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The Cultivation of Industrial Hemp as Alternative Crop in a Less-Favoured Agricultural Area in Southern Italy: The Pignola Case Study

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Abstract: Industrial hemp cultivation has the potential to be an environmentally friendly and highly sustainable crop and it can fit well in crop rotation practices to increase soil fertility. For this study, two commercial varieties of industrial hemp with low tetrahydrocannabinol (THC) content were used to test its reintroduction chance in the study area and to evaluate its response in terms of yield with respect to the soil and drought conditions of the area. During the vegetative period, non-invasive measures of the soil's water status were performed using Watermark probes and ground penetrating radar. In addition, hemp crops vigour monitoring was performed by means of Sentinel 2 multispectral optical remote sensing data. In the absence of precipitation and/or irrigation, and with high consumption of soil water by the hemp crop due to evapotranspiration, the crop has completed its cycle thanks to its resistance to water stress conditions. From the soil water and satellite monitoring results, there is a good agreement with the field results in terms of water stress and its effects on crop vigour. This study contributes to a better understanding of the possibility of hemp crop reintroduction in areas where water deficit occurs, which could open up the opportunity for selecting hemp crop cultivars that can be grown under different agro-ecological conditions and are also of great commercial interest for decision makers involved in sustainable crop management and in the reduction of fertilizers and pollutants released into the environment.

Keywords: industrial hemp; alternative crop; resilience; drought resistance; remote sensing; ground penetrating radar

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1. Introduction

The Council Directive 75/268/EEC on mountain and hill farming and farming in certain less-favoured areas encourages agricultural activities to preserve this activity to protect the territory and to stop depopulation, where a minimum level of population and the conservation of the natural environment would not otherwise have been ensured [1]. Furthermore, the European Green Deal [2] is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use (European Commission, Brussels, 11 December 2019). Through the European Green Deal actions, the transition to a sustainable agriculture will be achieved through the conservation and reproduction of natural resources and biodiversity and ensured by the economic sustainability of agricultural systems.

Within the context of a sustainable management of the environment and natural resources, the cultivation of industrial hemp as an alternative crop to be used in rotation with cereal crops such as wheat, barley, and oats, can be considered as an eco-compatible development model that can be reached through research and innovation [3]. The cultivation of industrial hemp was widespread in Italy in the past and, only in recent years, it has shown a significant interest in agricultural management practices. In fact, there has been a return to investing in industrial hemp due to the new interest aroused by its products in the fields of food and nutraceuticals, cosmetics, textiles, and pharmaceuticals obtainable [4–9]. In addition, hemp produces in the field of green building manufactured products, including thermal insulation, carbon-sequestering bioplastics, and lightweight concrete substitutes that reduce transportation costs [10]. For this multipurpose production, some dual-purpose industrial hemp varieties have been cultivated that yield both fiber and seed [11].

As reported by [12,13], industrial hemp cultivation has the potential to be an environmentally friendly and highly sustainable crop and can fit well in a crop rotation with the aim of increasing soil fertility, even in drought conditions. In fact, hemp crop gives a conspicuous residual fertility with a consistent quantity of organic residues left on the soil (15–20 t/ha of fresh weight) and thus the potential to efficiently suppress weeds [14].

As reported by [10], hemp crop has a deep root system which decays rapidly, thus providing both soil aeration and fertilization and it also shows an exceptional growing potential in pesticide- and herbicide-free conditions [15].

Arid and semi-arid regions are significantly affected by climate change and new strategies of crop management in these dry climate environments are welcome. In fact, climate change is responsible for a global temperature increase and a reduction in rainfall leading to reduced soil moisture. Drought due to reduced soil moisture is one of the most important environmental factors limiting crop production [16–18].

Therefore, this situation and future scenarios increase the need to identify and introduce crop and related cultivars that show high resistance to drought stress [19,20]. As reported by the literature, various mechanisms are involved in plants' response to water stress and drought resistance [21,22], e.g., by promptly closing their stomata to reduce water loss [23,24] with a reduction in CO_2 absorption available for photosynthesis and a premature leaf senescence and a decrease in leaf expansion [22].

