

Cup Plant (*Silphium perfoliatum*): Agronomy, Uses, and Potential Role for Land Restoration

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Abstract: In recent years, land degradation has become a major challenge for human society, with negative impacts on the natural habitat, the economy, and human well-being. A variety of anthropogenic and natural factors are exacerbating the processes of land degradation in the era of climate change. Land restoration is an important and proactive strategy to combat this negative situation. Among the many approaches, the use of vegetation plays a central role in restoring soil health, preventing erosion, promoting biodiversity, and improving water retention. Therefore, the identification of new plant species that have the properties to contribute to land restoration is a necessity today. The plant proposed in this conceptual review for land restoration is the cup plant (*Silphium perfoliatum* L.). After a brief presentation of the agronomy, adaptability, and multiple uses of this plant species, its potential to provide important ecosystem services useful for land restoration to combat land degradation is herein emphasized. Recent studies have shown that this plant has great potential for phytoremediation of soils contaminated with heavy metals (Zn, Pb, Cr, Cd, Ni, Hg, and Co), especially in post-mining areas where pollution exceeds ecological limits. Most studies have shown that the accumulation of heavy metals is higher at the lamina stage. There is also some evidence that the cup plant thrives in flood-prone areas and contributes to their restoration. Cup plant cultivation can also reduce greenhouse gases and increase the organic carbon content of the soil. Another method of land restoration related to the establishment of the cup plant in a given area is the suppression of weeds, particularly the prevention of the invasion of exotic weed species. Further research under different soil-climatic conditions is needed to investigate cup plant cultivation as a promising strategy for land restoration in a time when the climate is constantly changing.

Keywords: degraded lands; adaptability; ecosystem services; multipurpose crops; biomass



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1. Introduction

Land degradation is a complex, global cause-and-effect phenomenon [1]. Natural factors such as rainfall patterns, geomorphology, and soil characteristics as well as socio-economic factors such as agricultural intensification through unsustainable farming practices, land fragmentation, poor land use planning, mining activities, urbanization, and infrastructure development are some of the major causes of land degradation [2]. Climate change is expected to exacerbate many of these degradation processes, setting in motion a cycle of worsening environmental and social impacts [3]. The burning of fossil fuels, agriculture and livestock farming, deforestation, industrial activities, urbanization and

land use change, and the use of fluorinated gasses are among the man-made causes of climate change, while natural causes include solar variability, volcanic activity, and natural climate cycles [4]. The consequences of land degradation, which are exacerbated in the context of climate change, are manifold: soil erosion, drought, desertification, decline in agricultural productivity, water scarcity and pollution, loss of carbon storage, loss of biodiversity, poverty, and migration [5].

Land restoration is an important and proactive strategy to combat land degradation, especially in the context of climate change [6]. Agroforestry, conservation agriculture, water management, sustainable pasture management, etc., are useful tools in the development of effective land restoration strategies [7]. Among the many approaches, the use of vegetation plays a central role in restoring soil health, preventing erosion, promoting biodiversity, and improving water retention. One of the most promising strategies to combat land degradation is to increase or at least maintain vegetation cover. Plants can stabilize degraded land, restore soil organic matter, and even support carbon sequestration, making them powerful tools for ecosystem recovery [8]. Therefore, the identification of new plant species that have the properties to contribute to land restoration is now a necessity.

The plant suggested for land restoration in this conceptual review is the cup plant (*Silphium perfoliatum* L.). The cup plant has gained increasing interest in recent years due to its diverse applications in biogas production, livestock feeding, medicine, phytostabilization, and its remarkable adaptability to different environmental conditions. The cultivation of the cup plant offers several ecological advantages and reduces the environmental impact associated with conventional farming systems [9]. The crop can also be used to remediate polluted soils [10]. As it is a perennial species, it also requires less financial investment in tillage and fertilizers [11]. Its deep root system ensures efficient use of nutrients, and its cultivation avoids annual tillage, which improves soil structure, reduces erosion, and promotes biodiversity [12]. The cup plant is also a promising energy crop for biogas production, as it provides high biomass yields, which can also lead to high biogas yields. A recent example is Poland, where the biogas yield was over 8500 m³ ha⁻¹ [13]. At the same time, the crop supports pollination through its long flowering period (July–September), which provides pollinators with pollen and nectar sugar [14]. Nevertheless, this crop can provide high annual yields for up to 15 years without the need for replanting [15]. Efforts such as sustainable agricultural land management, reforestation, agroforestry, and nature conservation can all contribute to climate change mitigation and adaptation while improving human well-being and economic resilience [16]. All in all, developing sustainable strategies to restore land in a changing climate is critical to protecting the environment and creating a more sustainable world [17].

