basilicata) showed the real feasibility of saffron cultivation based on the building of tuff tubs in marginal fertile areas unsuitable for mechanized agriculture. In fact, the production of flowers and corms, as well as the quality of spice, are in accordance with what has been reported in the literature [84]. The use of tuff tubs was motivated by two main reasons: it is cheaper than the alternative cultivation systems based on the use of big plastic pots reported in the recent study by Cicco [48]; in addition, it is more ecological due to the reduction in the use of plastic materials characterizing the pots. It is well known that to maintain high qualitative standards, stigma should be separated within one day of harvest. Due to the short flowering period, securing sufficient labor and time for daily stigma separation from harvested flowers is challenging. Large growers are often forced to store flowers for several days, which can compromise product quality and, in some cases, lead to deterioration [89]. The proposed alternative system, designed for small family-run plots, avoids this issue by handling smaller quantities of flowers, ensuring more effective management and optimal product quality Moreover, it provides appreciable results on an annual basis, and it is very promising, taking into account that no treatment was applied to the plants.

However, further investigations will be carried out to evaluate the possibility of extending this system to corms of different geographical origins and dimensional classes. Furthermore, some investigations could be aimed at evaluating the effectiveness of this system on a biennial basis by also adopting additional agronomic techniques (e.g., biostimulants). The success of the local experimental trial suggests the potential opportunity to extend this type of cultivation to larger areas unsuitable for mechanized farming (excessive slope) and falling within marginal agricultural districts. Furthermore, the land suitability analysis conducted in a GIS environment recognizes a potentially exploitable area of over 31,000 hectares in Basilicata, thus becoming a planning tool that can be applied at the regional scale to revitalize marginal areas as indicated by national and European cohesion policies [99,100]. Furthermore, the potential cultivation of marginal areas with a high-value crop like saffron could initiate a virtuous cycle in land management, significantly reducing the risk of land degradation in steeply sloped areas, which are notoriously more prone to abandonment and, consequently, lack proper land maintenance. Moreover, the farming practices associated with the alternative saffron cultivation system presented in this study are minimal, requiring neither irrigation nor the use of agrochemicals. At the same time, non-intensive and diversified small-scale agriculture can be more resilient to market fluctuations and climate impacts. Ultimately, these practices are energy-efficient and environmentally sustainable while also enabling agricultural diversification, thus aligning well with the objectives of the 2023–2027 CAP. Local authorities should promote incentives to encourage saffron cultivation in marginal areas unsuitable for mechanization by favoring farmer cooperation to address global and local challenges.

In addition to this, the expansion of saffron cultivation in marginal areas is closely linked to the development of agricultural multifunctionality, where local traditional products play a crucial role in fostering experiential, proximity-based, and sustainable tourism. In turn, this form of tourism can effectively leverage all available resources in predominantly rural and marginal areas where the most marketable aspects of intangible heritage are closely tied to food [101].

Lastly, this system can be applied to other autochthonous medicinal plants of economic importance, potentially benefiting local economies through the marketing of new products with a strong territorial identity. The choice of plants for cultivation could be guided by the specific soil and climate conditions of the area of interest.

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