Within this context, vegetation indices applied to multi-/hyperspectral data are increasingly being used in precision agriculture as reliable cost-effective plant-based indicators to assess biophysical properties related to plant water status/stress [23–25]. It is very important to have near-real-time knowledge of the relationship between leaf spectral and physiological responses under variable water conditions. Crop spectral reflectance properties, in specific wavelength bands in the visible (VIS) and near-infrared (NIR) region, are strongly related to leaf water status, photosynthetic pigment concentrations, and photosynthetic activity [24]. In this study, to assess and monitor the hemp crops fields' vigour in the proposed study area, eleven Sentinel-2 (ESA) satellite multispectral reflectance images acquired between June and October 2017 were used. Many studies have proposed spectral reflectance indices for monitoring crop biophysical variables and water status, expressed as relative water content (RWC) [24,26] and photosynthetic status [27,28]. For this study, we applied to the Sentinel-2 reflectances a commonly used vegetation index, the Green-Red Vegetation Index (GRVI), due to its simplicity, applicability to temporal series of multispectral imagery, and well-understood underlying mechanisms [29]. The GRVI index exploits the balance between the reflectance in the green and in the red of the crop canopy, which changes in response to the state of health/vigour of the crop leaves related to the plant stress and plant water content. As reported by [29,30], the authors assessed the use of the GRVI as a phenological indicator based on multiyear stand-level observations of spectral reflectance and phenology at several representative ecosystems in Japan.

In conclusion, the main goal of the research is to contributes to a better understanding of the possibility of hemp crop reintroduction in areas where water deficit occurs, which could open up the opportunity for selecting hemp crops cultivars that can be grown under different agro-ecological conditions and are also of great commercial interest.

This is important as its reintroduction in areas, otherwise destined to be scarcely productive, contributes (a) to improve the socio-economic resilience; this because of its direct impact on the possibility of creating an agri-food chain with an increase in jobs opportunities and a decrease in the degree of depopulation and (b) to reduce the irrigation and fertilization in agricultural crops for a sustainable agricultural management.

2. Materials and Methods

A two-year cultivation test (2016–2017) was carried out at the ALSIA (Agency for the Agricultural Development and Innovation of Lucania) experimental Agricultural Farm "Pantano of Pignola", located in Basilicata Region, Southern Italy (Figure 1a). Meteorological data were provided by a weather station located in the farm. In 2016, two commercial industrial hemp varieties (Futura 75 and Uso 31 cultivars) with low tetrahydrocannabinol (THC) content were used (Figure 1b) [31]. The two hemp varieties show a monoecious character, with male and female flowers present on the same plant, guaranteeing a good production of grain and limited development in height (maximum crop height of 2 m). As reported by [12,31], monoecious varieties have been selected to reduce the agronomic problems related to the lack of an efficient mechanization for harvesting the seeds for sexual vegetative dimorphism present in dioecious varieties. The second year of testing (2017), based on the results obtained in the previous year in terms of yield and ground cover, the Futura 75 variety was investigated on an area of about 7000 square meters (Figure 1c).

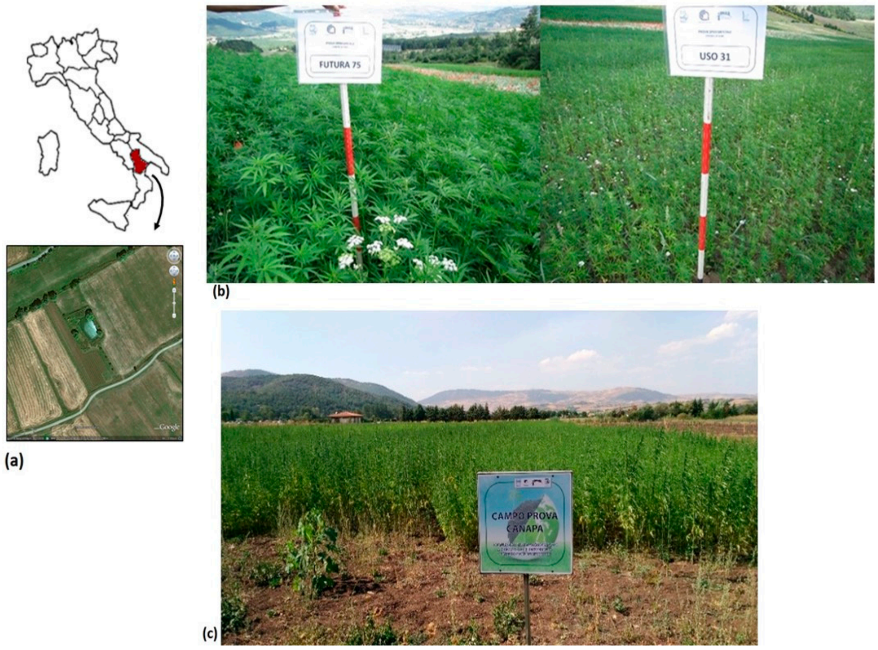

Figure 1. (**a**) Location of the study area in southern Italy (Google Earth 2015); (**b**) The Futura 75 and Uso 31 hemp crop varieties of 2016 used for this study; (**c**) The Futura 75 hemp crop variety applied for this study in 2017.