This conceptual review first provides a brief description of the crop in terms of its botanical characteristics, its environmental requirements, its multiple uses, and the agronomic practices suitable for its cultivation. It then highlights the crop's potential to provide important ecosystem services useful for land restoration to combat land degradation in a changing climate, both in conventional agricultural areas and in degraded marginal lands. Finally, the challenges and opportunities of cup plant cultivation and its role in land restoration under real field conditions in European agriculture are discussed.

2. Plant Description

The cup plant is native to the Great Plains region of North America, including parts of Alabama, Kansas, and North Dakota [12]. The cup plant is cultivated in various regions of North America, Europe, and Asia. Cultivation has spread to parts of Europe, especially Germany, Poland, and France. The *Silphium* species are divided into two sections: section *Silphium*, which includes *S. asperrimum*, *S. asteriscus*, *S. brachiatum*, *S. gracile*, *S. integrifolium*,

S. mohrii, *S. perfoliatum*, *S. radula*, *S. trifoliatum*, and *S. wasiotense*, and section *Composita*, which includes *S. albiflorum*, *S. compositum*, *S. laciniatum*, and *S. terebinthinata* [18]. The species of section *Silphium* have a fibrous root system [11] and a cauline growth habit, whereas the species of section *Composita* typically have taproots and scapose inflorescences with conspicuous basal rosettes [15].

The cup plant is a tall perennial with yellow flowers and a C3 photosynthetic pathway; it has a diploid chromosome number of 14 and exhibits considerable genetic diversity, with seeds available from different geographical regions [18]. In spring, when temperatures exceed 5 °C, the plant starts to grow and forms 12–15 leaves before forming several vertical stems that can reach up to 3 m in height [15]. The leaves are triangular to oval and toothed and form cups that can grow up to 40 cm long and 25 cm wide. The plant produces bright yellow flowers that bloom continuously for 10–12 days, with each stem producing 8–10 flower heads [15].

In the first year, it grows a large rosette up to 70 cm in diameter [18]. After winter, a flowering stem develops, reaching a height of 2–4 m in height and producing up to 17 leaves. Between late July and September, it produces a series of sunflower-like flowers, with each flower head consisting of a central disk and two rows of ray florets [15]. Although roots were found at a maximum depth of 1.5–1.7 m, the highest density of roots was found in the upper 0.3 m [12]. The root system of the plant allows it to utilize soil fertilizers efficiently, and it is recommended for areas with high soil erosion [19].

The few data currently available from articles in internationally recognized journals indicate that the annual biomass yield of the cup plant is between 13.3–16.5 t ha^{−1} [9,12,15]. In their field trials, Siwek et al. [13] reported biomass yields of over 20 t ha^{−1} with a two-cut strategy. According to Cumplido-Marin et al. [11], the cup plant is an extremely profitable and competitive crop with theoretical yields between 15.0 t ha^{−1} for Mediterranean areas and 16.3 t ha^{−1} for northern European regions.

3. Environmental Requirements

This crop is well adapted to the different European climate zones. The ideal temperature for its growth is between 18 °C and 30 °C, but the best optimum temperature is 20 °C. It can withstand low temperatures and is considered cold tolerant. Due to its perennial nature, it can overwinter and regrow from its root system every spring [15].

It tolerates a wide range of soil types, including sandy and clay soils, as long as the soil is not waterlogged. The crop thrives best in fertile, humus-rich soils with a good moisture supply. Rich soils in river valleys on riverbanks, lakeshores, ravines, damp sandy soils, etc., are suitable. Hydromorphic soils are unsuitable [15]. The plant prefers slightly acidic to neutral pH values between 5.5 and 7.5. A well-drained, deep soil is ideal for the development of its extensive root system, which contributes to its resilience and biomass production [12]. Full sun is essential for optimal growth [16]. The cup plant requires at least 6 h of direct sunlight per day [15,18] for healthy development and high biomass yields [15]. It is best suited to open, sunny fields where it receives ample light throughout the growing season [18]. The plant has a robust structure with tall, stable stems that offer a certain wind resistance. It is tolerant of moderate winds, but young plants may benefit from protection from strong winds until they are well established. Windbreaks or sheltered sites can promote the growth of the plant in its early stages [20].

4. Crop Management

Although the cup plant is not considered a commercial field crop cultivated on large agricultural areas, its agronomy has been studied by many researchers around the world, as summarized in some recent literature reviews [11,12,15,21] (Table 1).

Table 1. Recent review papers on the agronomy of cup plant.

