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Is the Potential for Multi-Functional Use of Industrial Hemp Greater than Maize under Saline Conditions?

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Abstract: There is a new and growing interest in using hemp as a raw material for a wide portfolio of food and non-food products. This study provides a synthesis of such information on the basis of literature and experimental data. For comparison, similar information on maize is provided. To document multiple uses of both crops, a list of products was compiled and the fraction of the total dry biomass of each plant part used for each product was estimated. A field experiment was carried out on the response of hemp and maize to irrigation scheduling and to the quality of irrigation water. Both literature and our experiment show that water and salinity stress reduce the total dry biomass, but do not modify substantially the relative availability for the intended marketable products. The field experiment did show that total biomass declined as salinity increased for both crops, but the partition in different fractions did not change significantly with the increase in salinity for all plant fractions and both crops. The market value of the observed, reduced, yield of maize and hemp was estimated. The experimental findings suggest that widespread use of hemp would lead to a more resilient and sustainable agri-food system, although regulatory and medium enterprise policies should be adapted to bring about this development.

Keywords: hemp; multipurpose; sustainability; salinity; market value

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1. Introduction

1.1. Sustainable Development vs. Multifunctional Crops

Goodland and Daly [1] suggested that sustainable development means striving for growth without using matter and energy beyond achievable regeneration. Kanter et al. [2] emphasized multiple alternative pathways to sustainable agricultural systems, whose performance varies with agroecological zones, farming systems, cultural preferences, governance, and policies. Strategies for sustainable water management and alternative crops are particularly relevant. This includes promoting the use of versatile crops, which may provide raw materials for a range of very diverse end-products.

There is a growing interest in multipurpose crops to improve biomass usability, e.g., as new sources of non-food oils, biomaterials, nutraceutical products, and other valuable bio-products. The first-generation biofuels were predominantly produced from crops like rapeseed and palm oil. Among the multipurpose crops, tobacco, poplar and thistle, as well as maize and hemp, are particularly relevant.

The challenge is to select plants that are eco-friendly, i.e., require low inputs and adapt to a wide variety of climates, especially in marginal areas, and can provide raw materials for a wide variety of marketable products. Among the options available, maize (*Zea Mays*

L.) and hemp (*Cannabis sativa* L.) can be valuable, since both are able to activate several production chains in food and non-food industries.

This study was focused on maize and hemp. Young [3] underscored that industrial hemp is a unique crop with a history spanning centuries of widespread use. On the other hand, in the last seventy years, hemp growers have been facing multiple constraints, unrelated to agro-technical challenges. The difficulty of enforcing separate rules, applying to industrial hemp and to the variety used to produce marijuana, led to severe restrictions on the cultivation of industrial hemp. As a result, the full development of the multi-functional potential of hemp has been limited by a combination of the regulatory framework and socio-economic misconceptions about industrial hemp. The latter suggests that effective dissemination of clear and reliable information requires urgent attention.

Recent literature documents a worldwide revival of interest in hemp cultivation [4]. Hemp is grown for either seed or fiber. Hemp can provide raw materials for high-quality paper, oil, cosmetics, plastics, various construction materials, fuels, and animal feed. A more detailed list of hemp marketable products is provided later. This highlights the potential of hemp as a multi-use crop that requires limited technical inputs and has a positive impact on the environment and on economic sustainability [5–9].

In the last 20 years, maize is often grown because of its multiple uses as food, feed, and fuel [10]. Maize is used in various production sectors, ranging from livestock fodder, for which the whole plant or only the grain or by-products obtained from other production chains are used, to the pharmaceutical industry and the food industries. Oil and starch are extracted from grains [11], with starch used to produce biodegradable plastic [12]. In recent years, it has become part of the energy supply chain [13–15], where either the whole plant (maize silage) or the grain or the residues of the cultivation or maize straw or cobs can be used.

1.2. Problem Statement and Specific Objective

Literature evidence (see also Section 3) does show that plant biomass is severely reduced in response to water and saline stress.while evidence on the response to biomass allocation is controversial or insufficient.

This led us to our first research question: is the current body of knowledge on the response of hemp yield and allometry to water and salinity stress sufficient to assess the multifunctional potential of hemp in a given environment?

The rapidly growing worldwide interest of the farming sector for hemp, just because of its versatility and multifunctional potential (see Section 2), was reviewed.

This led us to our second research question: How competitive is hemp with current crops in a given environment from the perspective of multifunctional use? And how is this assessment affected by the response of current crops to stressors such as water deficit and soil salinity? More specifically, how relevant is the better salt tolerance of hemp in terms of competitive advantages toward multi-functional, industrial use of plant raw materials?

The Volturno Valley is intensively used for maize (*Zea Mays* L.) production, for both human and animal use. The same area in the past was largely cultivated with hemp (*Cannabis sativa* L.). This led to choosing hemp and maize to address our two research questions detailed above. The choice to compare hemp with maize was determined by the fact that both crops are (maize) and were (hemp) widely cultivated in the study environment, so their adaptability is well documented.

1.3. Outline of the Study

This study is organized as follows: The industrial applications of hemp and maize were reviewed (Section 2) to identify the plant parts used for a range of final products and the corresponding fractions of plant biomass. This review documents the opportunities available in principle to increase farm revenues through the multifunctional use of hemp and maize. This is followed by the description of a case study, which includes an experiment to determine the impact of soil salinity on the biomass and allometry of hemp and maize and the evaluation of the market value of production at increasing levels of saline stress. The role of the case study in the economy of the study is not so much to provide experimental results on hemp and maize yield in response to salinity. The role is rather to document with a realistic case how far the opportunities, documented by the preceding review, to achieve higher farm revenues by growing multi-functional crops, are actually accessible in a specific context, notwithstanding the constraints due to the underdeveloped biomass processing facilities.

The specific lessons learnt drawn from the experiment cover two aspects: (a) the competitive advantage of hemp related to its resistance to soil salinity, with a focus on Campania in Italy and (b) the need for further experimental evidence to characterize the broader response of hemp and maize to water and salinity stress, particularly the allocation of accumulated biomass to plant parts.

2. Hemp and Maize in Industrial Applications: State-of-the-Art

2.1. A Short History of Maize and Hemp Use for Industrial Purposes

Hemp diffusion. According to García-Tejero et al. [16], hemp (*Cannabis Sativa*) is of Asian origin, and it has been widely used for fiber and fiber–oil extraction. Industrial hemp is an interesting and unique crop with a vivid history spanning centuries, but cultivation has been hindered by controversy in the last 70 years [3]. *Cannabis sativa*, i.e., industrial hemp, is a variety developed specifically for non-narcotic use and contains far lower levels of the psychoactive chemical THC (delta-9 tetrahydrocannabinol) than marijuana. THC is mostly concentrated in the flower buds, with a smaller amount located in the leaves. It is almost impossible to distinguish industrial hemp from the marijuana plant, and cultivation of both is forbidden in several countries due to the narcotic content. The latter nearly led to hemp disappearance due to the illegal status of the cultivation of *Cannabis* and the confusion between the two plants.

In principle, 30 countries in Europe, Asia and North and South America allow farmers to cultivate industrial hemp. Worldwide (excluding Canada), in 2016, hemp was grown in 77.698 ha for seed and tow waste, with a total production of 172,000 tons [17]. Canada is a major hemp producer and exporter [17]: if we consider Canada, in 2016, the total area cultivated with hemp was 91.052 ha. Canada is the major supplier to U.S. of hemp products, particularly of hemp-based foods and food ingredients. According to FAOSTAT, Europe is the world's single largest hemp producer. In 2019, European countries grew hemp on 56.196 ha, i.e., more than the 27% of global hemp hectares (Table 1, 207,901 ha). Table 1 shows the cultivated hemp areas in different continents. The total area cultivated with hemp in Europe is shown (Table 1), with national values given for the countries with larger areas [18]. In Italy, the hemp-cultivated area decreased from 4000 ha in 2019 to 603 ha in 2021 [19]. The total production of hemp worldwide was 2.50×10^5 tons in 2020 [20]. For the other countries, there have been no major changes.

Table 1. Area (ha) cultivated with hemp in 2019.

Country	Area (ha)
Canada [21]	22,243
China [22]	65,927
U.S. [23]	63,535
Europe [18]	56,196
France [18]	17,900
Lithuania [18]	9182
Estonia [18]	4555
Italy [18]	4.000
The Netherlands [18]	3833
Romania [18]	3400
Germany [18]	3114
Total	207,901

Hemp legislation. Several countries lifted their bans on hemp production in the 1990s and, until recently, also subsidized the production of flax and hemp under the EU agricultural policy. In Italy, the 1975 law No. 685 22/12/1975 forbade the cultivation of *Cannabis indica* because of its narcotic content, but in practice, the consequence was the prohibition of fiber-hemp *Cannabis sativa*, resulting in the complete disappearance of hemp. In Italy, the reintroduction began in 1998, but, in 2001, the hemp-cultivated area was only 200 hectares [24] increasing to 4000 ha in 2019 (Table 1). The increase in hemp cultivation was also promoted by recent legislation (2016) that clarified several criteria such as the allowed level of δ-9-tetrahydrocannabinol (THC). The latter should be $\leq$0.2%, with an additional tolerance, in practice to allow the cultivation of cultivars that may occasionally reach up to THC = 0.6%. Hemp can be grown as a fiber, seed, or dual-purpose crop and activate nine submarkets: agriculture, textiles, recycling, automotive, furniture, food and beverages, paper, construction materials, and personal care.

Maize diffusion. Maize (*Zea mays*) is of Mexican origin. Maize cultivation developed to meet the demand of animal husbandry, which found in this cereal the main raw material for animal feed in the meat, milk and egg supply chains. Today, over 80% of maize is consumed for animal feed, while human nutrition does not reach 5%. The remaining part is exploited for industrial uses, mainly for the production of starch and bioethanol.

The growth in world area planted with maize, paused in 2008 and then resumed to reach 197 $\times$ 10^6 ha in 2018. Maize cultivation spans both emerging economies and the developed world [25] including 165 countries distributed across the Americas, Asia, Europe and Africa [20]. Maize also shows marked yield differences between regions. The total maize production was 1.17 $\times$ 10^9 tons in 2020 [20]. The Americas contributed with 49.6% to the global maize production, followed by Asia: 32% and the remainder by Europe 11% and Africa 7.4% [25]. In Italy, the maize cultivated areas was 5.88 $\times$ 10^3 ha in 2021, with a production of 6.06 $\times$ 10^6 tons [19]. The maize area in Italy is distributed 88% in the north, 6% in the center and 5% in the south [19]. As regards the south, 44% was in Campania, and 43% of this area was within the province of Caserta. The dependence of Italy on foreign imports has increased exponentially, going from 11% of total demand at the beginning of the new millennium to 49.7% in 2019 and 53.29% in 2020 [26].

Multiple use of hemp and maize. In this third millennium, there is a renewed interest of farmers to grow cereals for alternative uses such as the production of ethanol, as a fuel, or as maize silage to obtain biogas or for biodegradable plastics, besides the use in the food industry.

A notable characteristic of hemp is that all parts of the plant find industrial uses, from the leaves for the production of cannabidiol (CBD), to the seeds from which oil is extracted or used as fodder. As regards maize, the main product is grain, as both foodstuff and fodder, but use of green biomass is limited, although maize feeds several industrial lines of products. A worldwide revival of interest for hemp cultivation is documented.

The evidence summarized above highlights the potential of hemp for multi-functional use, i.e., by supplying the raw materials for a broad range of consumer products.

2.2. Marketable Products

Sustainable agriculture. Worldwide, agriculture consumes about 70% of the water resource, uses 30% of land area and is indicated as the main cause of the greenhouse gas emissions [27,28]. Furthermore, the expected increase in population by 2050 will not improve this situation, and the pressure on agriculture is expected to increase. Agriculture is expected to supply not only nutritious food but also employment, energy resources, clean water, biodiversity conservation and more. According to Garnett and Godfray [29], sustainable agricultural intensification and climate-smart agriculture promise opportunities to increase agricultural productivity and to improve rural livelihoods, while minimizing negative environmental effects. The successful transformation of the agricultural sector to meet these multiple goals, therefore, requires the ability to pursue multiple outcomes, such as those stemming from crops able to activate multiple production chains like multipurpose crops, e.g., hemp and maize. The inputs required to grow maize and hemp are very different and correlated with environmental impacts, so yield and inputs have to be evaluated against the benefits associated with supplying raw plant materials for a range of final, marketable, products.