Following the principle of minimum tillage that is contemplated by a conservative agriculture [32,33], the loam clayey soil rich in organic matter (35 g/kg) was prepared with a rotary tiller to favor the burying of the seed. Hemp normally does not require irrigation and does not require any phytosanitary and herbicide treatment; therefore, none of these interventions were performed in our experimental fields with benefits on the soil but also on the rational use of resources with a consequent reduced use of chemicals and water consumption.

During the vegetative period, non-invasive measures of the soil's water status were performed. Watermark probes (Irrometer CO, Riverside, CA, USA) buried at 20, 40, and 60 cm were used for the soil water potential measurements; moreover, a ground-penetrating radar (GPR), a non-invasive geophysical technique able to provide images of the subsoil useful to monitor the groundwater level was used.

The water potential of a soil expresses, in terms of tension, the force with which the water is retained by the soil, quantifying the energy that plants must spend for the absorption of water [34]. The watermark probe is a granular matrix sensor containing two electrodes that measure soil matric potential indirectly by electrical resistance. Its operation is based on the same principle as other electrical resistance sensors. In fact, soil water variations are reflected in variations in electrical resistance between two electrodes imbedded in the probe and that decreases with increasing soil water.

The GPR is an active electromagnetic technique whose working principle is the one of a common radar system. A transmitting antenna radiates an electromagnetic wave, which propagates downward through the sub-surface materials at the velocity determined by the soil dielectric permittivity. When this propagating wave encounters any change in the bulk electrical properties of different subsurface lithologies, mineralogy, and/or the character of the sediment interface, some of the energy is reflected to the surface [35]. For the experiment at hand, GPR surveys with 20 parallel acquisitions, spaced by 1 m from each other were carried out with a GSSI SIR 2000 subsurface interface radar system (Geophysical Survey Systems Inc., Nashua, NH, USA) equipped with a monostatic antenna with 400 MHz peak frequency.

Furthermore, hemp crop monitoring was performed using European Space Agency—(ESA)'s Sentinel-2 multispectral satellite (S2-MSI) data acquired during the hemp crop growing season in 2016 and 2017 over the study area. The S2 satellite has 13 spectral bands ranging from the Visible to the short-wave infrared spectral regions with a 10-, 20- and 60-m spatial resolution [36]. For this study, eleven S2 images (Figure 2) were acquired and pre-processed using the SNAP ESA toolbox [37] to obtain reflectance images at 10 m of spatial resolution, from which deriving spectral indices useful to monitor the hemp crops.

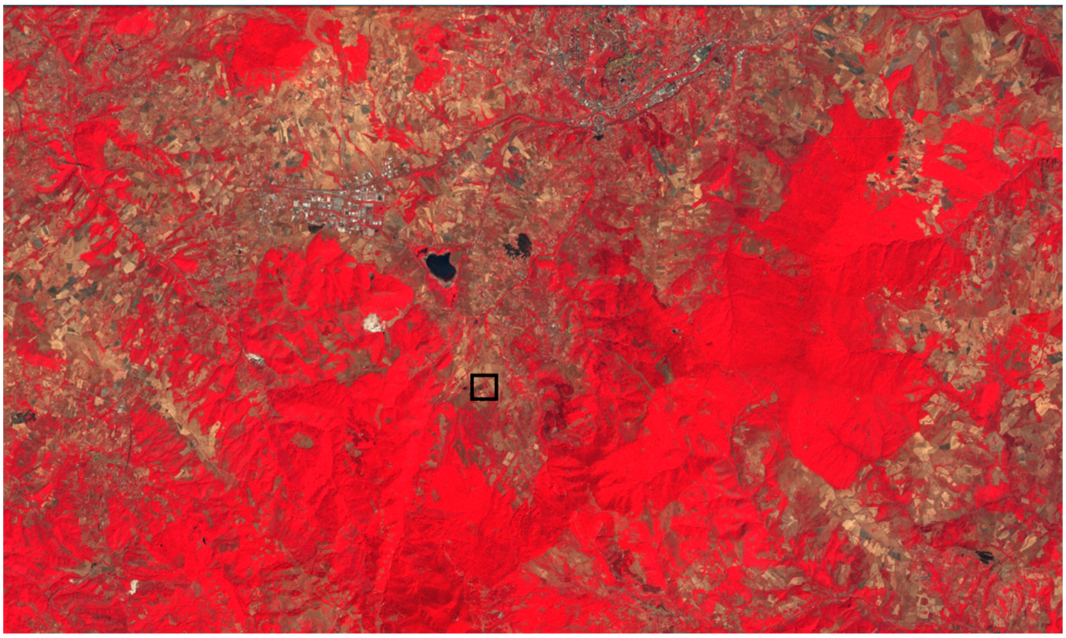

Figure 2. Example of a S2 (R: 842 nm; G: 560 nm; B: 490 nm) imagery acquired on the study area (black box) in 2017 (6 August 2017; center coordinates of the black box/zoom image are: 40°33′37.54″ N and 15°45′40.64″ E).