Authors	Year	Journal	Publisher
Peni et al. [12]	2020	<i>Agriculture</i>	MDPI
Gansberger et al. [15]	2015	<i>Industrial Crops and Products</i>	Elsevier
Cumplido-Marin et al. [11]	2020	<i>Agronomy</i>	MDPI
Van Tassel et al. [21]	2017	<i>Crop Science</i>	Wiley

Deep plowing or primary tillage is often performed to loosen compacted soil, improve drainage, and promote root penetration [12]. This is followed by secondary tillage, such as harrowing or cultivating, to create a fine seedbed. In this way, contact between seed and soil is established, and the problem of germination is reduced [18].

For optimal growth, the plant requires regular moisture, but once established, it can also tolerate drought [12]. It thrives best in areas with an annual rainfall of 600 mm to 1200 mm, which ensures healthy growth throughout the season. More specifically, it requires 200–250 mm during the growing season and 400–500 mm for the rest of the year [22,23]. Although its dense and deep root system indicates a potential for drought tolerance [21], lower water use efficiency was found in a 2-year experiment, indicating lower drought tolerance [22]. The irrigated cup plant produced 37% and 23% more shoot biomass than the drought-stressed cup plant [24].

The cup plants should be fertilized as early as possible in the year. The fertilizer requirement depends on the nutrient supply of the soil and the expected nutrient uptake of the plants. In general, the crop needs 10 kg of nitrogen to produce 1 t of dry matter [18]. Mineral and organic fertilizers are both suitable. The Nitrates Directive, which is part of the EU Common Agricultural Policy, limits the application of organic nitrogen (N) to 170 kg ha⁻¹, phosphorus (P) to 25 kg ha⁻¹, and potassium (K) to 150 kg ha⁻¹. It also indicates that the cup plant requires a small amount of magnesium (Mg) (about 50 kg ha⁻¹) and calcium (Ca) (200 kg ha⁻¹). The combination of digestate and mineral fertilizers gives the highest yield [3]. In the first year, the cup plant grows slowly, and ground cover is achieved in summer. This makes it clear how important early weed control is for the successful establishment of the crop. Peni et al. [12] suggested two or three mechanical weeding in the first growing season to allow the crop to grow and develop a dense canopy that shades the soil and suppresses weed growth in the following years of the plantation. However, there is a lack of original data on the effects of weed interference on the growth and productivity of the cup plant. During the vegetation stage, the spaces between the rows must be repeatedly hoed and loosened either by machine or by hand. Selective herbicides could significantly reduce this effort, but there are currently no herbicides approved that are compatible with the cup plant [15,22]. From the second year onwards, the crop quickly achieves complete ground cover, making further weed control superfluous.

Insecticides should be tested to prevent pest infestation, as some insect pests have been observed on the cup plant. For example, root damage by the ground-dwelling beetle has been reported [12]. More recently, insect pests such as the larva of *Eucosma giganteana*, the tumbling flower beetle, an aphid, and a parasitic wasp have been discovered in South Dakota and Wisconsin [25]. Red aphids are occasionally found on the underside of the leaves [12].

The same applies to the management of diseases. Fungi can also reduce yields, with wet summer weather favoring infections [15]. There are currently no specific fungicides for the cup plant, but early harvesting can help prevent the spread of fungi by preventing the fungus from forming permanent fruiting bodies. That said, the cup plant should be grown after weed-suppressing crops such as root crops, cereals, and maize but not after unfavorable preceding crops such as oilseed rape, sunflowers, peas, vegetables, and

potatoes, as these are generally considered as potential host plants for the fungal disease attributed to *Sclerotinia* spp.

The selection of plant populations may vary, but a planting density of four plants per m^{-2} is often recommended. Some studies have used 100 cm spacing between rows and 50 cm distance between seedlings in each row [25–27] or three plants m^{-2} with 90–100 cm $\times$ 40 cm [28–30]. Some other studies have shown that the best method is to plant the seedlings using a pattern of 70 cm $\times$ 30 cm [31].

5. Uses

The cup plant is a versatile non-food crop with good adaptability to different environments where it can be grown for bioenergy production, as fodder, and as a medicinal plant (Figure 1).