Hemp marketable products. Approximately more than 25,000 products in nine submarkets are derived from hemp raw materials: agriculture, textiles, recycling, automotive, furniture, food and beverages, paper, construction materials, and personal care are made with hemp [17]. Hemp fiber is used in fabrics and textiles, yarns and spun fiber, paper, carpeting, home furniture, construction and insulation materials, auto parts, and composites. Hemp seed and oilcake are used in a range of foods and beverages, e.g., salad and cooking oil and hemp dairy alternatives, and can be an alternative food and feed protein source. Oil from the crushed hempseed is used in soap, shampoo, lotions, bath gels, and cosmetics. Hemp is also being used in nutritional supplements and in medicinal and therapeutic products, including pharmaceuticals. It is also used in a range of composite products. Hempcrete, a mixture of hemp hurds and lime products, is being used as a building material. Hemp is also used as a lightweight insulating material and in hemp plastics and related composites for use as a fiberglass alternative by the automotive and aviation industry. Hemp is also promoted as a potential biodiesel feedstock [17].

A graphical summary of the wide utilization of hemp (Figure 1a) was developed by Morin-Crini et al. [30]. Most of the EU countries produce hurds, seeds, fibers and pharmaceuticals. Other non-EU countries with reported hemp production include Russia, Ukraine, and Switzerland. China is another major producer of most hemp textiles and related products, as well as a major supplier to the U.S. Besides these countries, FAO reports hemp production in Chile, Iran, Japan, south and North Korea, Pakistan, Syria and Turkey. In addition, health foods and products, although currently a small industry, are getting more attention and popularity [3]. Industrial hemp seems to respond to this demand and is widely regarded as a crop contributing to sustainability. To make hemp an economically viable industrial crop, there is a need to better identify how to use the entire plant, i.e., its uses, markets and technologies. In general, dual use crop production seems to be the most economically viable.

Maize marketable products. Maize is mainly used to feed cattle after silage. Multiple products are widely used (Figure 1b), as such as a slab aggregate obtained after oil extraction from the germ. Some products, as flour, come from the starch chain production [31] and are used to a limited extent as cattle fodder. Maize marketable products (Figure 1b) such as oil, starch and alcohol are used in a wide range of industrial applications. The latter span from human food, e.g., flour, popcorn, cornflakes and oil, to pharmaceutic as a component of tablets, as filler in the manufacture of plastics, as diluent and carrier for the production of insecticides and pesticides. Marketable products derived from starch include paper across a range in quality, food and confectionery, baked goods, ice creams, jam, sauce, pharmaceuticals and biodegradable plastics [32]. Moreover, maize can be used for silage and fodder for livestock animals.

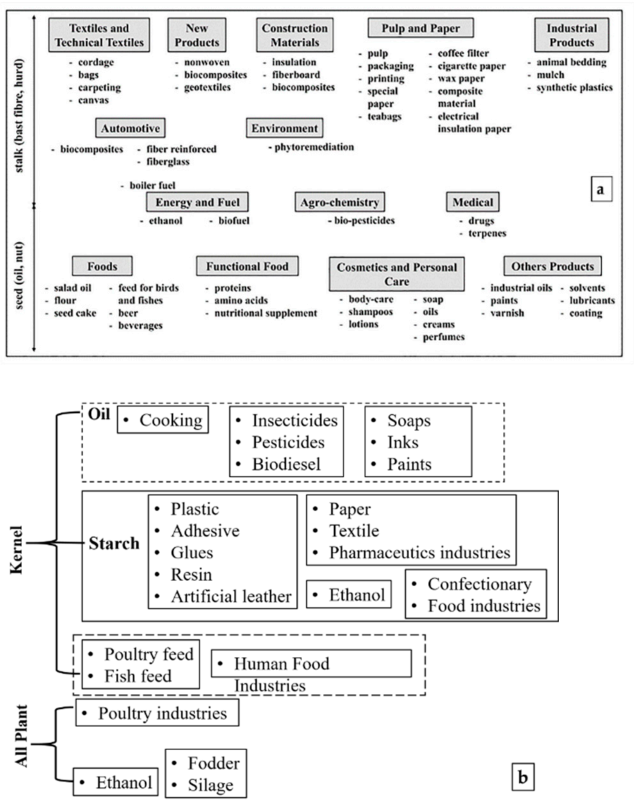


Figure 1. Multi-purpose hemp (**a**) marketable products for domestic and industrial use (after [30]) and maize (**b**) (after [32]).

2.3. Market Value of Raw Plant Materials

Hemp market value. The richness and diversity in marketable hemp products (Figure 1a) suggest that hemp parts have a rather high market value, possibly varying across market segments. This hypothesis seems to be confirmed by the scarce data (Table 2) on market value that are available for very few countries (Table 2). The US data for the food segment, for example, show the high value of seeds, mainly consumed as such, but at the same time highlight the high value of the cosmetic segment and, even more, of the CBD product. The China data are less detailed but clearly document the market relevance of both CBD and fiber. The data on the highly developed Canada market provide multiple and relevant insights. First, the value of both fiber and hurd depends very much on the final marketable products: fiber is most valuable if used for composite materials, while hurd should be best used for pet-litter. The Canada data confirm the high relevance of the cosmetics segment.

Table 2. Aggregated market value of hemp parts and end products (10^6 US$).

Country	**Products**							
	CBD	**Fiber**		**Seeds**		**Food**	**Cosmetic**	
			Oil	**Seed**	**Seedcake**			
U.S. [23]	3830		5.03	57.43	4.67	67.1	* 120	
China [22]	800	1200						
	CBD		**Bast Fiber**			**Hurd**	**Infused beverage**	**Cosmetic**
		Concrete	**Composite**	**Textiles**	**Pet litter**	**Potting mix**		
Canada [33]	22,000	3000	116,000	12,000	5000	1800	4600	430,000

* U.S. imports of hemp seeds reached a record of 191 million pounds, mostly from Canada.

A better understanding of product-specific market value in relation with the required plant materials would provide useful references to farmers as regards the choice of both varieties and farming practices. This analysis is presented in the next section.

Maize market value. Raw maize materials are used for multiple marketable products (Figure 1b), although the richness and diversity of such products seem less than hemp's (Figure 1a). As regards the market value of specific maize parts, we found scarcer information, which is described and used in Section 6c.

2.4. Product-Specific Plant Materials

Hemp plant materials. Fike [4] suggested that hemp has a great, multi-functional potential and articulated a scheme (Figure 2a) to show how hemp green biomass is partitioned in green leaves and stems, estimating the relative dry matter content of each plant element. Such a scheme allows estimates of raw plant material available for different marketable products, given total plant green biomass. The latter depends on varieties, environment and the purpose of the cultivation, i.e., whether fiber, seed or dual-purpose.

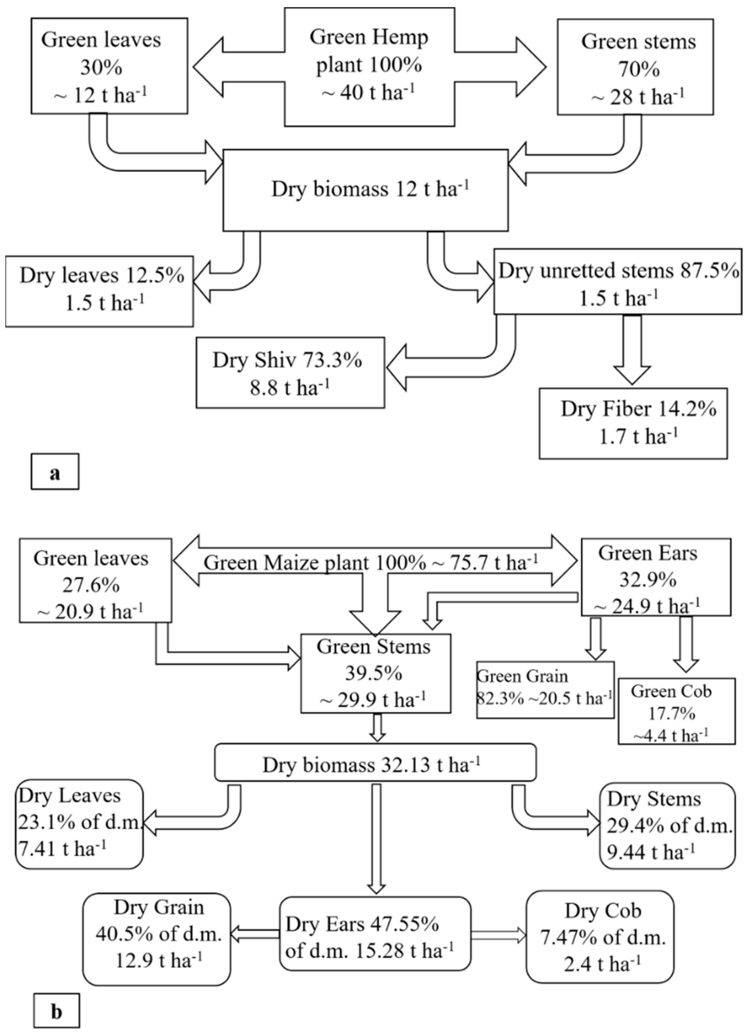


Figure 2. Allocation of accumulated biomass: (**a**) hemp allometry (data source: [4]); (**b**) maize allometry estimated according to literature.

Maize plant materials. Maize silage is derived from the whole maize plant, harvested at the waxy maturation stage of the grain, when the dry matter content of the whole plant is around 32–35%, chopped and preserved. The Maize grains is the principal material to produce starch and other marketable products. It is essential to harvest maize when grains have a water content higher than 24% [11].

In the last 20 years, there has been an increasing investment to produce energy from biomass, which however is still a small share compared to common energy sources. Corn is a well-placed plant for energy use either by direct use of grain, or maize silage, or residuals of processing for other purposes. Hŭtnan et al. [34] evaluated the biogas production from maize by comparing grains with maize silage. They show that the grain has higher energy efficiency compared to maize silage. On the other hand, Mazurkiewicz et al. [35] evaluated the utilization of straw left in the field after the cultivation to be used in biogas production. They concluded that maize straw can be a valuable substrate for a biogas plant, especially if the material has a higher dry matter content, leading to a higher methane yield than maize silage. They suggested that farmers should know the moisture content of harvested maize straw to increase their biogas production. Maize grain, stalk and cob can be utilized for biogas and/or ethanol production.

Maize allometry. A chart applying to maize allometry (Figure 2b) was developed on the basis of literature. Most literature references give the partition of biomass into leaves, stems and ears. Almost all studies evaluated yield, specifying the total biomass and grain. Koca and Erekel [36] evaluated maize allometry, detailed in leaf, stem and ear and based on experiments in Turkey over three years. Wasaya et al. [37] provided similar data relating to different production systems in Pakistan. The data shown in (Figure 2b) are indicative, since many plant characteristics determine the partition of total biomass, e.g., the earliness of the hybrid, of having or not green leaves at harvest, the sowing density, the degree of ripeness at harvest and so on. Due to the use of cob as synonymous of ears in some references, in the data of this work, Cob refers to the part of the ear left after kernels are removed.

The allometric information in Figure 2 was used to estimate the partition of the biomass of each plant element into different marketable products (Table 3). As regards hemp, most data were generated by the EU project Multihemp (www.multihemp.eu, accessed on 1 February 2021). For maize, not so much information was available, and the data reported in Table 3 were adapted from Angelini et al. [38]. For both plants, it was not easy, sometimes, to identify the part of plant that is used and the fraction of final products that can be obtained.

The table can be used to estimate the expected end-products on the basis of the initial raw material available, as done in the following simple example. Let us take a hemp seed dry biomass of 25 kg. This can be used to produce either 4 L of hemp oil, i.e., the 15% for "oil food" in Table 3 and 17.5 kg for "hemp flour", i.e., the 70% in Table 3, or all the products listed in the column except hemp flour. Likewise, 34 kg of maize grain fresh biomass will yield 1 L of corn oil, corresponding to the 3% in Table 3. In general, the information in Table 3 can be easily applied to assess the potential marketable production of hemp and maize.

Raw materials to produce paper are obtained from different hemp and maize plant parts: stalk for hemp and grain for corn. Maize kernels are used to produce starch, which improves the properties of paper and hardboard. More in general, starch is used for fiber adhesion or coating to produce paper, yields stronger packaging products and improves opacity, brightness and surface smoothness of paper for better printing results. Maize is a major source of starch: about 1.6 tons of maize yield 1 ton of starch. Maize starch is a major ingredient in home cooking and processed foods. Maize starch can also be used for industrial purposes such as manufactured bioplastics, or further processed into various starch derivatives.

Table 3. Hemp marketable products vs. hemp and maize plant elements; values shown are relative to the total dry biomass of each part (column headings); X = plant part used, but % not known.