3. Results

Table 1 shows the adopted cultivation techniques and the relative hemp crop yields for the two years of testing. The sowing and harvesting of the grain were carried out with a seeder and combine harvester.

Table 1. Adopted cultivation techniques and yields.

	2016	2017
Previous crop	Multi-year weed	Multi-year weed
Soil preparation	Minimum tillage	Minimum tillage
Fertilization	No	No
Cultivar	Futura 75, Uso 31	Futura 75
Sowing date	April 28	May 02
Sowing	In rows 10 cm apart	In rows 10 cm apart
Irrigation	No	No
Weed control	No	No
Harvest date	September 29	October 06
Yield	Futura 75: 520 kg/ha Uso 31: 120 kg/h	Futura 75: 171 kg/ha

3.1. Climatic Conditions

Figure 3 shows the climatic trend over the last ten years, in the province of Potenza (Basilicata Region-Italy) where the test area is located. It is apparent that the maximum annual temperature is slightly increased, while the rainfalls are reduced and the potential consumption of water by crops is increased. Obviously, over the years there are fluctuations in the average values.

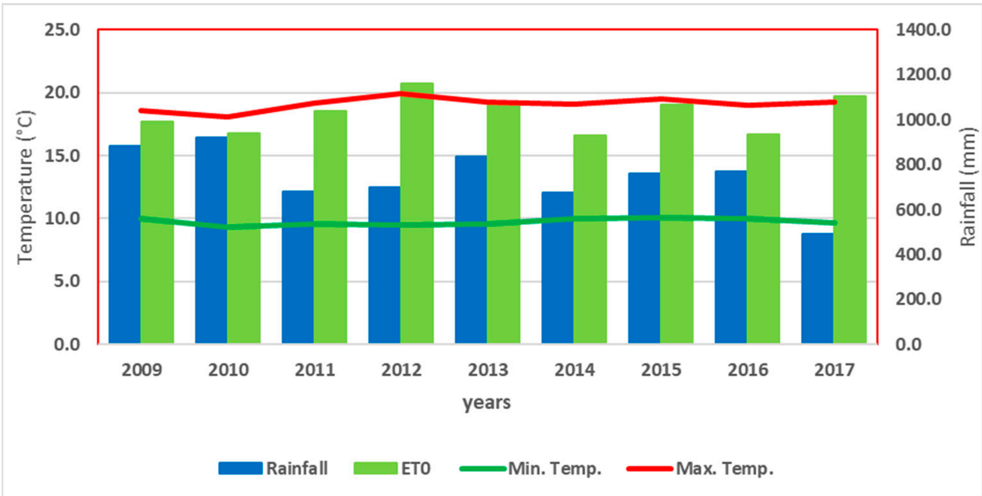

Figure 3. Average values for the maximum and minimum annual temperature, rainfall (mm/year), and potential evapotranspiration (ET0—mm/year) relative to the last ten years for province of Potenza (Basilicata Region) (source: Ministry of Agricultural, Food and Forestry Policies-Italy).

Figures 4 and 5 highlight, for the study area, the climatic trend in the two years of experimentation. There was a marked decrease in rainfall in these two years with respect to the five-year period 2010–2015, with a peak in June and July, the two fundamental months for the hemp vegetative growth. On the contrary, after the severe drought, at the beginning of September, the rains resumed profusely, also accompanied by a reduction in temperatures (Figure 4). For the crop and its production this is not desirable and to remedy the sowing of the crop could be anticipated if the climatic conditions allow it.

In the months of May–August, in the water balance, the consumption of water by the hemp crop was greater than the rains (Figure 5).

3.2. Soil's Water Status and Satellite Monitoring

In the second year of the trial, soil water content and hemp crop vegetative state were also performed. In particular, the results of the soil water potential, measured using a Watermark sensor during the growing phase of the hemp crop, revealed that the low rainfall occurred has caused a persistent dryness of the soil that persisted in the deeper layers (60 cm) even after the rains of September 2017 (Figure 6).