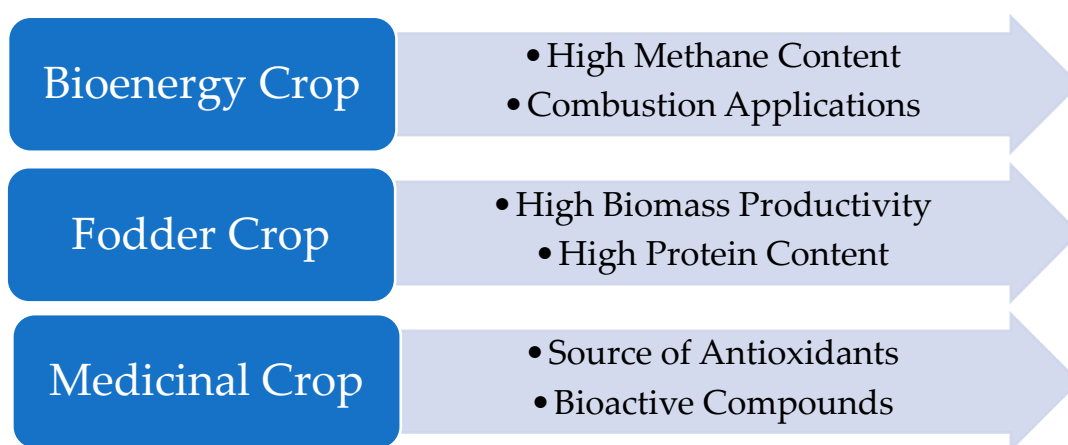


Figure 1. Summary of the multiple uses of the cup plant.

5.1. Bioenergy Crop

The cup plant offers promising potential as a renewable energy crop, especially for biogas and combustion applications. It can occasionally reach methane contents of 51.1% to 56.3%. Factors such as lignin content and harvest time significantly influence the biogas yield. Annual methane production from this crop ranges from 2.2–8.6 L m^{-2} . Nevertheless, the energy ratio can be very favorable, reaching up to 25.3 m^{-2} without fertilization, although it drops to 12.9 with intensive use. Economic obstacles include the high initial costs, which amount to EUR 2.6–3.2 m^{-2} , partly due to the expensive seed [15]. The cup plant can be used for both anaerobic digestion and combustion. While the energy yield from combustion is moderate (858.28 kWh Mg^{-1}), the yield from anaerobic digestion is significantly higher—up to 1069 kWh Mg^{-1} for shredded biomass and 850 kWh Mg^{-1} after high-temperature extrusion (175 °C) [32]. Processing techniques such as extrusion and shredding improve the quality of the biomass and increase the dry matter content and methane yield, with high-temperature extrusion increasing methane output by up to 90.4%. In summary, this method combines high biomass productivity with remarkable environmental and energy efficiency benefits. Although there are still economic and process engineering challenges, it remains a compelling candidate for diversified and sustainable bioenergy production [33].

5.2. Fodder Crop

The cup plant is very promising for various applications, including animal feed. In particular, it is characterized by a high protein content and a considerable biomass yield, making it well suited for feeding livestock [12]. The content of crude protein, crude fat, and

crude fiber, which are all easily digestible components, is optimal when an early harvest date is preferred (>50 , 21 , and 230 g kg^{-1} , respectively); at the end of the growing season, a reverse trend is observed, when the content of ash and fiber, which are not digestible, increases and the content of digestible components decreases [15]. The plant reaches full maturity in 4–5 years and can be harvested economically for up to 15 years without the need for replanting (as is the case with alfalfa plantations, for example), which underlines its long-term viability and sustainability [9].

5.3. Medicinal Crop

The cup plant is also gaining attention for its wide-ranging applications in pharmacy and cosmetics due to its rich profile of bioactive compounds [12]. Some 16 compounds have been identified, some of which have immunosuppressive effects that could be relevant for organ transplantation. Its extracts also show antibacterial, antifungal, and antioxidant effects, largely due to phenolic acids such as caffeic acid and ferulic acid [34]. The plant contains a variety of essential nutrients and bioactive components, including proteins, amino acids, fats, cellulose, and minerals such as potassium and calcium. The seeds are particularly rich in proteins, fats, sugars, and cellulose, while the leaves, rhizomes, and inflorescences provide numerous bioactive substances that are valuable to the pharmaceutical and food industries. Studies show that the content of polyphenols varies greatly in the different parts of the plant and growth stages, with the leaves having the highest concentrations during the flowering period [12]. These polyphenols, including flavonoids and phenolic acids, exhibit strong antioxidant and anti-inflammatory properties, supporting the potential of the cup plant as a natural source of antioxidants for commercial use. In addition, antimicrobial properties, particularly against plant pathogens, suggest a potential role as a biocontrol agent in agriculture. Recent research on the diterpenes chlorsilphanol A and silphanepoxol isolated from the leaves has provided new structural and stereochemical insights confirmed by X-ray crystallography. This contributes to the understanding of these compounds and their potential applications in medicinal chemistry [34].

