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Communication

How to Reintroduce Arable Crops after Growing Perennial Wild Plant Species Such as Common Tansy (*Tanacetum vulgare* L.) for Biogas Production

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Abstract: The cultivation of perennial wild plant mixtures (WPMs) is becoming increasingly important in Germany for providing sustainably produced bioenergy. However, perennial energy cropping systems always raise the question of how to reclaim the land for arable crops. This study examined this issue by looking at how a former WPM area was returned to arable cropping for an organic farm. From 2013 to 2018, the WPM area was harvested annually in the autumn. From 2019 to 2020, it was co-managed with the surrounding land as a semi-intensive grassland under a three-cut regime. The area was then ploughed in the spring of 2021 to grow silage maize. Weeds were controlled mechanically once. Nevertheless, the perennial wild plant species grew vigorously, with common tansy (*Tanacetum vulgare* L.) standing out with a total fresh matter share of 29.0%. This maize–WPM mixture achieved a dry matter yield of 15.5 ± 5.5 Mg ha^{-1}, which was notably but not significantly ($p < 0.05$) lower than that of silage maize growing next to the former WPM area (23.4 ± 5.5 Mg ha^{-1}). After silage maize, winter wheat was sown in the autumn of 2021 and further regrowth of common tansy was observed in the spring of 2022. Yield and quality effects must therefore be given special consideration in the first arable crop following WPM cultivation.

Keywords: agrobiodiversity; crop rotation; cutting tolerance; grassland; herbicide avoidance; perennial crop; removal; weed management; wild flower; wild plant

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1. Introduction

Land use conflicts are expected to increase further in the future due to increasing societal demands and environmental challenges [1]. In addition, recent geopolitical developments have shown that reliable long-term planning is not always possible for the import of energy or raw materials [2]. Therefore, it is becoming increasingly important to use available resources as efficiently as possible within sustainable agriculture [3,4] and, in particular, rely on locally available resources and close nutrient circles as much as possible [5]. Here, perennial energy crops (PECs) can play an important role in bioeconomy, be it through their high tolerance to climate change-related cultivation limitations [6,7], their high nutrient use efficiency [8,9] or through their fulfillment of numerous ecosystem services, apart from the provision of biomass [10–12], which helps to substitute fossil energy sources. In addition to common PECs such as willow [13,14], *Miscanthus* [15,16], Sida [17,18], switchgrass [19,20] and cup plant [21,22], the cultivation of perennial wild plant mixtures (WPMs) is becoming increasingly important in Germany [23]. The cultivation of WPMs enables farms to specifically contribute to the promotion of biodiversity through a high number of flowering wild plant species and, at the same time, gain significant biomass yields for bioenergy production [24,25]. Therefore, in some federal states, WPM cultivation is or will be subsidized, for example within the support program for agri-environment, climate protection and animal welfare ("FAKT", part of the Common Agricultural Policy) by up to EUR 500 per hectare per year [26].

In the early 2000s, WPMs were selected and mixed in such a way that the species composition provided suitable biomass quantity and quality for biogas production over at least five years of cultivation [27]. The use of WPM biomass in biogas production could then also contribute positively to climate change mitigation because fossil fuel energy resources would be replaced by renewable resources. With an average specific methane yield (SMY) of 241.5–248.5 l_N $kg_{VS}{}^{-1}$ [28], wild plant species perform worse than silage maize (about 330 l_N $kg_{VS}{}^{-1}$) [29] and *Miscanthus* (300 l_N $kg_{VS}{}^{-1}$) [30], mainly due to the high amounts of lignin in WPM biomass. The degradation of this lignin prior to anaerobic digestion in the biogas plants could enable a much higher SMY. This was shown for Sida biomass, for example, in which the SMY could be increased to almost 600 l_N $kg_{VS}{}^{-1}$ using a pretreatment with microwave thermohydrolysis and hot water [31]. However, a qualitative assessment of WPMs is not easy because of their high, yet intended, species composition dynamics within the WPMs during their cultivation, especially during the first three years [25,32]. This is because in the first year, the annual species dominate the plant stand, then the biennial species and from the third year onward, the perennial species [32]. In subsequent years, WPM stands then become increasingly impoverished as usually only one or two perennial wild plant species establish themselves as permanently dominant within the stand [32]. Surveys with farmers who have first-hand experience of WPM cultivation for several years have shown that common tansy is one of these important yield-relevant species and that WPMs help to increase biodiversity in the agroecosystem [33,34]. It is currently unknown for how long common tansy can be cultivated until biomass yields decrease and are no longer profitable [24]; however, it is likely that common tansy can persist for longer than five years because it has great self-seeding potential. Due to the revised regulations for PEC in several German states, it will also be possible for farmers to cultivate WPMs for longer than five years without losing the arable status of the fields on which the WPMs are grown.