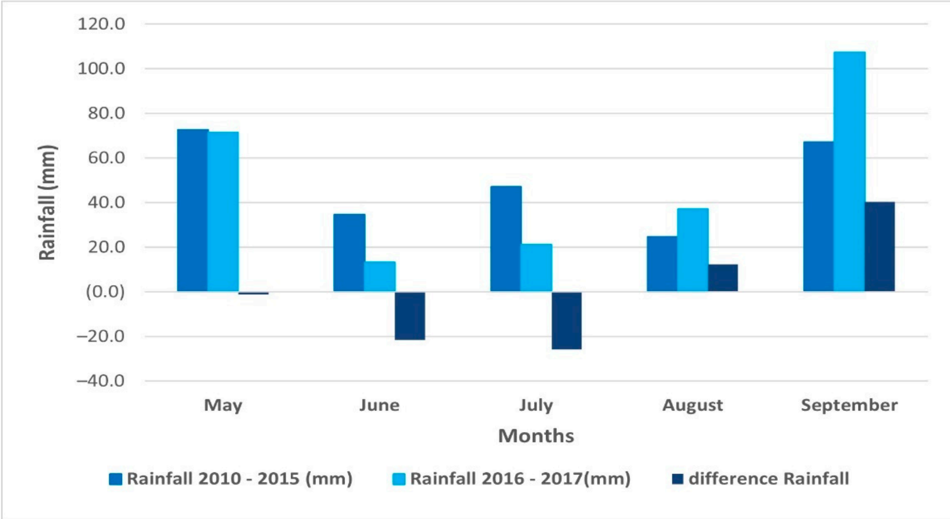

Figure 4. Comparison of monthly rainfall values recorded by the weather station of the farm.

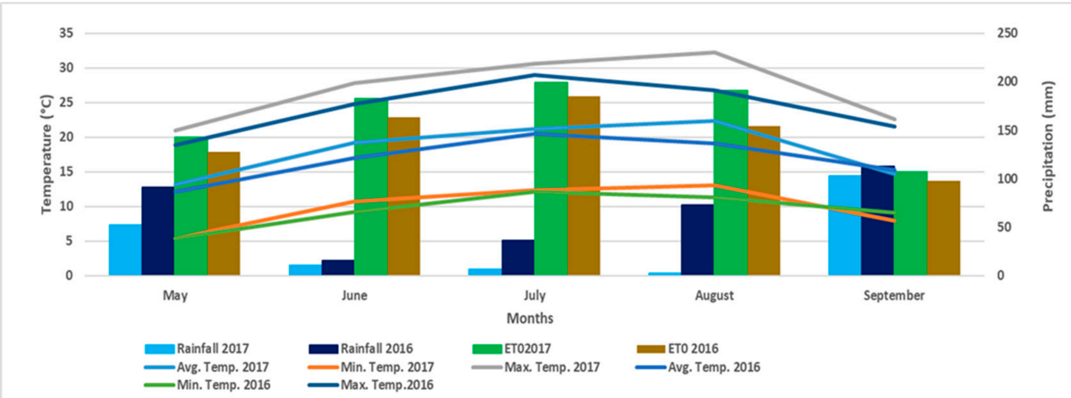

Figure 5. Climatic trend relative to the two years of test, 2016 and 2017.

This condition of limited availability of soil water was confirmed by the investigation with the GPR. In fact, Figure 7 presents the radargrams obtained from the geophysical prospection from May to August 2017, which clearly show the absence of precipitations and the high consumption of water by the hemp crop due to evapotranspiration. From Figure 7, it is evident that the water table drops from about 70 to 140 cm below the soil surface, with a consequent limited water supply for the plants due to capillary rising [38]. Furthermore, the reduction of the soil water content in the period May–August, due to the absence of rains and the high temperature, has determined substantial variations in the three radargrams, probably because the roots explore the soil to reach the water table [39].

Despite this and without irrigation, the hemp crop has completed its cycle thanks to its resistance to water stress conditions.

Concerning the satellite monitoring of the hemp crops during their growing phase in 2016 and 2017, among the different spectral indexes [29] tested on the S2 reflectance images, the one that provided the best results for monitoring the state of health/vigor and phenology of the hemp crops was the Green-Red Vegetation Index (GRVI) [30,40–42]. The GRVI index exploits the balance between the reflectance in the green and in the red of the crop canopy, which changes in response to the state of health/vigor of the leaf. The threshold "GRVI = 0" could be very effective for 0.5 for the hemp crop, indicating the vigour of the vegetation [30]. The analysis of the GRVI index trends for the different dates of S2 images provided a good correlation with the crop growth status and phenology of the hemp. In Figure 8, the S2 images in RGB (R: 842 nm; G: 560 nm; B: 490 nm) are presented on the left with the relative GRVI map on the right. High values of the GRVI index are represented (only for visualization purposes) in red colour and show a high correlation with the hemp maximum stage of the crop, i.e., between June and September 2017 (Figure 8a–j).