6. Land Restoration

The cup plant can contribute to land restoration in degraded areas, mainly due to its remarkable potential for phytoremediation, adaptability to flood-prone areas, mitigation of greenhouse gasses, promotion of soil organic carbon content, prevention of weed invasion, soil erosion control, and pollinator support (Figure 2).

6.1. Phytoremediation

Various types of xenobiotics or natural substances enter the environment through natural weathering or anthropogenic activities (mining, intensive agriculture, improper waste disposal, etc.) and disturb the natural ecosystem, leading to the creation of polluted and degraded marginal lands [35]. These marginal lands are usually unsuitable for conventional agriculture due to poor soil quality and environmental pollution. However, recent modeling and field studies have shown that they are suitable for cellulosic biomass production and contribute to carbon sequestration, reduction in greenhouse gas emissions, and improvement of water quality [36]. Despite the development of various chemical and physical remediation technologies such as ion exchange, membrane filtration, and soil washing, their high cost, environmental risks, and low efficiency limit their large-scale use [10]. In contrast, phytoremediation has proven to be a more sustainable and cost-effective alternative [36]. Certain plant species, especially hyperaccumulators, are able to absorb and store heavy metals in their roots and shoots, thus mitigating soil contamination [37]. These plants must exhibit rapid growth, high biomass production, stress tolerance, and deep root

systems [38]. Among the most promising candidates for both bioenergy production and phytoremediation is the cup plant, which has a high adaptability to a range of degraded soils, including acidic, sour, drought-prone and contaminated sites [39]. Its resistance to drought and adaptability to poor soils make it particularly suitable for marginal land. The cultivation of such plants on marginal land could improve ecosystem services and at the same time reduce competition between food and energy crops [40]. Nevertheless, heavy metal pollution remains a major problem, as these pollutants are persistent and can bioaccumulate in ecosystems [39].

There is evidence that this crop has great potential for the phytoremediation of soils contaminated with heavy metals, especially in post-mining areas where pollution exceeds ecological thresholds [10,36,38,39,41–43] (Table 2).

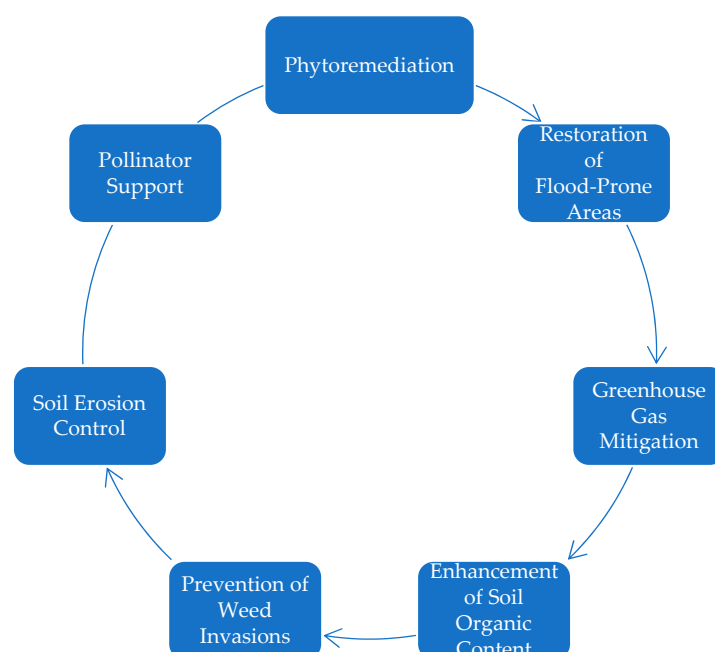


Figure 2. Methods of land restoration through cup plant cultivation.

Table 2. Heavy metals related to the phytoremediation potential of cup plant in recent case studies.

Authors	Heavy Metal							
	Zn	Cu	Pb	Cr	Cd	Ni	Hg	Co
Nescu et al. [36]	✓	✓	✓	✓				
Sumalan et al. [10]	✓	✓	✓	✓				
Angelova and Koleva [41]	✓	✓	✓	✓	✓		✓	
Mockevičienė et al. [42]	✓	✓	✓			✓		
Sumalan et al. [43]	✓	✓	✓		✓			
Zhang et al. [38]	✓				✓			
Lopushnyak et al. [39]			✓		✓	✓		✓