When harvested as late as September, the first seeds are already ripe and can drop out and contribute to the building up of a common tansy seed bank in the soil. On the one hand, these seeds could contribute to the steady regeneration of the common tansy stand; on the other hand, they could make it more difficult to return the cultivated area to arable use or significantly increase the costs and resources required for the weed management of the following crop. Therefore, not only should how to optimize the cultivation of WPMs or common tansy be investigated [24,29], but also which problems can arise when returning former WPM areas to arable use and how these problems could be counteracted. Similar studies have already been undertaken for other PECs, such as *Miscanthus*, and important lessons have been learned [35]. Therefore, this study aimed to (i) communicate the need for the same investigation into WPM land based on the results of a preliminary field trial and (ii) derive promising approaches for targeted large-scale field trials in the future. For the preliminary field trial, it was hypothesized that WPMs as a pre-crop could have a significant effect on the performance of subsequent arable crops, such as silage maize.

2. Materials and Methods

The field trial with WPMs was established at a field near the University of Hohenheim (48°42′53.3″ N, 9°12′41.1″ E; 407 m above sea level) (Figure 1) in 2013. This field is located within the continental agro-ecological zone [36] and was characterized by an average annual temperature of 9.3 °C and a total precipitation of 619.1 mm in 2021 (Figure 2). The soil is a Luvisol with a clayey loam.