Application	Hemp					Maize			
	Seeds	Fiber	Leaves	Flower	Shivs	Grain	Stems	Spathes	Cobs
				%					
Oil Food	15					3			
Oil Feed	0.5								
[1] Flour	70								
Cosmetics	0.5								
Whole seeds: food	5								
Whole seeds: feed	67								
Dehulled seeds: Feed	2%								
Dehulled seeds: Food	9.5								
pharmaceutical			X	X		10			
Feed			X			1			
Food						27			
Tea/infusion			X						
paper		55				28			
Moulding (automotive)		14							
Mulch & other		5							
Insulation material		26							
Construction					15				
Bedding material					63		X	X	X
Other					22	4			
Ethanol					X	30	X	X	X
Confectionary						30			

[1] This value applies to an alternate use of seeds where only flour and oil is produced, with any residual usable as feed.

In the case of hemp, on the other hand, it is the fiber itself and the cellulose that are used to produce paper. One hectare of hemp provides the same amount of raw material for paper as 4 hectares of trees [39].

Hemp and maize response to abiotic stresses. Both crops have a broad multi-functional purpose, even if hemp has a greater multifunctional scope than maize, as illustrated in Table 3. Moreover, the two crops respond in different way to abiotic stresses (Section 3). Their adaptability to different stresses can be different, as well as processes of dry matter partitioning and biomass temporal distribution [40]. Until now, few indications are available to estimate biomass production and its partition when stress occurs. Particularly, the impact that such stresses have on the decrease of raw plant material available for different marketable products is even less known when the crops are cultivated under salinity stress. On the other hand, global warming and the expected population growth will lead, even in the Mediterranean area, to a decrease in water availability and an increase in the risks of salinization of the lands.

Therefore, it is important to verify the effect of salinity on the response of hemp and maize and to evaluate how stress affects the availability of total biomass and the various biomass fractions needed as raw material for the different commercial products. The assessment of the adaptability of the two crops to saline stress and their allometry allows for choosing the crop that best responds under saline stress and that provides raw materials for the widest range of commercial products, i.e., likely to maximize farm revenues, notwithstanding the yield loss due to reduced water supply and degraded water quality.

3. The Hemp and Maize: Plants, Thermal and Water Requirements in Relation to the Response to Abiotic Stresses

Hemp is a dioecious annual herbaceous species that can reach up to 6 m in height, depending on the variety, and environmental and agronomic conditions. The differences in morphology and the asynchronous maturity make it difficult in dioecious types to choose the best time to harvest that may determine lower seed yield [4]. Hemp production is significantly affected by photoperiodicity [41,42], plant maturity is delayed under a long-day regime, and the plant sets seeds as photoperiods shorten over time [43,44]. Cultivars come from higher latitude and, if grown closer to the equator, produce lower fiber and grain yield. The interest in hemp seeds, the need to maximize economic return and the aim to use hemp for dual purposes led to an evolution in crop management [45].

Hemp grows best at temperatures between about 15 °C and 27 °C, but tolerance to quite low temperatures allows for earlier planting than corn (*Zea mays* L.) [46]. A heat or drought stress from sowing to flowering is harmful since it forces hemp to early blooming limiting crop height. Delays in the sowing period can reduce the number of plants per m^2 and reduce the plant height. Hemp is best suited for well-drained soils, with sufficient soil moisture during hemp establishment being essential. The plant is drought tolerant when roots are fully developed. Hemp has a deep root system, large biomass and high yield, and it is very competitive with weeds because it grows quickly. Its fertilizer requirements are modest [47], i.e., the high yield of hemp [48,49] is obtained with reduced technical inputs [45]. It has a positive environmental impact [50] and a high adaptability to a wide range of agro-ecological conditions [48] compatible with the modern requirements of a low-environmental impact, eco-friendly crop [51,52].

According to Baldini et al. [53], most of the cultivars have been selected in North Europe, Russia and China. According to Fike [4], a better understanding of the interactions of cultivar photoperiodicity with planting date and environmental conditions is needed to obtain a good performance of a hemp-oriented farming system. Because of the strong resistance to stress, Cheng et al. [54] considered that hemp can adapt to saline-alkali conditions, and Przemyslaw et al. [55] emphasized that it can also be useful in the reclamation of marginal lands. The abundant scientific literature on hemp covers many aspects, but studies on the hemp response to salinity are very scarce.

Lixandru et al. [56] summarized the findings of years of research in Romania on several cultivars grown on saline soil without irrigation. They documented a salinity tolerance to total soluble solids per 100 g of dry soil, according to which hemp was considered to be moderately sensitive. On the other hand, Cheng et al. [54] documented relatively large differences in salt tolerance among cultivars. According to Cosentino et al. [57], fiber hemp needs almost 250 mm of water for monoecious early genotypes and 450 mm for dioecious late genotypes. The same authors showed that higher biomass and stem dry yields were achieved with genotypes developed for central-southern Europe environments (dioecious cultivar).

Maize is of tropical origin, macrotherm and adapted to short days. The diffusion area of maize has greatly expanded. Self-adaptation and anthropic selection led maize to become photo-insensitive. Maize grows in a wide range of climatic conditions, and it is cultivated in a very wide latitudinal band, i.e., 50° N to 40° S. At higher latitudes, the main limiting factor is the temperature, so only the cultivation of very early and low-yielding hybrids is possible. In environments characterized by drought, the main limiting factor is water. The maize root system is superficial. The irrigation water requirement of maize is about 6000 m^3 ha^{-1} [58]. Experimental evidence suggests that water stress in the milky maturation stage leads to yield reductions of the order of 50–60%.

Maize is moderately sensitive to salinity and is salt-sensitive cereal [59]. Despite its position, as one of the leading food crops of the world, few efforts have been done to improve its salt tolerance. Elazab et al. [60] pointed out how field crops are usually exposed to multiple abiotic stresses (e.g., drought, salinity, higher than optimal temperature, nitrogen deficiency), which affect their production in response to the timing, duration and intensity of the stress. Krishnamurthy et al. [61] reported that the effect of drought on the development of a plant is a lower production of biomass and/or a change in the distribution of this biomass among different organs. Such consideration applies also to the effects of other abiotic stress.

Plant productivity under multiple stresses is strongly related to the processes of dry matter partitioning and temporal distribution in the accumulation of biomass [40]. Therefore, as regards to maize and hemp, two question arise:

(a). the response of maize and hemp biomass under water and salinity stress;
(b). maize and hemp allometry under stress to estimate the dry matter partition.

The literature found for both hemp and maize (Tables 4 and 5) to answer points (a) and (b) contrary to what we thought initially is not very abundant. In particular, there are very few studies with details on the partition of biomass in response to stress. Di Bari et al. [62] carried out an open field trial on three cultivars during three years and in two environments to analyze biomass partition in hemp (Table 4) under drought stress. In this study, four water application schedules, designed to restore the root zone to 100, 68, 34 % of the field capacity (FC) of the soil layer 0–40 cm and a rainfall treatment (182 mm), were applied (Table 4). As expected, the total dry matter decreased as water stress increased. The biomass partition to leaves, stems and hurd did not change much upon increasing water stress, while the fiber fraction was lower in the rain-fed treatment. The large impact of water stress on total biomass and the limited changes in the partition of biomass were confirmed by Cosentino et al. [57], who documented the response to water stress and the partition into leaves and stems with a field trial where four water application schedules designed to restore 100, 50, 25 % of Etm, besides the rainfall treatment, were applied during the growth cycle (Table 4). The data refer to a one-year field experiment on Futura 75 with two harvest dates. Hemp responds to water stress by increasing (Table 4) both Water Use Efficiency (WUE) and Crop Water Productivity (CWP). The latter applies to both fiber (CWF) and stems (CWS).

Table 4. Hemp literature data reported for drought stress. H = height, HI = harvest index; CWF = crop water productivity in relation to fiber production; WUE = water use efficiency; CWS = crop water productivity in relation to stem production; Crop maximum evapotranspiration (ETm), FC = field capacity. Green biomass and total dry matter (dm).

Treatment	H cm	Green Biomass	% dm Biomass	Total dm Biomass	Partition in % of dm				HI	CWF	WUE	CWS
					Leaves	Stems	Hurd or Shive	Fiber				
							%					
% FC-mm					Drought stress-Di Bari et al. [62]—Biomass (t ha^{-1})							
100–612	231	42.5	39.1	16.6	21.7	78.3	60.3	18.0	0.18	0.5	2.7	2.12
68–416	237	39.0	37.7	14.7	18.4	81.6	61.5	20.1	0.20	0.7	3.5	2.88
34–282	207	33.6	37.2	12.5	20.0	80.0	61.5	18.5	0.18	0.8	4.4	3.55
0–182	212	27.6	35.1	9.7	20.6	79.4	62.5	16.9	0.17	0.9	5.3	4.23
Harvest 23/6					Cosentino et al. [41]—Biomass (t ha^{-1})							
ETm %												
100	102			6.24	33.8	66.2					1.91	1.26
50	98			7.06	33.7	66.3					2.37	1.57
25	98			6.91	30.7	69.3					2.43	1.69
-	95			6.62	31.9	68.1					2.48	1.69
Harvest 13/7												
100				12.02	27.6	72.4					2.73	1.97
50				11.09	26.2	73.8					3.13	2.31
25				9.84	29.5	70.5					3.15	2.22
-				9.77	27.0	73.0					3.63	2.65

Literature on the hemp response to salinity is rather scarce, which makes the studies by [56,63] very valuable, particularly the latter which reviewed experimental data on several rainfed cultivars. Hemp was assessed as being moderately sensitive.

As regards maize (Table 5), the biomass partition in response to drought and salinity stress is poorly documented. Most studies focused on total biomass, while in a few cases the grain yield was indicated and even fewer authors evaluated the leaf and stem yield components. In relation to drought stress, Amer [64] carried out an open field trial on one cultivar during one year and observed a strong reduction in total biomass, i.e., 25.2 t ha^{-1} to 16.2 t ha^{-1} in response to a reduction in water application from 634 mm (1.4 ETm) to 272 mm (ETm 0.6). The authors did specify the grain yield for the two irrigation treatments, i.e., 29% and 28% of dry matter. In addition, Hussain et al. [65] and Yi et al. [66] observed a much larger effect of water stress on the total biomass than on the grain yield (Table 5). Hussain's treatments were two water application schedules to restore 75% and respectively 50% of the field capacity (FC) in a field trial on two cultivars during two years. Instead, in Yi et al. [66] (open field trial during two years), three treatments were applied by SI = supplementary irrigation, during which soil moisture was maintained at 70–85% of the FC, RF = rain-fed and FM = film mulching, which was also under rain-fed conditions.

Table 5. Maize literature data reported for salinity and drought stress. Electrical conductivity of the irrigation water (ECw). Electrical conductivity of the soil solution (ECs), salt concentration of the irrigation water is expressed in ppm. Crop maximum evapotranspiration (ETm), H = height, FC = field capacity, HI = Harvest Index, CWP = Crop Water Productivity, WUE = Water Use Efficiency. SI = supplementary irrigation, RF = rain-fed; and FM = film mulching. Green biomass and total dry matter (d.m) biomass are reported.

Treatment	H cm	Green Biomass	% dm Biomass	Total dm Biomass	Partition in % of dm					HI	CWP	WUE
					Leaves	Stems	Grain	Cob	Ear			
							%					
ECw (dSm^{-1})				Salinity stress-Akram et al. [67]—Biomass (g pt^{-1})								
3.0	79	33.44	10.5	3.52								
8.8	58	29.36	10.3	3.01								
13.0	44	16.18	10.0	1.62								
Salt concentration in ppm of $^{+}$Na ion				Hussein et al. [68]—Biomass (g pt^{-1})								
250	70			39.01	54.45	45.55						
2000	57			27.14	57.89	42.11						
4000	48			21.43	53.34	46.66						
ECw-ECs (dSm^{-1})-(mm)				Amer [64]—Biomass (t ha^{-1})								
0.89–2.68–453				27.1			32.25			0.32	1.93	5.98
2.81–5.38–423				24.6			30.28			0.30	1.76	5.81
5.73–7.25–380				19.3			28.50			0.29	1.45	5.08
ETm-(mm)				Drought stress-Amer [64]—Biomass (t ha^{-1})								
1.4–634				25.2			29.4			0.29	1.17	3.97
1.2–544				25.5			32.2			0.32	1.51	4.69
1.0–453				26.2			33.4			0.33	1.93	5.78
0.8–362				22.2			32.2			0.32	1.98	6.13
0.6–272				16.2			27.8			0.28	1.65	5.96
%FC-mm				Hussain et al. [65]—Biomass (t ha^{-1})								
75–516	153			18.74			30.74			0.31	1.12	3.63
50–440	148			14.95			29.16			0.29	0.99	3.40
%FC-mm				Yi et al. [66]—Biomass (t ha^{-1})								
SI-467				25.6			60.2			0.60	3.30	5.48
RF-371				19.9			59.3			0.59	3.18	5.36
FM-365				24.0			60.0			0.60	3.95	6.58

As regards the response to salinity stress, Akram et al. [67] documented (Table 5), a one-year pot trial of 10 cultivars with harvest 28 days past sowing. The impact of the treatments on total fresh and dry biomass was observed, but no information was provided on its partition. Hussein et al. [68] carried out a pot trial during one year on a hybrid cultivar for fodder with harvest 3 weeks past sowing. Observations on biomass partition at increasing salinity stress were observed, but differences across treatments were rather small. On the other hand, total biomass decreased from 39.01 g pt^{-1} to 21.43 g pt^{-1} with salinity increasing from 250 ppm to 4000 ppm. The actual composition of irrigation water was not specified in [67], who, however, explained that the irrigation water used in the experiment was produced by diluting Mediterranean sea water with fresh (tap) water. We may then assume that the concentrations (ppm) apply to Na^+, which is the dominant ion in sea-water.