In the recent study by Nescu et al. [36], it was reported that the cup plant on polluted soil in Romania, where the initial Zn concentration was above 300 mg kg^{−1}, accumulated more than 60 mg Zn kg^{−1}, 33 mg Zn kg^{−1}, and 85 mg Zn kg^{−1} in the root system, petiole, and lamina, respectively. In the same study, Cu accumulation in roots, petiole, and leaf lamina was 26.12 mg kg^{−1}, 29.86 mg kg^{−1}, and 65.29 mg kg^{−1}, respectively, and the initial Cu soil concentration was 208.34 mg kg^{−1}. Similarly, the potential of the cup plant for phytoremediation of Cr and Pb was similar. In another work in Romania, the authors found that the bioaccumulation factor (BAF) of the cup plant for Zn, Pb, Cr,

and Cu was 5.63, 7.66, 8.20, and 10.17, respectively, on soil where the initial Zn, Pb, Cr, and Cu soil concentrations were 260.01 mg kg⁻¹, 175.18 mg kg⁻¹, 299.08 mg kg⁻¹, and 234.66 mg kg⁻¹, respectively [10]. They also reported that the enrichment was higher at the lamina stage. Others found that the cup plant accumulated more than 172 mg Zn kg⁻¹, 74 mg Zn kg⁻¹, and 291 mg Zn kg⁻¹ in the root system, petiole, and lamina of the plant, respectively, on pole-polluted soil in Bulgaria, where the initial Zn concentration was above 1694 mg kg⁻¹ [41]. In the same study, Cu accumulation in roots, petiole, and leaf lamina was about 12 mg kg⁻¹, 13 mg kg⁻¹, and 51 mg kg⁻¹, respectively, and the initial Cu soil concentration was 54 mg kg⁻¹. The potential of the cup plant for phytoremediation of Cr and Pb was similar. In the experiment conducted by Mockevičienė [42] in Lithuania, the Cr, Pb, Cu, and Zn concentrations in the aboveground biomass of plants at 45 t ha⁻¹ sewage sludge were 0.23 mg kg⁻¹, 0.29 mg kg⁻¹, 5.76 mg kg⁻¹, and 21.52 mg kg⁻¹, respectively, while the treatment with 90 t ha⁻¹ sewage sludge resulted in significantly higher values. The initial range of heavy metal concentration in soil was 50–80 mg kg⁻¹ for Cr, 50–80 mg kg⁻¹ for Pb, 50–75 mg kg⁻¹ for Cu, and 160–300 mg kg⁻¹ for Zn. In the experiment by Sumalan et al. [43] in Romania, which was carried out in soilless culture, the peak concentrations of Cu, Zn, Cd, and Pd exceeded 400 mg kg⁻¹, 120 mg kg⁻¹, 159 mg kg⁻¹, and 2024 mg kg⁻¹, respectively.

6.2. Restoration of Flood-Prone Areas

Reproductive success, as measured by the number of capitula, was much greater in these hydrologically favorable zones, with plants producing up to 841 capitula, compared to significantly fewer in drier soils [12]. Remarkably, the number of capitula was positively correlated with plant height and not with the number of shoots, suggesting that flood-resistant conditions not only promote vegetative growth but also increase reproductive potential. Even in the first growing season, some plants started to develop shoots, especially under wet conditions, indicating a tendency towards early vigor when exposed to sufficient soil moisture [22]. This resilience, combined with its ability to thrive in moist or intermittently flooded environments, makes the cup plant a promising candidate for biomass production and ecological restoration of flood-prone or seasonally saturated soils. Although these indications appear encouraging, they should be confirmed in further temporally and spatially replicated studies.

6.3. Greenhouse Gas Mitigation

The cup plant is increasingly recognized not only for its biomass potential but also for its role in reducing greenhouse gas (GHG) emissions in agricultural systems. The greenhouse gas balance of bioenergy crops is significantly influenced by the emission of carbon dioxide (CO₂) and nitrous oxide (N₂O) during cultivation [44]. Due to its perennial nature and low nutrient requirements, the cup plant offers advantages over traditional annual crops such as maize. Especially under conditions with high water-filled pore space, which are often associated with increased N₂O emissions, the cup plant showed more stable and lower nitrous oxide fluxes compared to maize [37]. Its soil exhibited significantly lower gas diffusivity under high water-filled pore space conditions, which may favor denitrification to inert N₂ instead of climate-damaging N₂O, reducing the N₂O/(N₂+N₂O) ratio [44]. In addition, the slightly higher bulk density and lower porosity of the soils likely contribute to this reduction in gaseous diffusion and total emissions [45]. Although the differences in total N₂O fluxes were not statistically significant under the conditions tested, the perennial nature of the cup plant, its deep root system, and its lower nitrogen mineralization rates suggest a potential for lower GHG emissions in the field over time [37]. These characteristics emphasize the importance of the cup plant for the development

of climate-friendly cropping systems that reduce GHG emissions in agriculture while generating renewable energy. Further studies are needed to obtain reliable data to quantify greenhouse gas reduction in cup plantations.