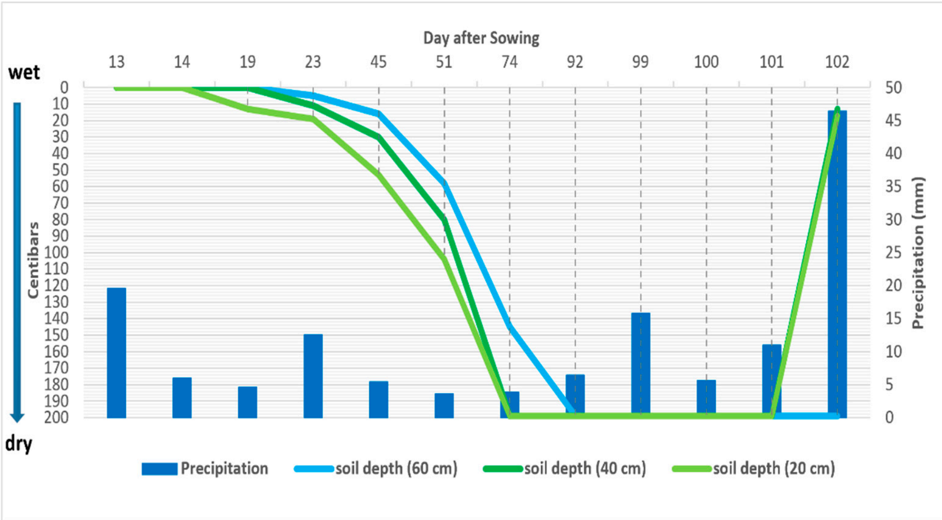

Figure 6. Measurements obtained from Watermark sensors of soil moisture tension measured at 20, 40 and 60 cm of depths (May–September 2017).

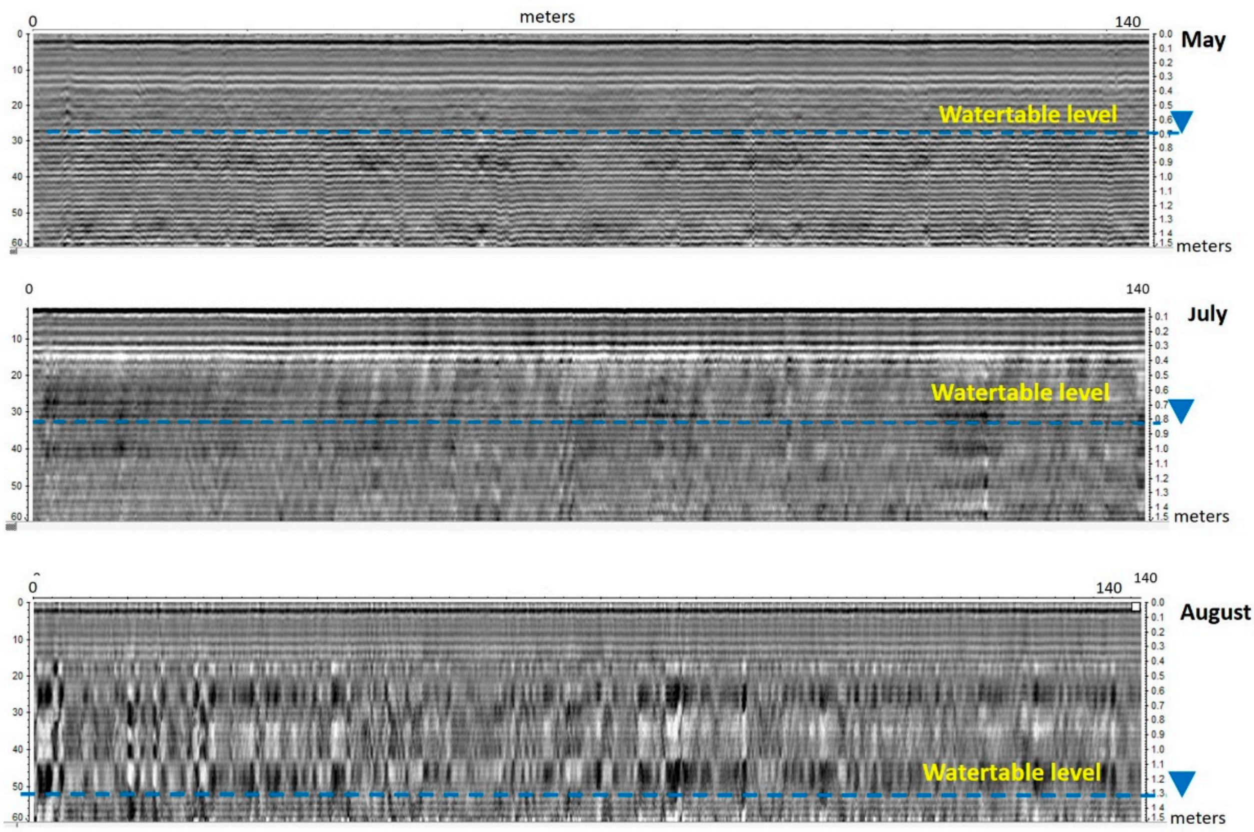

Figure 7. GPR images (radargrams) of the soil profile and oscillations of the water table in three different moments of the veg-etative cycle of hemp (May–September 2017).