It should be noted (Table 5) that both crop water productivity (CWP) and water use efficiency (WUE) decreased in response to saline stress, while increased in response to water stress.

The literature analysed on hemp and maize shows that stress (drought and salinity) has an effect on the total biomass, while the effect on the biomass partition seems less evident. This literature does not allow for drawing clear conclusions from findings that are even contradictory in some cases. Eziz et al. [69] conducted a meta-analysis and concluded that drought had almost no impact on allometric relationships among different plant parts. Acosta-Motos et al. [70] provided an extensive review on the adaptive mechanisms that plants put into action when under salt stress. Some studies associated the decrease in fresh or dry biomass with a reduction in the number of leaves or in leaf abscission in response to salt stress. Other studies described a reduction in total leaf area. Many studies indicated that stem growth is normally reduced by high salt concentrations. A decrease in leaves and stems tends to reduce all aerial part sizes and plant height.

4. Case Study: Response of Hemp and Maize to Saline Stress

4.1. Motivation and Description of the Case Study

The evidence reviewed in the preceding sections shows that both maize and hemp can provide raw materials for different end products and market segments in both food and not food sectors. Furthermore, it has been detailed which end products can be obtained from the different parts of the plant, although it was not easy to document completely how the total crop yield is allocated to end-products. The analysis also showed that saline and water stress affect the final total biomass, while evidence on the effect of stress on the allocation of biomass to plant parts is limited and to some extent contradictory.

Estimating the yield loss, in response to stress, for individual portions of the plant, would help to understand which end-product could be penalized, since a decrease in e.g., hemp stalk means a decrease in fiber and so in the paper end-product as well as a decrease in hurd for bedding end-products. Moreover, such estimates would allow us to assess whether production costs would still be sustainable against the market value of the end-products, notwithstanding the impact of abiotic stresses.

To try to address this issue, available experimental data on the response of maize and hemp to saline stress under sufficient water supply were used. The experiment had two elements: (a) a laboratory experiment on germination, (b) a field trial on crop yield. The germination test gives information about the loss of germination and the delay in germination due to the salinity level. This information is also useful when planning sowing in terms of seed quantity and density. The field trial was carried out in the Volturno plain, Southern Italy during 2002 to evaluate the yield response of hemp and maize to saline stress, and we evaluated the biomass partition. Next, the production cost and the market value of the end-products for hemp and maize were evaluated. Literature was used when necessary due to gaps in our own data.

4.2. Germination Test

The laboratory test was carried out on maize seeds of the hybrid Sacro (FAO 500) and on hemp seed of the cultivar Fibranova to evaluate the tolerance to salinity during the germination phase. The germination test was carried out on one hundred seeds of each crop that were placed on filter paper in Petri dishes containing different salt solution (NaCl) as described in Supplementary Materials (SM). The germination percentage (%) at 12 days and the mean germination time (MGT) were determined (see Supplementary Materials for additional details).

4.3. Field Trial

In Southern Italy at the CNR-ISAFOM experimental station located in Vitulazio (CE) in the Volturno river plain (25 m a.s.l.; 14°12′ E and 41°07′ N) in 2002 on a clay loam soil (Table S1), a field trial on maize hybrid Sacro (FAO 500) and on hemp cultivar Fibranova (F) was carried out. The soil on which the trial was carried out has a high level of salinity [71], due to previous long-term irrigation by saline water (see Supplementary Materials for details), that determined salt accumulation through the soil profile. Specific sites were identified having significantly different values of EC_e by carrying out a survey on soil salinity. Electrical conductivity of the saturated paste EC_e and soil texture on soil samples taken at three depths (0.0–0.3, 0.3–0.6 and 0.6–0.9 m) were measured [72]. The different values of EC_e (Table S2) were grouped into four saline treatments (C, S_1, S_2 and S_3) that had increasing EC_e initial values. The treatments were distributed in randomized blocks in four repetitions for a total of 16 plots, each of size 100 m^2, for both maize (1600 m^2 plus some space among adjacent plots to avoid interferences among treatments) and hemp (1600 m^2 plus the space indicated before), so in total 32 plots. A detailed description of the experiment is provided in the Supplementary Materials.

On maize and hemp, from emergency till harvest with a 14-day interval, the leaf area index (LAI), the leaf area duration (LAD) and the total plant dry matter (W) were estimated. Taking into account the frequency of the plant sampling, the crop cycle has been divided in 14-day intervals (see Supplementary Materials) [73]. At harvest, the fiber content of hemp was determined. Soil moisture and electrical conductivity of the soil profile during the crop cycle were measured as well (see Supplementary Materials). Statistical analysis of data was performed by SPSS 16.0 software (SPSS for Windows, Version 16.0, Chicago, IL, USA). All of the data obtained were analysed using ANOVA, and the mean values of all variables were compared using Duncan's multiple range test.

5. Results

5.1. Germination Test

In general, the germinatin decreased while the MGT increased with increasing salinity (Table S3), but up to 9.6 dS m^{-1}, no significant difference was observed in germination as salinity increased for both maize and hemp. Starting from 13.8 dS m^{-1}, maize responded to increasing salinity differently from hemp: the reduction in germination was greater and significant, while differences with hemp were progressively larger. The maximum observed gap was 50% less germination at the highest salinity level (26.4 dS m^{-1}). MGT of the two crops remained the same up to 9.6 dS m^{-1}, while starting from 13.8 dS m^{-1} the MGT significantly increased with increasing salinity, with the MGT of maize being one day longer than hemp at 26.4 dS m^{-1}.

5.2. Root Water Uptake

The mean EC_e of the layer 0.0–0.9 m did not change significantly in all treatments during the crop growth cycle, while it increased significantly with depth in the treatments S_1, S_2, S_3 (see Table S2b Supplementary Materials for additional details).

Hemp extracted a larger share than maize of total water uptake from the deeper, more saline soil layers (Table 6). This is made possible by the taproot system of hemp in combination with the greater tolerance to high salt concentrations, and it was still beneficial to hemp because of its greater tolerance to salinity, as described below.

Table 6. Electrical conductivity of the saturated paste (EC_e) of soil for each crop and soil layer. Fraction of soil water extracted from each soil layer (ETa); values are averages across all the treatments. Interaction crop × layer. Values followed by a different letter are significantly different at $p \leq 0.01$, standard deviation given in brackets.

Soil Layer (m)	EC_e (dS m^{-1})		Water Extracted % of the Total ETa	
	Maize	Hemp	Maize	Hemp
0.0–0.3	2.65 (±1.62) c	3.24 (±2.05) c	52.7 (±1.1) a	50.9 (±2.8) a
0.3–0.6	3.46 (±2.13) bc	3.85 (±2.29) ab	41.9 (±2.2) a	35.6 (±1.3) b
0.6–0.9	4.12 (±2.73) a	4.20 (±2.36) a	5.4 (±6.1) d	13.5 (±4.8) c
0.0–0.9	3.41 (±2.08)	3.76 (±2.19)	100.0	100.0

5.3. Crop Water Use, Leaf Area Duration, Dry Matter Accumulation and WUE

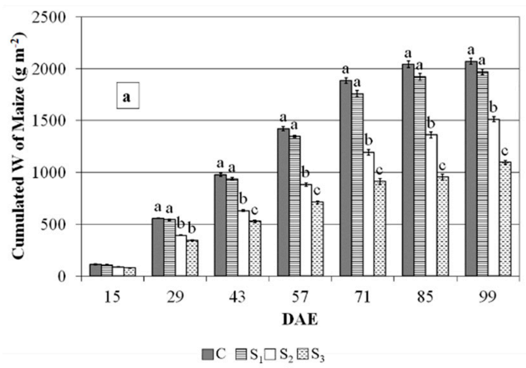
Actual crop evapotranspiration, ETa, was estimated as the sum of irrigation water retained after each irrigation in the layer 0.0–0.9 m, rainfall during the crop cycle and the change between emergence and harvest in soil water storage in the layer 0.0–0.9 (Table 7).

Table 7. Water balance of the soil layer 0.0–0.9 m for each crop and treatment; ETa: actual crop evapotranspiration; $\overline{EC_e}$: mean seasonal soil electrical conductivity of the saturated paste. For each crop, ETa values followed by a different letter are significantly different at $p \leq 0.01$; standard deviation given in brackets.

Treatment ($\overline{EC_e}$ dS m^{-1})	Irrigation Water Retained (mm)	Rainfall (mm)	Change in Soil Water Storage (mm)	ETa (mm)	ETa/ET0
			Maize		
C = 0.95	200.7	123.6	75.7	400.0 (±14.8) a	0.81
S1 = 2.25	192.0	123.6	57.4	373.0 (±15.6) ab	0.76
S2 = 3.96	185.1	123.6	20.3	329.0 (±7.2) bc	0.67
S3 = 6.48	179.6	123.6	1.8	305.0 (±12.0) c	0.62
			Hemp		
C = 0.95	178.5	112.2	58.9	349.6 (±10.0) a	0.76
S1 = 2.88	179.5	112.2	41.6	333.3 (±9.6) ab	0.72
S2 = 4.18	170.0	112.2	23.3	305.5 (±11.4) bc	0.66
S3 = 7.03	163.0	112.2	7.6	282.8 (±10.8) c	0.61

For both crops, the ETa significantly decreased with increasing salinity, i.e., from treatment C to S_3, and the difference between maize and hemp remained approximately constant through the crop cycle. The effect of salinity on maize appeared earlier than on hemp, i.e., 29 DAE (days after emergence) vs. 54 DAE (see Figure S2a,b in Supplementary Materials). As regards LAD, the effect of salinity appeared from 43 DAE for maize (Figure S3a in Supplementary Materials) and from 40 DAE for hemp (Figure S3b in Supplementary Materials). The cumulative LAD of each crop was significantly different between the extreme treatments (S_2, S_3). The difference among treatments progressively increased over time and the cumulated LAD was correlated with ETa (data not shown; r = 0.96 for maize and r = 0.98 for hemp).

The accumulated dry matter significantly decreased with increasing salinity from 29 DAE for maize (Figure 3a) and from 40 DAE for hemp (Figure 3b). The difference among treatments progressively increased over time and at the end of the crop cycle a good correlation was observed between W and LAD (r = 0.99 and 0.94 for maize and hemp, respectively; data not shown).



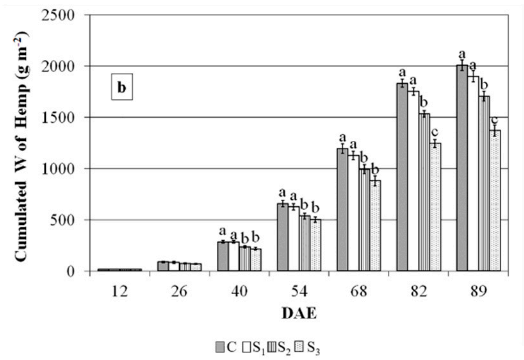


Figure 3. Cumulated Shoot dry weight (W) vs. Days After Emergence (DAE): Maize (**a**) for each saline treatment (C = 0.95 dS m^{-1}, S_1 = 2.25, S_2 = 3.96 and S_3 = 6.48 dS m^{-1} for the soil layer 0.0–0.9 m). Hemp (**b**) for each saline treatment (C = 0.95 dS m^{-1}, S_1 = 2.88, S_2 = 4.18 and S_3 = 7.03 dS m^{-1} for the soil layer 0.0–0.9 m) at different DAE. At each DAE, any pairs of values indicated by bars are significantly different at $p \leq 0.01$ if labelled with different letters; standard deviation indicated by error bars.