6.4. Enhancement of Soil Organic Carbon

The incorporation of the cup plant into agricultural systems has been shown to increase soil organic carbon (SOC) content and improve soil aggregation. A study conducted during the 2018 growing season at three sites with different soil conditions in northern Germany showed that the cup plant significantly increased the SOC concentrations in silty loam soils compared to maize. In particular, in Chernozem and Histosol soils, cup plant showed a 64% higher mean aggregate weight diameter in spring and higher aggregate-associated SOC in fall, indicating improved soil aggregation and carbon sequestration [12]. The improved aggregation and higher SOC content under cup plants are attributed to several factors. First, the perennial nature of the cup plant results in continuous root systems that contribute to the formation and stabilization of soil aggregates. Nevertheless, long-term cultivation of cup plants may increase the water holding capacity of the soil due to the increased C input into the soil through their root systems [22]. In addition, the absence of tillage operations, typical of perennial cropping systems, promotes the formation and stability of macroaggregates. In addition, the root system of the cup plant, which partially survives the winter, may contribute to higher aggregate stability over the winter months [15]. In summary, cup plant cultivation is a promising approach to increasing soil organic carbon content and improving soil aggregation, especially in fine-textured soils. These benefits emphasize the potential of the cup plant as a sustainable alternative to conventional annual crops, contributing to soil health and long-term agricultural productivity [12]. Soil organisms play an essential role in maintaining soil functions such as decomposition of organic matter, nutrient cycling, carbon sequestration, and degradation of pollutants. It is also recommended for the remediation of intensively farmed soils, as it can contribute to earthworm numbers increase and long periods without agrotechnical operations such as plowing, resting, and cultivation [46]. The potential of the cup plant to sequester and store atmospheric C in the soil needs to be investigated under real field conditions and in different environments where different cultural practices are applied.

6.5. Prevention of Weed Invasions

Another concept for land restoration through the cultivation of cup plants is the suppression of weeds and particularly the prevention of the invasion of exotic weeds that displace the native flora [47]. It can be assumed that the dense canopy of the cup plant can shade the soil and suppress the growth of weeds, as is often mentioned for non-food crops grown for industrial and energy purposes [48]. It should be borne in mind that non-crop areas and abandoned degraded land are very susceptible to invasion by exotic weeds [49]. In view of this, the resilience of the crop and its adaptability to such areas offers the possibility of using cup plants as a natural barrier to the establishment of invasive weeds, thus further contributing to land restoration. However, field studies are needed to assess the cup plant's ability to compete with invasive weeds, as no data have been published in scientific journals.

6.6. Soil Erosion Control

The deep root system and robust, perennial growth of the cup plant provide year-round ground cover and stabilize the soil on degraded areas and slopes. Regarding the more recent findings on the contribution of the cup plant to soil erosion control, the results of Auerswald et al. [50] showed that soil erosion due to intense rainfall under cup plants over a cultivation period of at least 10 years is reduced to less than a quarter of the erosion

normally observed in conventional cropping systems. The results of Koch et al. [51] also showed a reduction in soil erosion and higher infiltration rates for cup plant compared to maize cultivation. The authors concluded that cup plants can therefore contribute to achieving the goals stated in the European Green Deal by reducing soil erosion and improving soil health. In addition, the study by Zaalishvili et al. [52] proved that protective strips of perennial herbs, including the cup plant, with a well-developed root system are resistant to stress factors of the mountainous zone and create the conditions for reducing soil wash-out. In erosion-prone soils, further research is needed to better assess the potential of the cup plant as a crop that can mitigate this threat to soil health.

6.7. Pollinator Support

The long flowering period of the cup plant, i.e., from summer to early fall, together with its bright yellow, nectar-rich flowers, attracts bees, butterflies, and other beneficial insects and promotes biodiversity in degraded ecosystems [14]. As for some available evidence from the northeastern Balkans, Cîrlig [53] reported that ten insect species belonging to six families and four orders were found in cup plant plantations. The presence of species belonging to the family Apidae, which are very important pollinators, namely *Apis mellifera*, *Bombus terrestris*, and *Bombus lapidaries*, was found in high abundance on cup plant flowers. To further improve pollinator activity, Mueller et al. [54] suggested irrigating cup plant stands to achieve soil moisture levels of 50% to 80% of available water capacity. According to these researchers, this practice leads to a threefold increase in nectar production compared to rain-fed stands and thus to increased insect visitation. They also pointed out that the early harvest of the cup plant restricts wild pollinators with a late activity period. In another work, it was found that the production of pollen and nectar sugar was highest in late summer due to the high number of inflorescences per plant at this stage [14]. Further case studies in different environments are needed to determine the importance of the cup plant in supporting pollinator activity and to optimize cropping protocols to further exploit this ecosystem service provided by cup plant cultivation.