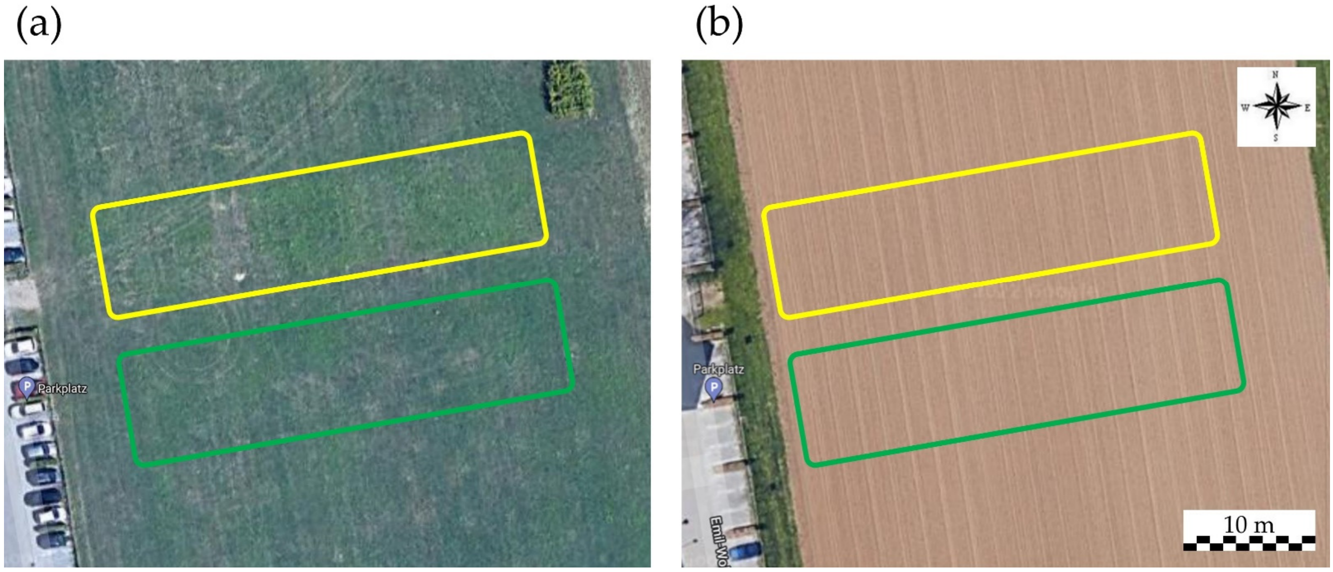

Figure 1. Satellite images (Maps Data: Google, © 2022 GeoBasis-DE/BKG) of the preliminary field experiment that was carried out in this study. One image was taken before the field was ploughed in the spring of 2021 (**a**) and one was taken in the winter of 2021–2022, when winter wheat was sown but was not yet visible from space (**b**). The yellow frame indicates the area in which wild plant mixtures were grown during the years of 2013 to 2018 and the green frame indicates the area from which the maize control samples were taken in September 2021.

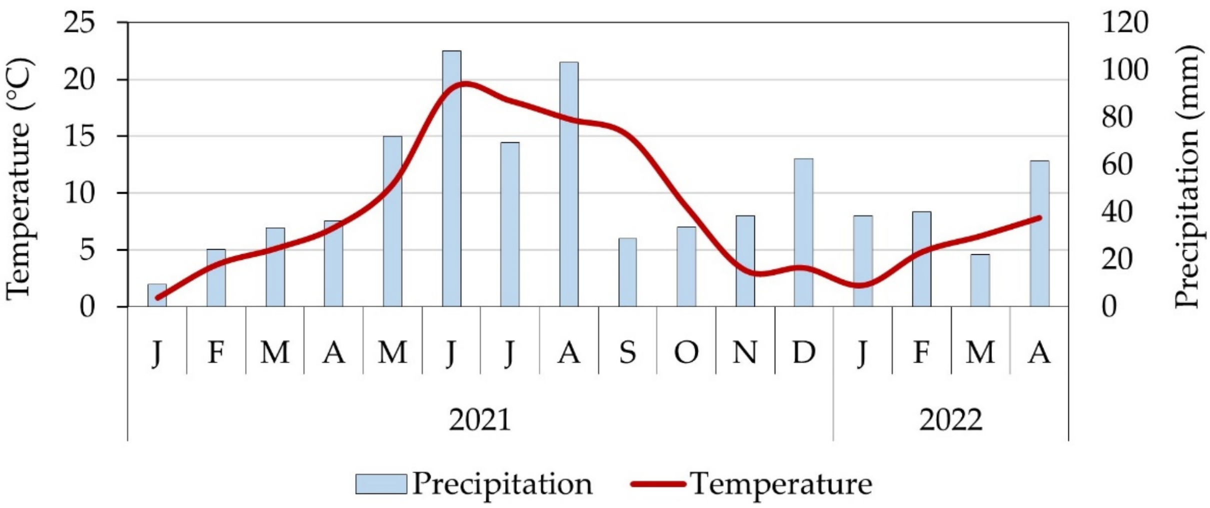

Figure 2. The monthly average temperature and precipitation at the experimental site in Hohenheim.

The field trial establishment procedure followed an approach that was previously published by von Cossel et al. [32], whereby the WPM field trial measured 432 m^2 (12 m × 36 m) and from the second year of WPM cultivation onward (in 2015), the plant stand was dominated by common tansy (Figure 3). On the surrounding land, grassland management was carried out according to the usual four-cut method with an ordinary mower.