The S_1 to S_2 and S_3 treatments gave large and significant reductions in LAI, LAD and W variables. The decrease in LAD and W for maize was larger in treatments S_2 and S_3 than in S_1 (Table 8). Furthermore, in the same treatment (e.g., S_2) the decrease in LAD and W was significantly different from LAI, i.e., −26% and −27%, respectively, LAD and W vs. −20% the LAI. In the S_3 maize treatment, the decreases were significantly different for all variables. In hemp, the reductions in LAI, LAD and W with increasing salinity were lower than in corn. As regards LAI, for example, the decrease in S_2 for hemp was −12% vs. −20% for maize. In response to S_3, hemp had a higher reduction in all the three variables in comparison with S_1 and S_2. On the other hand, in S_3, the reductions were again smaller for hemp than for maize. For example, the reduction in LAD was −28% for hemp vs. −38% for maize. The decreases in LAI, LAD and W were not significantly different in hemp (Table 8). The reduction in biomass (W) was significant: −27% and −47% for the treatments S_2 and S_3 in maize and −32% for the S_3 treatment in hemp. No significant reduction was observed in the treatment S_2 for hemp (Table 8).

The different evolution of the WUE (Figure 4a,b) showed that the differences among treatments occurred earlier in maize (29 DAE) than in hemp (40 DAE). In maize, one month after the emergence, the WUE was already at its peak value and moderately degraded until the end of the crop cycle, while in hemp it reached a maximum comparable to that of maize gradually and only at the end of the cycle. This different behavior can be explained by the earlier development of the maize leaf system (Figure S3) and with a consequent earlier accumulation of biomass (W) (Figure 3).

Table 8. Relative reduction in LAD and W at harvest, and LAI measured at full growth of the treatments S_1, S_2 and S_3 compared to values applying to the control treatment C and taken equal to 100%. For each treatment, the values followed by a different letter are significantly different at $p \leq 0.01$, if labelled with different letters.

		Maize	
Treatments	**LAI (%)**	**LAD (%)**	**W (%)**
S_1	−5 (±1.7)	−6 (±0.7)	−5 (±9.6)
S_2	−20 (±4.0) b	−26 (±3.5) a	−27 (±1.4) a
S_3	−31 (±3.8) c	−38 (±0.5) b	−47 (±0.7) a
		Hemp	
S_1	−3 (±4.8)	−3 (±1.3)	−5 (±2.0)
S_2	−12 (±5.8)	−18 (±0.8)	−15 (±1.2)
S_3	−28 (±6.2) a	−28 (±1.4) a	−32 (±1.7) a

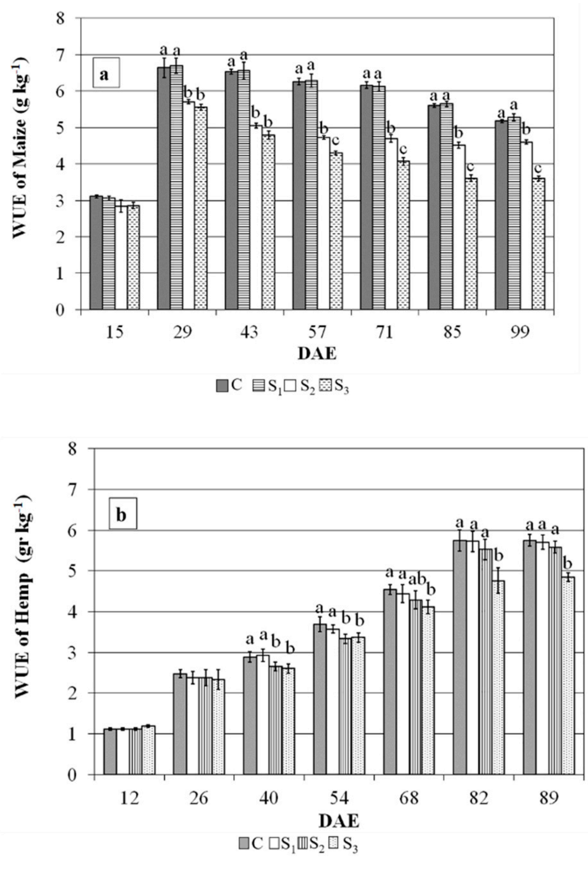


Figure 4. Effect of salinity on the water use efficiency (WUE) at different days after emergence (DAE): Maize (**a**) (C = 0.95 dS m^{-1}, S_1 = 2.25, S_2 = 3.96 and S_3 = 6.48 dS m^{-1} for the soil layer 0.0–0.9 m) and Hemp (**b**) (C = 0.95 dS m^{-1}, S_1 = 2.88, S_2 = 4.18 and S_3 = 7.03 dS m^{-1} for the soil layer 0.0–0.9 m). Among the observations at each DAE, the values indicated by bars are significantly different at $p \leq 0.01$ if labelled with different letters, standard deviation indicated by error bars.

5.4. Response to Water and Salt Stress, and Salt Tolerance

The Ky, as defined by Doorenbos and Kassam [74], relates the relative yield decrease (1-Ya/Ym) to the relative evapotranspiration deficit (1-ETa/ETm), where: Ya = actual yield; Ym = maximum yield; ETa = actual crop evapotranspiration; and ETm = crop evapotranspiration of the C treatment.

In our study, Ky was applied to W and LAD for both maize and hemp. Details on the calculation of (1-ETa/ETm), and (1-Ya/Ym) for the shoot dry matter W and (1-LAD_a/LAD_m) for LAD are given in the Supplementary Materials. The yield response factors were then calculated as K_W, K_{LAD}, respectively, for W and LAD for maize and hemp.

The salinity tolerance of the two crops was also evaluated with the linear model of Mass and Hoffman [59]. The model, commonly accepted by the scientific community for the classification of plant tolerance to salinity as a function of EC_e, distinguishes four classes of tolerance (Figure S6). The Mass and Hoffman relationship describes the decrease in relative yield (Yr) as a function of soil salinity: Yr = 100 − b ($\overline{EC_e}$ − a), where $\overline{EC_e}$ is the seasonal average of electrical conductivity of the saturated paste (dS m^{-1}). The a value is the salinity threshold above which a yield reduction (slope b) per unit increase in salinity occurs.

As regards the effects of reduced ETa due to the water and salinity stress (see Figure S5), throughout the growing period, the decrease in LAD and W were proportionally greater than the reduction in relative ETa, i.e., K > 1. In fact, K_{LAD} was 1.41 and 1.47 for maize and hemp, respectively. The K_W of maize (1.79) was significantly higher than K_W of hemp (1.47). The maize biomass (W) was the most sensitive to salt stress followed by LAD.

In Table 9, the water use efficiency of all treatments throughout the growing season (WUE) for both maize and hemp had a value of 5.13 and 4.98 (g kg^{-1}; where g is g of dry matter and kg is kg of water), respectively. They were not significantly different, despite the high correlation between the variables W and ETa, i.e., R^2 = 0.89 and 0.93 for maize and hemp. The non-negligible RMSE, i.e., 203 and 174 (g m^{-2}), for maize and hemp, respectively, indicates a difference among treatments.

Table 9. Ky, as defined by Doorenbos and Kassam [74], calculated for biomass (K_W) and leaf area duration (K_{LAD}), as well as the Mass and Hoffman relationship (M & H), (a) value of the salinity threshold above which a yield reduction (slope b) per unit increase in salinity occurs. Moreover, the water use efficiency (WUE) is reported.

Stress Indicators									
Maize					Hemp				
Ky		M & H		WUE	Ky		M & H		
K_W	K_{LAD}	a (dS m^{-1})	b%	(g kg^{-1})	K_W	K_{LAD}	a (dS m^{-1})	b%	WUE (g kg^{-1})
1.79	1.41	1.38	9.1%	5.13	1.47	1.47	2.34	6.2%	4.98

In Table 9, the relative yield for the M & H was referred to the grain production (Gr) for maize; instead, for hemp, it was referred instead to fiber production (Fbr). With reference to grain yield (Gr), maize was placed in the class of moderately sensitive crops plant according to the M & H classification. In addition, the fiber yield (Fbr) of the Fibranova hemp was placed in the same class but was clearly less sensitive to salinity, as shown by the much higher $\overline{EC_e}$ threshold value (2.34 vs. 1.38).

5.5. Crop Yield and Crop Water Productivity

The biomass of the two crops had the same order of magnitude and trend with increasing salinity (C = S_1 > S_2 > S_3) and was equally correlated with the LAD, i.e., r = 0.99 and 0.94 for maize and hemp, respectively (Table 10; see also Section 5.3).

Table 10. Summary table of selected crop production and growth variables for maize and hemp; *dm*: dry matter; CWP: crop water productivity, $\overline{EC_e}$: mean seasonal soil electrical conductivity of the saturated paste. Values followed by a different letter are significantly different at $p \leq 0.01$; standard deviation given in brackets.

		Crops							
		Maize				Hemp			
Paramters	**Unit**	**C**	**S_1**	**S_2**	**S_3**	**C**	**S_1**	**S_2**	**S_3**
$\overline{EC_e}$	dS m^{-1}	0.95 (±0.14) d	2.25 (±0.18) c	3.96 (±0.36) b	6.48 (±0.36) a	0.95 (±0.08) d	2.88 (±0.32) c	4.18 (±0.30) b	7.03 (±0.35) a
dm biomass	t ha^{-1}	20.7 (±0.29) a	19.7 (±0.26) a	15.1 (±0.23) b	10.97 (±0.18) c	20.1 (±0.51) a	19.0 (±0.53) a	17.1 (±0.47) b	13.7 (±0.56) c
dm grain	t ha^{-1}	9.2 (±0.25) a	8.5 (±0.12) a	7.1 (±0.31) b	4.9 (±0.15) c	-	-	-	-
Kernels per spike	n.	502 (±4.0) a	492 (±16.0) a	489 (±22.0) a	394 (±12.0) b	-	-	-	-
Weight of 1000 seeds	gr	305 (±15) a	288 (±18) a	242 (±11) b	207 (±10) c	-	-	-	-
dm stems	t ha^{-1}	-	-	-	-	17.8 (±0.56) a	17.1 (±0.58) a	15.4 (±0.36) b	12.5 (±0.51) c
Fiber/Stems	%	-	-	-	-	22.5 (±0.52)	22.8 (±0.46)	22.7 (±0.56)	22.4 (±0.37)
dm fiber	t ha^{-1}	-	-	-	-	4.0 (±0.16) a	3.9 (±0.12) a	3.5 (±0.15) ab	2.8 (±0.04) b
WUE of *dm* Biomass	kg m^{-3}	5.18 (±0.04) a	5.28 (±0.1) a	4.59 (±0.07) b	3.60 (±0.09) c	5.75 (±0.15) a	5.71 (±0.17) a	5.61 (±0.15) a	4.84 (±0.1) b

The production of maize kernel decreased with increasing salinity with the same trend as biomass: with treatments S_1, S_2 and S_3, yield decreased by −8%, −23% and −47%, respectively, while biomass decreased by −5%, −27% and −47%. The large decrease for the S_3 treatment was due to the lowest number of seeds per spike, i.e., the apex of the sterile or aborted spikes. The same treatments of Hoffman et al. [75] mentioned earlier demonstrated a similar trend with a reduction in crop yield of −35%, −37% and −75%, while biomass decreased by −2%, −26% and −46%.

In hemp, the production of dry stems followed the trend of the biomass, while no differences in the ratio fiber/stems were observed. However, small variations in this parameter led to a trend in fiber production different from biomass and dry stems, partly reducing the differences across treatments, i.e., C = S_1 = S_2; C = S_1 > S_3; S_2 = S_3, unlike what was observed for the kernel production in maize.

5.6. Biomass Partition

Saline stress reduces the total hemp biomass as salinity increases; this behavior was observable also in the different plant fractions. The partition of dry matter did not change significantly with the increase in salinity for all plant fractions including fiber (Table 11). The fiber, in fact, is part of the stems, and no significant differences were found in the variation in stem relative yield across the different treatments, and the distribution of dry matter did not vary with the increase in salinity. However, even if there was no change in the distribution of dry matter with increasing salinity, the biomass decreased, thus the different fractions of total biomass did also decrease. As was to be expected, in our fiber crop, the majority of dry matter is allocated to the stems since the harvest was done in full male bloom when the plants had already lost many leaves. In summary, the allocation of dry matter to the different fractions approximately follows the ranking leaves < fiber < stems. A similar behavior seems to emerge from the response to water scarcity in the reworked data from literature (Table 4, [57,62]). The relative distribution of the dry matter across the different biomass components did not change as the water deficit increased, even with a reduction in the dry biomass. The differences that emerge from the data of the mentioned authors are probably related to the time of harvest and the cultivar characteristics.

Table 11. Total dry matter (dm) Biomass and the different component for both crops (t ha^{-1}) for each salinity level. Moreover, partition in different component as percentage (%) of the total dry matter biomass. Values followed by a different letter are significantly different at $p \leq 0.01$ when lowercase letters are used, and significantly different at $p \leq 0.05$ when uppercase letters are used; standard deviation given in brackets.