7. Opportunities and Challenges in Cup Plant Cultivation

The cup plant offers considerable potential as a multipurpose crop in sustainable agriculture that can contribute to land restoration. Apart from its potential in degraded areas, the plant should be considered as an important future component of innovative crop rotation systems on agricultural land. The selection of non-food multipurpose industrial and/or energy crops is based on several agronomic, ecological, and economic criteria. Ideal rotation crops should improve soil fertility and structure, increase water retention, contribute to nutrient cycling, and at the same time help to reduce pest and weed pressure [55]. Such crops as the cup plant should also provide satisfactory and stable yields, be marketable, and show profitability, especially under changing climatic conditions. Rotation of crops with different rooting depths, such as alternating shallow-rooted cereals with deep-rooted species like the cup plant, can maximize the use of water and nutrients in different soil layers and thus improve the efficiency of the system in reusing resources [56]. In this context, the cup plant proves to be a promising candidate for crop rotation systems. Its perennial nature allows it to act as a soil-regenerating phase in crop rotation, especially after demanding annual crops, and its resistance to drought and soil compaction supports its integration into climate-resilient crop rotation systems [57]. In addition, the cup plant can be expected to be a candidate for the rehabilitation of fields infested with troublesome weeds, preventing weed invasion due to the extensive shading of the soil by its dense canopy. Thus, apart from its value for bioenergy, the cup plant fulfills several agronomic

functions that make it a strategic component in sustainable crop rotation systems developed for either commercial agricultural land or degraded marginal land.

However, the cultivation of this species is not without its problems. If grown uncontrolled, the species may become invasive [58], raising concerns about its ecological impact if not properly managed. Even if the cup plant thrives on marginal soils, the initial establishment phase may in some cases require considerable effort, including fertilization, amendments, and sometimes irrigation, which can increase production costs and contradict the concept of low-yield cultivation. In addition, it should be remembered that the cup plant is not yet a commercial crop and that no pesticides are approved for use in this crop in the EU. There may also be restrictions on the mechanical equipment required to carry out important field work. In addition, the cultivation of the cup plant may face socio-economic barriers, as farmers do not always welcome the concept of growing such novel crops for non-food purposes.

Below is a brief summary of the ecosystem services, benefits, and challenges associated with the cultivation of cup plant (Table 3).

Table 3. Summary of ecosystem services uses and challenges related to cup plant cultivation.

Ecosystem Services—Ways of Land Restoration	Uses	Challenges
Phytoremediation	Bioenergy Crop	Lack of Registered PPP
Soil Erosion Control	Fodder Crop	Lack of Equipment
Restoration of Flood-Prone Areas	Medicinal Crop	Socio-Economic Barriers
Reduction in Nutrient Leaching		Invasive Character
Long-Term Weed Suppression		
GHG * Mitigation		
SOC Increase		
Pollinator Support		

* CHG, greenhouse gases; SOC, soil organic carbon; PPP, plant protection products.

8. Conclusions

In summary, the cup plant is a versatile plant that can adapt well to a wide range of environments. Current knowledge on the agronomic aspects of its cultivation under real field conditions shows that it is a low-input perennial crop that can thrive in a given area for many years, producing large amounts of biomass that can be used as a feedstock for bioenergy production, industrial purposes, and animal feed. The crop can also be used for medicinal purposes as well. In addition, the introduction of the cup plant in degraded lands is a promising strategy for land restoration, as the plant has significant potential for phytoremediation and is well adapted to flood-prone areas. There is also evidence that the cup plant helps to reduce greenhouse gasses and increase the organic carbon content of the soil. In addition, the cultivation of cup plants can be seen as a novel natural “barrier” against the invasion of alien weed species, whose presence leads to a loss of biodiversity and a deterioration of land quality in the infested areas. Researchers should further explore the agronomy of the cup plant on both arable and marginal land and present results that encourage the adoption of the cup plant by companies and government agencies as a crop for which commercial cultivars, approved pesticides, specialized cultivation equipment, etc., are available. Scientists are also tasked with educating farmers and stakeholders about the plant’s potential to deliver economic returns and valuable ecosystem services for land restoration in a changing climate in order to promote the adoption of the cup plant among the wider community.

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