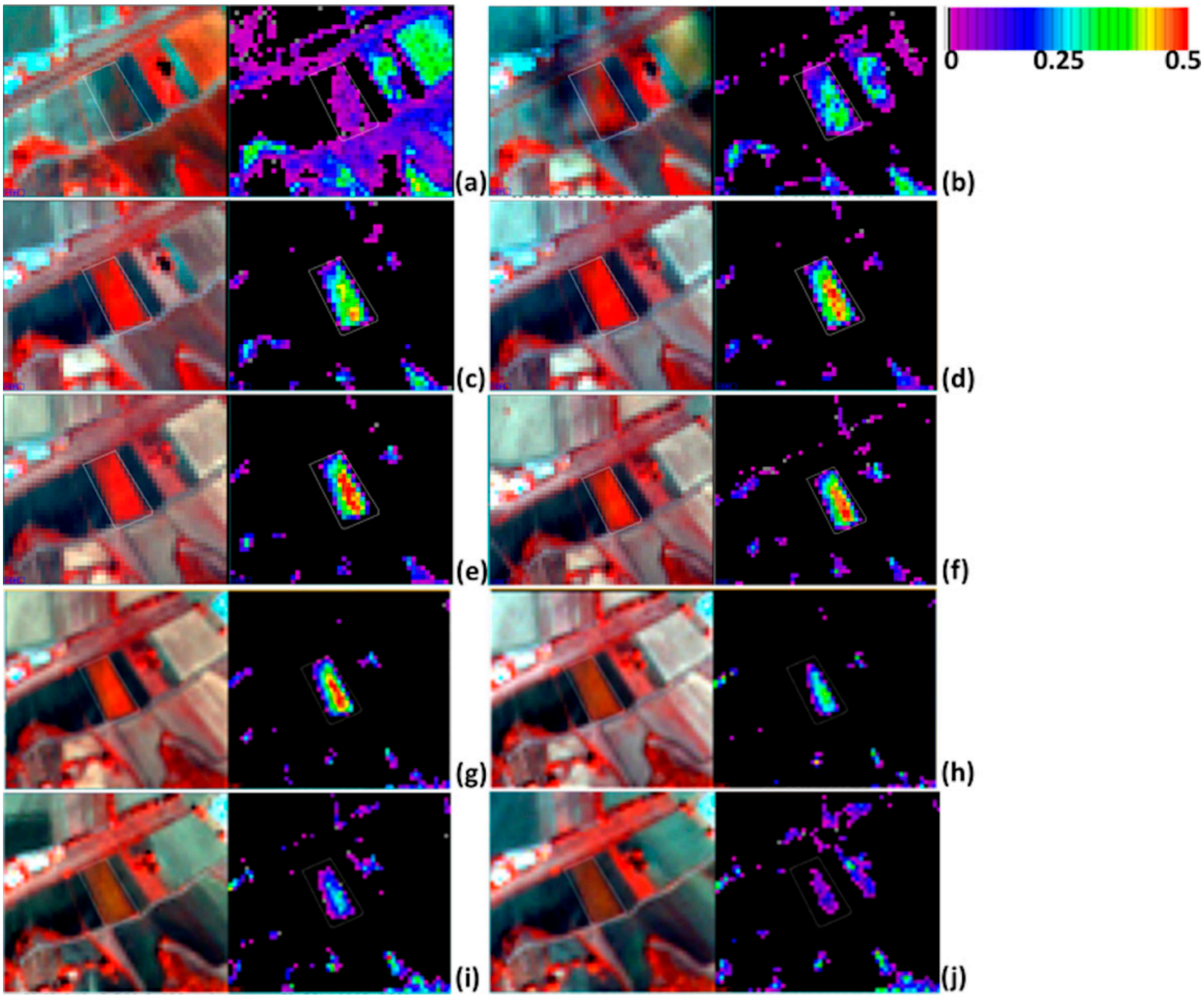

Figure 8. S2 multispectral satellite images zoom on the hemp crop fields acquired on the study area from June to October 2017: (**a**) 14 June; (**b**) 27 June; (**c**) 7 July; (**d**) 27 July; (**e**) 6 August; (**f**) 16 August. (**g**) 23 August. (**h**) 5 September; (**i**) 15 September; (**j**) 22 September. For each zoom imagery, the left image shows the S2 RGB (R: 842 nm; G: 560 nm; B: 490 nm), while right image depicts the corresponding classified imagery (with a GRVI range of values between 0 and 0.5 and the relative colour legend).