Maize											
		dm					**Partition in % of dm**				
Treatment	**ETa**	**Biomass**	**Leaves**	**Stems**	**Ears**	**Grain**	**Leaves**	**Stems**	**Cob**	**Grain**	**Ears**
$\overline{EC_e}$ (dS m^{-1})	(mm)	t ha^{-1}					%				
C = 0.95	400	20.7 (±0.29) a	1.17 (±0.05) a	7.2 (±0.4) a	12.4 (±0.1) a	9.2 (±0.1) a	5.6 (±0.1)	34.7 (±2.2)	14.9 (±3.2)	44.8 (±1.1)	59.7 (±2.3)
S_1 = 2.25	373	19.7 (±0.26) a	1.14 (±0.16) a	7.6 (±0.6) a	11.0 (±0.8) b	8.5 (±0.7) a	5.8 (±0.7)	38.5 (±3.6)	12.7 (±1.1)	43.0 (±2.3)	55.7 (±3.3)
S_2 = 3.96	329	15.1 (±0.23) b	0.66 (±0.05) b	5.5 (±0.5) b	8.9 (±0.6) c	7.1 (±0.4) b	4.4 (±0.5)	36.5 (±3.2)	12.0 (±2.9)	47.1 (±2.0)	59.1 (±3.3)
S_3 = 6.48	305	11.0 (±0.18) c	0.54 (±0.03) b	3.8 (±0.1) c	6.7 (±0.2) d	4.9 (±0.1)c	4.9 (±0.2)	34.4 (±1.3)	15.4 (±1.5)	45.3 (±0.4)	60.7 (±1.2)
Hemp											
		dm					**Partition in % of dm**				
Treatment	**ETa**	**Biomass**	**Leaves**	**Stems**	**Fiber**	**Fiber/Stem**	**Leaves**	**Shiv**	**Fiber**		**Stems**
$\overline{EC_e}$ (dS m^{-1})	(mm)	t ha^{-1}				%	%				
C = 0.95	350	20.1 (±0.51) a	2.5 (±0.6) A	17.6 (±0.56) a	4.0 (±0.16) a	22.5 (±0.25)	12.4 (±3.8)	67.7 (±3.0)	19.9 (±0.7)		87.6 (±3.8)
S_1 = 2.88	333	19.0 (±053) a	1.9 (±0.3) AB	17.1 (±0.58) a	3.9 (±0.12) a	22.8 (±0.12)	10.0 (±1.2)	69.5 (±1.1)	20.5 (±0.5)		90.0 (±1.1)
S_2 = 4.18	305	17.1 (±0.47) b	1.7 (±0.3) BC	15.4 (±0.36) b	3.5 (±0.15) ab	22.7 (±0.31)	10.0 (±1.5)	69.5 (±1.5)	20.5 (±0.7)		90.0 (±1.5)
S_3 = 7.03	283	13.7 (±0.56) c	1.2 (±0.5) C	12.5 (±0.51) c	2.8 (±0.04) b	22.4 (±0.15)	8.8 (±0.8)	70.8 (±1.1)	20.4 (±0.6)		91.2 (±0.8)

Maize response to salinity is very similar to hemp. The total biomass and the different biomass components decreased as salinity increased (Table 11). Also in this case, if the partition of dry matter is analyzed, most dry matter is allocated to the ear. Our grain maize crop was harvested when the whole plant was dry, so the driest leaves were also lost. It is therefore not surprising that most dry matter was allocated to the ear with an average of about 60% of the three saline treatments, with the smaller fraction represented by the leaves.

With respect to the control treatment C (Table 12), in maize, in the average of all the plant fractions, a significant increase in the decrease in dry matter was observed with the increase in salinity according to the sequence $S_1 < S_2 < S_3$ for $p = 0.01$. The same trend with $p = 0.05$ was also observed for the individual fractions, although with some overlap in the case of leaves and cobs, which on average had the largest decline, perhaps due to some inaccurate observations at the time of the harvest, e.g., a mistake in evaluating the leaves.

In the case of hemp with respect to the control (Table 12) for all the plant fractions, in agreement with what was observed for the biomass, a significant increase in the decrease in dry matter is observed with the increase in salinity according to the sequence $S_1 < S_2 < S_3$ for $p = 0.01$. At all levels of salinity, the leaves recorded the highest loss of dry matter compared to biomass and other plant fractions due to the lower initial leafiness at the time of harvest.

Table 12. Percentage decrease of the saline treatments against the control treatment, significant at $p = 0.01$ (lowercase letters). The interaction saline treatments × plant fraction is significant at $p = 0.05$ (uppercase letters); standard deviation given in brackets.

		Maize					
Treatment							
$\overline{EC_e}$ (dSm^{-1})	ETa (mm)	Biomass %	Leaves %	Stems %	Grain %	Cob %	Average
C = 0.95	400	-					
S_1 = 2.25	373	4.8 (±0.9) D	3.1 (±9.8) D	0.0	8.7 (±6.0) D	17.5 (±9.9) C	6.7 (±7.8) c
S_2 = 3.96	329	27.3 (±1.2) C	43.6 (±2.6) AB	23.7 (±4.2) C	23.5 (±3.7) C	37.9 (±11.1) B	31.8 (±10.8) b
S_3 = 6.48	305	47.1 (±0.6) A	53.8 (±2.1) A	47.3 (±4.4) A	46.1 (±0.7) A	43.5 (±10.7) AB	47.5(±11.1) a
Average		26.4 (±17.1) b	33.8 (±19.1) a	23.7 (±18.1) b	26.1 (±16.5) b	33.0 (±15.3) a	
		Hemp					
Treatment							
$\overline{EC_e}$ (dSm^{-1})	ETa (mm)	Biomass %	Leaves %	Stems %	Fiber %		
C = 0.95	350	-					
S_1 = 2.88	333	5.5 (±3.5)	17.8 (±16.0)	3.9 (±2.7)	2.5 (±9.6)		7.4 (±10.2) c
S_2 = 4.18	305	14.9 (±7.0)	26.4 (±12.5)	13.2 (±4.6)	12.3 (±5.1)		16.7 (±10.9) b
S_3 = 7.03	283	31.8 (±8.0)	43.7 (±15.2)	29.4 (±4.7)	29.4 (±2.3)		33.6 (±4.3) a
Average		17.4 (±10.7) b	29.3 (±18.2) a	15.5 (±11.0) b	14.7 (±11.2) b		

6. Discussion

This study addressed three broad research questions:

(a). Is the multifunctional potential of hemp and maize documented in detail, including the relation of consumer products with plant raw materials?

(b). Is the current body-of-knowledge on the response of hemp yield and allometry to water and salinity stress sufficient to assess the multifunctional potential of hemp in a given environment?

(c). Is multifunctional use of maize and hemp an attractive option to farmers, notwithstanding environmental constraints, which may lead to sub-optimal yield?

Ad a. **Evidence on the multifunctional potential of hemp and maize.** Literature evidence documents in a solid and detailed manner the global potential of hemp as a multi-functional crop, but the challenge remains to understand to what extent this potential applies to a given region. The very diverse and multiple consumer products described in Sections 1 and 2 require specialized processing of crop raw materials, which may not be available everywhere. Due to the large efforts spent on the selection and breeding of maize cultivars leading to a wider range in environmental requirements, maize has a wider global scope than hemp.

Hemp has a great adaptability to different climatic environments, although work on selection had a better continuity and intensity in Northern Europe, e.g., France and The Netherlands (see Baldini et al. [53]) who reported the availability of 69 monoecious cultivars considered ideal for multipurpose use. It remains important to evaluate the suitability of a hemp variety in a specific location for multipurpose use [53]. It has been shown that hemp can be used to produce more than 25,000 consumer products [17] in nine submarkets.

Maize has larger, more developed, markets but provides for fewer consumer products than hemp. Maize can be processed into a variety of food and industrial products, including starch, sweeteners, oil, beverages, glue, industrial alcohol, fuel ethanol and bioplastic film [14,76]. The issue is to verify how each line of production is developed in a specific country.

The multi-functional potential of hemp and maize is documented in detail by the data retrieved from literature (Table 3) on the fraction of dry biomass necessary to produce each consumer product.

An issue applying to both maize and hemp is the allocation of agricultural land to produce biofuels. The long-term benefits are open to debate as pointed out by e.g., Gomiero [76] and Lark et al. [77]. Different uses of plant raw materials may yield greater benefits and even the expected contribution of biofuels to reduce GHGs seems to be open to debate.

Ad b. **Response of hemp yield and allometry to water and salinity stress.** Multi-functional cultivation of maize and hemp is potentially very relevant to the sustainability of marginal lands. Giupponi et al. [78] showed that in Italy a large fraction, i.e., 43% of the hemp farms investigated, is located in marginal or abandoned lands, including areas severely affected by water and saline stress.

Multi-functional crops and the related processing and marketing sectors could offer a sustainable perspective with high value consumer products, notwithstanding sub-optimal yield. The case study in Southern Italy described above has provided information to evaluate this potential in a real setting. Hemp and maize in the study area were considered because they have a well-known tradition as multi-functional crops. Maize has already been used for a long time, for food, energy generation, confectionary industry, animal feed, etc. Hemp as a multipurpose crop is a reality in northern Europe and Canada where the size of the hemp-related market is very large. In Italy, in the past, it was a very important crop, providing raw materials to produce textiles and paper. Today, it struggles to find a stable market position, while it is used in particular as food and phytotherapy products. There is a significant demand for hemp fiber, but this demand is generally met by importing fiber.

The case study presented in Section 4 serves a two-fold purpose: (a) document, in combination with literature, expected yield losses in response to water and saline stress and (b) estimate the value of on-farm marketable end-products, taking yield losses into account.

Yield losses under saline conditions start with failed germination: the fraction of germinated seeds decreased with increasing salinity for both maize and hemp. As regards maize, the impact of salinity was significant above 9.6 dS m^{-1}. Hoffman et al. [75] observed that 16 cultivars germinated well at soil water salinities up to 10 dS m^{-1}, i.e., comparable with our 9.6 dS m^{-1}. Slightly different findings were presented by Katerji et al. [79], who observed a 14% reduction in emergence at 7.6 dS m^{-1} on sandy clay and sandy loam, compared to a not saline control.

As regards the response in ETa, LAI and W to salinity, our results were similar to Amer [64] in Egypt, who irrigated maize with saline water at EC = 4.73 dS m^{-1}. They observed reductions in ETa, LAI measured at full growth and W of 16%, 31% and 33%, respectively, and the ratio ETa/ET0 was 0.68. Our results on the treatment S_2 for maize, characterized by an ETa/ET0 of 0.67 (Table 7), were comparable with Amer [64], i.e., the reductions in LAI and W (Table 8) were 20% and 27%, respectively.

As regards hemp, the observed ETa/ET0 = 0.66 (treatment S_2) and reductions in LAI and W (Table 8) of 12% and 15%, respectively, were significantly lower than maize. Our results show that hemp had a better response at high salinity than maize (S_2). In hemp only, the S_3 treatment gave significant reductions in LAI and W, 28% and 32%, respectively.

The decrease in biomass was lower in hemp, i.e., 5%, 15% and 32% in the three saline treatments, against the larger reductions in maize, i.e., 5%, 27% and 47%. Biomass is an important factor in the performance of a multipurpose crop, even more so its partition, which is discussed briefly below.

The experimental findings on yield reductions in response to salinity are relevant but not directly usable to estimate expected yield loss under conditions different from the treatments. To generalize the results of the field experiment, three indicators were evaluated: (a) the response factor K_y of Doorenbos and Kassam [74]; (b) the relationship between relative yield and soil salinity of Maas and Hoffman and (c) the Water Use Efficiency Steduto [80].

The response factor, Ky, is a metric applicable to the response of biomass (W) and LAD to water and saline stress. The Ky value can be applied to estimate expected losses for a given level of saline or water stress. Maize biomass was more sensitive to saline stress, i.e., K_w = 1.79 versus hemp K_w = 1.47, while LAD was smaller for maize, i.e., K_{LAD} 1.41, than for hemp, i.e., 1.47. Steduto et al. [81] estimated a much lower value for maize, i.e., Ky = 1.25, than our Kw = 1.79. If the target is consumer products depending on biomass, these values provide contradictory evidence on the expected loss of biomass: larger in maize than in hemp according to our findings, contrariwise according to [81].

The Maas and Hoffman relationship provides an estimate of the decrease in relative yield (grain for maize, fiber for hemp) in response to the seasonal average of the electrical conductivity of the saturated soil paste (dS m^{-1}). Our maize results gave an electrical conductivity threshold value of 1.38 dS m^{-1} beyond which yield decreased by 9% per unit increase in EC_e, a value which led to assess maize as a moderately sensitive crop (see Figure S6 in Supplementary Materials). Similar results were obtained by Jiang et al. [82], i.e., a threshold value of 1.20 dS m^{-1} and a rate of decrease of 12.7%.

As regards hemp, it was difficult to find published references on the Maas and Hoffman relationship, while our results, applying to fiber, gave a threshold value of 2.34 dS m^{-1} and a rate of decrease of 6.2%. The latter value ranked hemp as a moderately sensitive crop, although the rate of decrease in relative yield was much lower than the one observed in maize (Figure S6). Moreover, in our study, the fiber/stem ratio did not change significantly with salinity, i.e., the response of the stem production was similar to that of fiber yield, i.e., a = 2.06; b = 5.96%; (R^2 = 0.92), which implies that the relative stem yield decrease was 50% at 10.45 dS m^{-1}.

Once the expected yield in response to salinity has been estimated as shown above, the expected water use can be estimated on the basis of observed WUE. In all our treatments, a decrease in WUE with increasing salinity was observed. Shenker et al. [83], on sweet maize, found no significant differences in WUE in saline treatments up to 7.75 dS m^{-1} (on average WUE = 4.6 kg m^{-3}). In our experiment, instead, the WUE of maize at harvest decreased significantly from 5.28 (kg m^{-3}) in the S_1 treatment ($\overline{EC_e}$ = 2.25 dS m^{-1}) to 3.6 (kg m^{-3}) in the S_3 treatment (EC_e = 6.48 dS m^{-1}) (Table 10). The rate of decrease was thus larger, i.e., −32% across the three treatments.

Di Bari et al. [62] evaluated three dioecious cultivars, i.e., Fibranova, Red Petiol and Kompolti, grown in Campania (Vitulazio) under not saline conditions, with irrigation applied to restore the 66% and 33% of the available water (RAW). Their WUE estimates were close to our findings (Table 10), but the trend was different. According to Di Bari et al. [62], WUE increased with decreasing ETa, i.e., 4.89 kg m^{-3} vs. about 5.60 kg m^{-3}, i.e., +14%. The linear relationship of W vs. ETa (Figure S4) fitted the values of all treatments well for the entire crop cycle for both maize and hemp. The slopes, i.e., 5.13 and 4.98 (g kg^{-1}; where g is g of dry matter and kg is kg of water), respectively, were not significantly different and provided an estimate of the water use efficiency (WUE) of all treatments throughout the growing season. In agreement with standard practice, we have applied ECe as an indicator of soil salinity. Throughout the analysis of our experimental data, however, we have also evaluated ECs, the actual electric conductivity of the soil solution. This is in principle a better indicator of the salinity conditions experienced by a plant, but it is more complex to evaluate and interpret than ECe because it varies with soil water content. Accordingly, we have left out monitoring and interpretation of ECs out of our already complex study.

Our experimental findings were also analyzed to estimate changes in biomass allocation in response to water and saline stress, which is relevant to evaluate the multi-functional value of maize and hemp (see, e.g., Table 3) under such conditions.

Overall, the allocation of biomass to plant parts did not change significantly across our saline treatments. In addition, our findings were rather close to the ones of Fike [4] summarized in Figure 2a. For example, in the case study, the fraction of biomass allocated to leaves varied from 12.4% for the non-saline C treatment to 8.8% for the most saline S_3 treatment (Table 11), against the 12.5% in Figure 2a. Such 10% loss in leaf biomass would have a slight impact on the final production of pharmaceutical products and fodder. Larger differences were observed as regards the fiber biomass fraction, which in our experiment varied from 19.9% in the C treatment to 20.4% of the saline treatments (S_3), against the 14.2% given by Fike [4]. This discrepancy could depend on different factors, first of all the timing of harvest. As regards fiber, Table 3 does not provide information about biomass needed to produce fabrics, which is a potentially attractive consumer product. Just as a tentative indication, in Italy, about 3.5 kg of raw material are needed to produce 11 m^2 of a 180 gr m^{-2} fabric (Tessitori F.lli Liotti personal communication). In addition, our findings on the biomass fraction allocated to shiv did not differ significantly from the ones in Fike [4], since our experiment indicated that this fraction was 67.7% for the C treatments and between 69% and 70% for the saline treatments, i.e., closer to the 73.3% of Fike [4].

It should be noted that our field experiment was limited to one year. As mentioned above in some detail, however, our findings are generally in line with the literature evidence we could gather as regards: germination, Hoffman et al. [75] and Katerji et al. [79]; maize yield, Amer [64]; the Maas and Hoffman relationship for maize, Jiang et al. [82]; WUE of hemp, Di Bari et al. [62] and Cosentino et al. [41]; biomass allocation in hemp, Fike [4] and Husein et al. [68]. Some deviations were observed in a few cases, but neither these deviations or the yield losses estimated on the basis of our experiment had a critical impact on our core findings and conclusions, which relate to the current and potential market value of hemp products, as discussed in the next paragraph.

In the case of maize, overall, our results were also in agreement with estimates by Fike [4] on hemp and our own on maize (Figure 2b), notwithstanding the short duration of our experiment. Our experiment gave a grain fraction varying between 45% for the C-treatment and 47% for S_2 (Table 11) against 40% in Figure 2b. This would mean that, for example, a fraction of dry grain biomass equal to 30% and 28%, respectively, would be used to produce confectionary and paper (see column Maize/grain in Table 3). In other words, despite the water and salt stress, the dry grain biomass of our salt treatments will not compromise the total value of the end-products confectionary and paper.

Ad c. **Attractiveness of multifunctional use of maize and hemp to farmers.** The market value of the observed, reduced, yield of maize and hemp was estimated to interpret and bring together our literature findings on the multi-functional value of maize and hemp and the results of our experiment. The production and the transformation costs and the market values of maize and hemp were estimated first (Table 13). The production cost of each end-product was estimated to be a fraction of the cost of producing maize and hemp biomass, proportional to the value of each end product. Estimated price and cost values apply to 2020.

The market for maize end-products is far more developed than it is the case for hemp, but it has been difficult to retrieve all the required information on costs of the different stages in the production of each end-product and on the corresponding market value. As regards maize, for example, the maize raw pressed oil is imported in Italy and only the final stages of the process are completed by domestic producers. Accordingly, the cost estimates for the production of maize oil are based on the price paid to import the raw oil, to which the bottling costs have been added, on the basis of data provided by Olio Dante Spa (https://www.oliodante.com, accessed on 1 October 2021). Only 4% of the biomass production cost is allocated to oil. The retail price of oil is around 2.20 € lt^{-1}. The first stage in the transformation of the grain into oil consists of the elimination of the germ. The oil yield is generally about 8% of the kernel used, and 65% is the flour yield from the grain, if the flour is not whole-meal (the yield in whole-meal flour is 100% from the grain). As regards the production costs, 85 to 95% of the total production cost of maize biomass, i.e.,1530 €, was allocated to flour, to which the milling cost needs to be added. As regards the latter, two options were considered: industrial and stone milling. A sub-product is obtained in this process, i.e., about 25% to 35% of the initial biomass, which is used as animal feed, but it was not possible to determine the market value of this product.

Table 13. Biomass production cost for hemp and maize. For hemp, production costs (840 to 1340 € ha^{-1}) refer to whether the farmer produces directly or hires contractors for production. In addition, the cost of biomass for each end-products ranges according to the production range reported above. For the end-products considered for hemp (flour, oil, fiber and hurd) and for maize (flour and oil), the fraction of the total market value is considered. For hemp, oil yield is 20% of the seed biomass, against a 70% flour yield (fraction of seed biomass). Hemp Cost transformation (milling and oil extraction) is reported as well as Packaging costs, estimated assuming a 250 mL and 250 g package size for oil and flour, respectively. For maize, the cost of biomass (1300 ÷ 1453) ranges in the case the costs are referring to the stone mill processes to extract normal flour, i.e., 1300, or 1453 for industrial wholemeal flour extraction.

		Hemp		
Cost of produced total biomass (€ ha^{-1})	840 ÷ 1340			
Fraction end-products	**flour**	**oil**	**fiber**	**hurd**
Fraction of total market value	20%	22%	15%	42%
Cost of biomass € ha^{-1}	168 ÷ 268	185 ÷ 295	126 ÷ 201	353 ÷ 563
Fraction of seed biomass	70%	20%		
	Milling cost 60 € q^{-1}	Oil extraction cost 80 € q^{-1}		
	Flour packaging cost 0.9 €/250 g	Oil packaging cost 0.9 € / 250 mL		
Market value	10 € kg^{-1}	38 € L^{-1}	60 € q^{-1}	50 € q^{-1}
Fraction end-products	flour	oil	fiber	hurd
		Maize		
cost of produced total biomass (€ ha^{-1})	1530			
Fraction end-products	**flour**		**oil**	
Fraction of total market value	85 ÷ 95% *		4%	
Cost of biomass € ha^{-1}	1300 ÷ 1453		61	
Fraction of seed biomass	65 ÷ 100% #		8%	
	Industrial mills extraction cost 0.07 € kg^{-1} Stone mills extraction cost 0.25 € kg^{-1}		Importation cost including packaging cost (1.47 € lt^{-1})	
	Flour packaging cost (0.25 € kg^{-1})			
Market value	♦ 1.5 ÷ 4.0 € kg^{-1}		2.2 € lt^{-1}	

* The percentage varies according to the type flour and the milling process, i.e., 85% = stone mill to get normal flour, 95% for industrial extraction to obtain wholemeal flour. # the variation in yield depends on whether it is normal or wholemeal flour, i.e., 65% normal flour, 100% is the yield in case of wholemeal flour. ♦ The retail price may vary according to the normal flour or wholemeal flour and if it is produced by an industrial process or stone mill.

Depending on the production process selected on the basis of the options mentioned above, the flour retail price may vary between 1.5 and 4.0 € kg^{-1}. Specifically, the retail market value of flour was estimated for two different biomass processing procedures: (a) industrial extraction to produce wholemeal flour and (b) non-wholemeal stone milling. The data required for this assessment have been kindly provided by Mr. Francesco D'Amore (Coldiretti), Vice President of the Caserta Unit of Coldiretti.

In the analysis of the case study, the expected market value of maize end-products was estimated by combining the coefficients in Table 13 with the see yield in our experiment treatments (Table 14).

Table 14. Market value, transformation cost and net benefit for oil and flour maize. The data are obtained by considering the seed production and multiple to the correspondent cost reported in Table 13. ◊ The range of the packaging cost is related to the packaging in the case of wholemeal flour, i.e., 100% yield (e.g., 2300 € ha^{-1}) or in case of normal flour, i.e., 65% yield (e.g., 1495 € ha^{-1}). ♣ Total net benefit considered once the flour benefit comes from wholemeal industrial extraction and once the flour benefit comes from a stone mill.

		Maize			
		C	S_1	S_2	S_3
Seeds	q ha^{-1}	92	85	71	49
	Market value seeds (30 € q^{-1})	2760	2550	2130	1470
Flour	Market value industrial extraction and wholemeal flour (€ ha^{-1})	36,800	34,000	28,400	19,600
	Market value stone mills extraction standard flour (€ ha^{-1})	8970	8288	6923	4778
	Industrial mills extraction € ha^{-1}	644	595	1154	796
	Stone mills extraction € ha^{-1}	1495	1381	1775	1225
	Flour packaging € ha^{-1}	2300 ÷ 1495 ◊	2125 ÷ 1381	1775 ÷ 1154	1225 ÷ 796
	Net benefit chain industrial exctraction wholemeal flour € ha^{-1}	32,403	29,827	24,675	16,579
	Net benefit chain stone mills exctraction flour € ha^{-1}	4680	4226	3315	1886
Oil	Market value € ha^{-1}	1619	1496	1250	862
	Importation cost plus packaging cost € ha^{-1}	1082	1000	835	576
	Net benefit oil € ha^{-1}	476	435	354	225
	Total net benefit (flour and oil) € ha^{-1}	32,878 ÷ 5155 ♣	30,262 ÷ 4661	25,029 ÷ 3669	16,804 ÷ 2111

If the C treatment and wholemeal flour industrial processing is considered, a 100% marketable yield is available with a market value of 4.0 € kg^{-1}. The C treatment produced 92 q ha^{-1} of grain i.e., a market value of 36,800 € ha^{-1} from which we have to subtract: (1) the production cost of flour, i.e., 644 € ha^{-1} for the industrial extraction; (2) the packaging cost, i.e., 2300 € ha^{-1} for wholemeal and (3) the cost to produce the raw biomass, i.e., 1453 € ha^{-1}. Thus, the net benefit is 32,403 € ha^{-1}. If the oil produced is also considered, there will be an additional value, estimated assuming an 8% yield in oil and a retail market value of 2.2 € lt^{-1}, which gives for the C treatment a total market value of 1619 € ha^{-1} for oil. The costs of purchasing oil and bottling (1082 € ha^{-1}) and the cost to produce the grain biomass have to be subtracted, which is only 4% of the total 1530 € ha^{-1}, i.e., 61€ ha^{-1}. Thus, the total net benefit for oil is 476 (€ ha^{-1}), which can be added, although it is nearly negligible, to the net benefit of flour to have a total benefit for maize, i.e., (32,403 + 476 = 32,878 € ha^{-1}) for the whole-meal chain, or 4680 + 476 = 5155 € ha^{-1} for stone milling.