4. Discussion

Within the context of climate change, it is necessary to introduce alternative crops to develop strategies for sustainable water management. Moreover, droughts and water shortages in general are a huge factor limiting crop yield in an increasing number of areas of the globe. Global warming, which among others, strongly affects biogeophysical cycles, will surely increase the water scarcity not only in arid and semi-arid zones, but also in temperate regions. In this view, it is essential to understand plant functional responses to soil drying in order to mitigate the effects of drought on crop yield. The hemp plant is highly adaptable to a large variety of climate and pedological conditions and it does not require much effort, both in terms of irrigation and fertilization, for its growth and development [15].

As reported by [43], the revaluation of the hemp crop can provide a significant incentive in the recovery and safeguarding of disadvantaged territories. The choice of suitable cultivars that adapt to the environment is of fundamental importance for the success of hemp cultivation. Based on the results obtained in the first year in terms of yield, the Futura 75 variety has provided the best results and it was decided to continue with this cultivar in the study of reintroduction of hemp cultivation to encourage agricultural activities and improve the income of farmers in disadvantaged agricultural areas to protect the territory and to stop depopulation.

Several studies report that different areas of the Basilicata region are particularly affected by drought [44–47]. The study area is characterized by dry summer with rainfalls that are 30–35% of potential evapotranspiration.

In the hemp cultivation period between May and September 2016, the climate of the study area was characterized by frequent rains and temperatures slightly below the average. On the contrary, in the second year, the climate had an opposite trend with high temperatures and a significant drought period during the summer months.

From the results obtained, the water scarcity (due to very low rainfall) that occurred in southern Italy in 2017 has partially compromised the hemp grain production. Hemp crop, albeit resistant thanks to the genetic mechanisms that regulate drought tolerance [48], suffered drastic water deficit that lasted too long accompanied by prolonged periods of high temperatures.

However, hemp crop has a capacity to grow quickly, and due to the fast-growing dense canopy, is a natural weed suppressor [13]. This results in an absence of competition for water in drought situations. In general, in hemp crop, there is no irrigation; in our experimental test, irrigation interventions were intentionally not planned to evaluate the behaviour of this crop in water stress conditions. Unfortunately, in situations of significant scarcity or absence of rain, increasingly frequent because of climate change, the scarcity of water becomes the major constraint for the crop and the absence of irrigation leads to fluctuations in yields over the years. Therefore, in the presence of these extreme events, it could be effective to intervene with an emergency irrigation that for our study area could be effective in the second half of August. In fact, during this period, the cultivars generally reached the grain-filling phase.

Sentinel 2 satellite results indicate that there is a good agreement ($R^2 \geq 0.80$ for the two fields of interest) with the field results in terms of water stress and its effects on crop vigour, which is highly correlated with crop biophysical parameters retrievable from S2 imagery, such as LAI, FAPAR, chlorophyll content in the leaf (Cab), and canopy water content (Cw). For this study, the estimation of crop water content, which is recognized as a key variable for assessing crop physiological status due to its close association with plant transpiration, vegetation stress, and biomass productivity [49], will be further assessed by means of ad hoc field campaigns on hemp crop experimental fields.

We are aware that two years of experimentation are few to test the validity of the selected cultivar and its benefits and impact for a sustainable management of agricultural practices; however, we started to test the validity of the proposed methodology on a small dataset. However, the provided remotely sensed products can surely provide near-real-time monitoring of crops and guide operations at the regional scale with no costs for both farmers and decision-makers.

5. Conclusions

The promotion of as the reintroduction of hemp crops in abandoned territories allows to strengthen the bond with the territory and combines with the strategies of sustainability and profitability, facing demanding challenges such as considerable pressure on natural resources, climate change, and loss of biodiversity. The optimization of agricultural practices and the use of natural resources with interventions that exclude any chemical substance, which aims at the regeneration of soil fertility through minimum tillage and the incorporation of organic matter, allows to obtain positive effects in terms of erosion and desertification of the land and the environment in general.

The cultivation of hemp is spreading considerably worldwide thanks to the vast field of use of its products and there is a renewed interest in this crop in Italy as well. Due to its functions in improving soil quality and high resistance to drought, hemp is an excellent crop to be used for crop rotation programs to optimize the yield of the main cropping system. For this study, among the two years of testing, we noticed a great variability in hemp crop yield and factors such as temperature during the growing season and water availability have influenced its production. Therefore, we can assume that it is advantageous to choose hemp varieties that fit better to local environment of cultivation. Remote sensing results show a good agreement ($R^2 \geq 0.80$ for the two fields of interest) with the field results in terms of water stress with the GRVI index (related to crop plant stress) spatial distribution.

Further years of experimentation are surely necessary to test the validity of the selected cultivar, to identify the optimal agronomic techniques and the most suitable hemp varieties for cultivation in Mediterranean areas. This is also to promote hemp as a crop capable of contributing to the reduction of the environmental impact in agriculture, the loss of biodiversity and to the recovery and enhancement of the territory.

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Conflicts of Interest: The authors declare no conflict of interest.

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