The same approach was applied to flour and hemp oil that, at the moment, are in high demand. Likewise maize, the production and the transformation costs and the market values of hemp were estimated first (Table 13). The information on costs and values was provided by Hemp Farm Lab and Centro Operativo Sviluppo Canapa del Sud Soc.Coop.Agr. a.r.l., which operates as a primary producer, in the first processing stage and as a point of contact with a network of small enterprises which transform the raw materials into marketable products. Our data on yield (Table 15) combine our observations on fiber production for the different experiment treatments with a re-analysis of the data by Di Candilo et al. [24] on seed production determined in the same environment and for the same varieties as in our experiment. In the case of hemp, the cost of produced total biomass varies according to whether the farmer produces directly (840 € ha^{-1} Table 13) or hiring contractors (1340 € ha^{-1} Table 13). An example is presented below of the calculation of the net benefit of oil, hurd and fiber for the case in which the farmer produces the biomass without hiring contractors.

Table 15. Market value, transformation cost of the oil and flour hemp. The data are obtained by considering the seed production and multiple to the correspondent cost reported in Table 13.

		Hemp			
		C	**S_1**	**S_2**	**S_3**
Seeds	q ha^{-1}	4.8	4.6	4.1	3.4
	Market value seeds (180 € q^{-1})	864	828	738	612
	Market value oil € ha^{-1}	3648	3496	3116	2584
	Market value flour € ha^{-1}	3360	3220	2870	2380
	Cost for oil extraction € ha^{-1}	384	368	328	272
	Cost for milling € ha^{-1}	202	193	172	143
	Cost Oil packaging € ha^{-1}	346	332	295	245
	Cost Flour packaging € ha^{-1}	1210	1159	1033	857
	Net benefit oil (range) retail without contractor/with contractor (€ ha^{-1})	2733 ÷ 2624	2612 ÷ 2502	2308 ÷ 2198	1892 ÷ 1782
	Net benefit flour (range) retail without contractor/ with contractor (€ ha^{-1})	1780 ÷ 1680	1699 ÷ 1599	1497 ÷ 1397	1212 ÷ 1112
Fiber	q ha^{-1}	40	39	35	28
	Market value € ha^{-1}	2400	2340	2100	1680
	Net benefit fiber (range) retail without contractor/with contractor (€ ha^{-1})	2274 ÷ 2199	2214 ÷ 2139	1974 ÷ 1899	1554 ÷ 1479
Hurd	q ha^{-1}	138	132	119	97
	Market value € ha^{-1}	6900	6600	5950	4850
	Net benefit hurd (range) retail without contractor/with contractor (€ ha^{-1})	6548 ÷ 6337	6248 ÷ 6037	5598 ÷ 5387	4498 ÷ 4287
	Total net benefit (range) without contractor/with contractor (€ ha^{-1})	13,335 ÷ 12,840	127,73 ÷ 12,277	11,377 ÷ 10,881	9156 ÷ 8660

It should be noted that the crop management choices have a much higher impact on the total net benefit of hemp production than the yield losses due to saline stress (Table 15). The net benefit of seed production varies in the range 2894 (1782 + 1112) (€ ha^{-1}) to 4513 (2733 + 1780) (€ ha^{-1}), depending on which combination of saline stress and production process is considered. If the crop would be cultivated to produce fiber and hurd, the net benefit would be in the range 5766 (1479 + 4287) (€ ha^{-1}) to 8822 (2274 + 6548) (€ ha^{-1}). In other words, the net benefit in the case of seed production and treatment C (not saline) would be about 30% lower than the net benefit in the case of fiber and hurd production and treatment S_3 (most saline). Similar conclusions are reached when considering the range in the total net benefit for oil and flour maize (Table 14), even for each treatment separately.

The net hemp oil benefit, i.e., 2733 € ha^{-1}, for the C treatment was obtained from a market value of 3648 € ha^{-1} minus oil extraction cost 384 € ha^{-1} minus packaging cost 346 € ha^{-1} minus cost for seeds production without hiring contractors, i.e., 22% of 840 € ha^{-1} = 185 € ha^{-1}, to give an estimated total benefit of 2733 € ha^{-1}.

From the production of hemp, there still remains a source of income which are the stalks, from which fiber and hurd can be obtained. The net fiber benefit, i.e., 2274 € ha^{-1}, comes from a market value of 2400 € ha^{-1} minus cost for biomass production, i.e., 15%

of 840 € ha^{-1} = 126 € ha^{-1}. It is the same procedure for the net benefit for hurd, i.e., 6548 € ha^{-1}, obtained from a market value of 6900 € ha^{-1}, minus production cost of 42% of 840 € ha^{-1} = 353 € ha^{-1}.Therefore the total benefit is 11,555 € ha^{-1}, i.e., 2733 + 2274 + 6548 € ha^{-1}. This total benefit can increase to 13,335 € ha^{-1} if 1780 € ha^{-1} from flour is included. For flour, the market value is 3360 € ha^{-1} minus flour milling cost 202 € ha^{-1} minus packaging cost 1210 € ha^{-1} minus cost for seeds production, i.e., 20% of 840 € ha^{-1} = 168 € ha^{-1}, reaching 1780 € ha^{-1}.

Our case study suggests that maize would be more profitable both for the control and for the salt treatments. It must be emphasized that the highest net benefit is achieved with maize flour, while the market demand for hemp oil seems more limited, which was to be expected in Italy where olive oil is generally used. In Italy, demand for hemp products is still very limited. Demand is booming for the hemp inflorescence, due to loopholes in current legislation. In Italy, the absence of well-distributed and properly equipped processing centers does not help to improve market penetration of hemp products. These difficulties start with harvesting. Combine harvesters designed for wheat are widely used [78], but this is a sub-optimal solution because such machines do not operate easily in the small hemp plots, and the cutter bars tend to get clogged by hemp fiber.

This gap could be filled by promoting a better and more efficient integrated farming system to produce, process, transform and sell hemp consumer products. The organizational model could be a stable consortium of stakeholders to span all the segments from hemp production to consumers. This model could possibly achieve two key-objectives: (a) optimize the location of processing plants and distribution centers taking into account the production sites and (b) minimize overhead. At the moment, in Italy, there are two distribution centers, one in the north and one in the south, which leads to higher distribution costs.

Hemp could keep its promises if, as already pointed out by other authors, it is recognized as a multipurpose crop. This would maximize the use and value of all the parts of the plant or the waste coming from some productions. For example, in France, quality filter paper for cigarettes is produced from residual stalks of a hemp crop managed to produce seeds. Another example is the use of hemp leaves for animal feed, while seeds and stalks are used for other products. This evolution requires clearer rules and legislation, a remark shared by Giupponi et al. [78], as demonstrated in countries in, e.g., Northern Europe, where a more efficient regulatory context has been put in place.

7. Final Considerations

From the analysis carried out, it is evident that hemp has a better potential to be an attractive multipurpose crop than others, for example, maize. Hemp can generate a broad spectrum of widely used end-products that yield significant value, as documented by evidence on both Canada and U.S. markets. In France, notwithstanding the somewhat restrictive European regulations, investments in the development and promotion of high value hemp products have been significant. Likewise, research and breeding of new varieties have continued. In other countries, rules and regulations applicable to hemp have been streamlined, while, in Italy, applicable legislation remains complex. The most critical issue remains the threshold on THC concentration in products such as infusions. For example, in Germany, a higher level of THC is allowed in combination with guidelines on THC in hemp-containing foods. Clear and detailed regulations are a necessary reference for farmers and for enterprises active in the transformation of hemp raw materials into end (consumer) products. Such clear regulatory framework is necessary to attract investments towards the development and implementation of technologies, leading to higher productivity and efficiency.

For several years, farms, especially small ones, have had difficulty in being competitive in the market and being able to have an adequate income for their livelihood [3]. In this complicated scenario, companies are looking for new valuable crops, especially good rotation crops that require little tending or resources. Hemp, with the wide range of end-products that it can generate, finds favor with farmers thanks to the low inputs it requires for cultivation, certainly less than maize. Hemp allows companies to obtain income in multiple sectors, such as food, fiber, construction, paper, etc., thus guaranteeing an increase in business volume and added value. On the other hand, hemp can adapt well in many climates and complex areas; therefore, it has the possibility of being a valid source of income even in marginal areas. Marginal areas suffer from environmental problems such as water scarcity, salinity, pollution, and/or for constraints on, e.g., the adoption of new technologies.

8. Conclusions

This study was triggered by a seemingly simple question: if the richness in final, marketable hemp products is so evident, why are farms not jumping on it? After some more thinking, this question was articulated as follows. A farmer would consider first the yield achievable under given environmental constraints. To evaluate the potential of hemp, we need to reverse the order of matters in defining a farm strategy: look first at the added value of final products, then compare those with the damage associated with potential yield losses. This is what we did in this study, first from a global point of view, then assessing a specific case in a former hemp-producing region in Italy. The same assessment was applied to maize to have a benchmark on both aspects.

The different end-products of hemp, but also of maize, are obtained from raw materials coming from different plant fractions. The income generation with multiple products is not necessarily compromised by biomass losses due to environmental stresses.

Specifically, the range in the net benefit of hemp cultivation depends much more on farming choices, i.e., seed vs. hurd and fiber, than possible yield losses due to abiotic stresses. Likewise, as regards maize, the choice of the milling process to produce flour has a far bigger impact on net benefit than saline stress.

The potential of hemp to provide raw materials for a broad range of marketable products is an important asset for farmers, since it leaves plenty of opportunities to diversify the production and improve profitability by focusing on consumer products with large added value.

Hemp is often included in the production systems of marginal areas, where the spectrum of viable cropping patterns is constrained by environmental conditions, e.g., water scarcity, salinity, etc., or access to new technologies. Both the literature reviewed and our experiment document the biomass loss due to water and saline stress, while the allocation of total biomass to plant parts remained largely insensitive to stresses. Overall, both literature and experimental data showed that losses in plant raw materials do not necessarily compromise farm viability, given appropriate choices of target final products on the basis of expected added value, rather than yield.

Evidence from both literature and our experiment showed that the reduction in biomass under stress was larger in maize than in hemp. Both crops are moderately sensitive to salinity, with maize being more sensitive than hemp. The reduction in plant fractions for hemp is not highly compromised to an extent that does not guarantee adequate raw materials required for the end products, and so the net benefit is not highly compromised.

Our simple case study on costs and revenues associated with flour and oil showed that maize was more profitable than hemp. However, it should be emphasized that the advantage of maize is that it is a well-established and widely used industrial crop, thus production costs have been reduced through upscaling of facilities and streamlining of technology. A good example is the difference in the cost of packaging maize flour, i.e., 0.25 € kg^{-1} against 3.6 € kg^{-1} for hemp. On the other hand, such rough estimates of costs and revenues should be revisited and extended to the broad spectrum of the hemp added-value products. A last comment is on our estimates of costs and revenues. Especially for hemp, we had to use information from scattered sources and a limited number of small stakeholders, i.e., this aspect should receive proper attention in any future study.

In conclusion, the sector could have growth opportunities if actions were taken to tackle simultaneously multiple issues, especially the regulatory system currently applicable to hemp. Much is now known about the hemp cultivation technique, which in combination with the adaptation capacity of farmers, bides well for effective improvements in the production system. Our findings suggest that widespread use of hemp would lead to a more resilient and sustainable agri-food system, although regulatory and medium enterprise policies should be adapted to bring about this development.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142315646/s1, Supplementary Material S1 (3.2.-Germination test), Supplementary Material S2 (4.3-Field trial), Table S1—Soil texture and the Soil Water Content; Table S2—Initial and mean seasonal values of the electrical conductivity of saturated paste Figure S1—Rainfall and mean air temperature; Table S3—Germination, (%) and mean germination time; Figure S2—Cumulated actual crop evapotranspiration (ETa mm) (a) Maize, (b) Hemp; Figure S3—Cumulated Leaf area duration (LAD): Maize (a) and Hemp (b); Figure S4—Dry weight shoot (W) plotted vs. actual crop evapotranspiration (ETa) Maize (a) and Hemp (b); 4.4 Response to water and salt stress, and salt tolerance; Figure S5—Response factor for leaf area duration (LAD) (a) and for shoot dry weight (W) (b); Figure S6, Mass and Hoffman relationship.

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