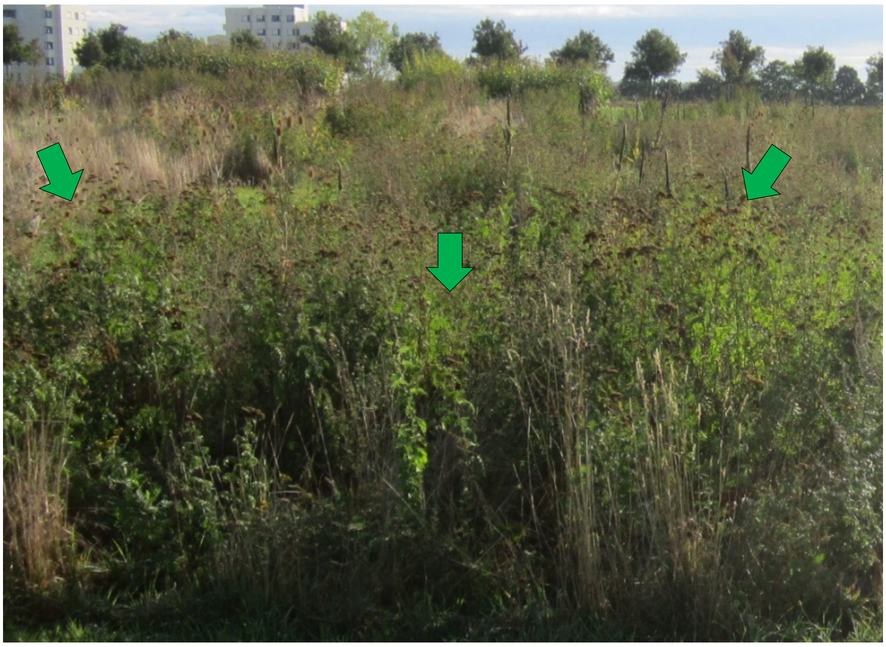

Figure 3. An overview of the WPM plant stand at harvest in 2015. The arrows indicate examples of individuals of common tansy, which dominated the plant stand.

In the spring of 2021, the area was ploughed at a 15–20 cm depth. In May 2021, silage maize (Ronaldinio, KWS, Einbeck, Germany) was sown at a row width of 0.5 m and a sowing density of 9 kernels/m^2. No nitrogen (N) fertilizer was applied because of the expected N mineralization from the grassland conversion. No synthetic chemical pesticides (e.g., herbicides, insecticides, etc.) were applied either during the maize cultivation in 2021 because it was intended to establish an organic farming system.

On 14th September 2021, three subsamples were taken from each experimental field (Figure 1a,b). For each of these subsamples, the above-ground biomass of a sample area of 1.13 m^2 was harvested by hand at a cutting height of about 10 cm. The fresh matter samples of both maize and common tansy were weighed individually to determine the fresh matter yield per hectare for each species and the respective proportion of the total fresh matter yield for both plants. Then, the fresh matter samples of both maize and common tansy were mixed and chopped with a stand chopper (ELIET PROF 5, Eliet Europe nv, 8553 Otegem, Belgium). These subsamples were then dried at 60 °C to a constant weight to determine the dry matter content and calculate the dry matter yield. In addition to the biomass yield and quality measurements, the height and the number of stems of maize and common tansy were measured at harvest.

All data were compiled using MS Excel. For the statistical analysis, the PROC MIXED procedure of the SAS® Proprietary Software 9.4 TS level 1M5 (SAS Institute Inc., Cary, CA, USA) was used. Both the degrees of freedom and the standard errors were approximated using the Kenward–Roger method [37]. Then, *t*-tests were applied to generate a letter display [38] when differences were found. The significance level of 5% of the alpha error was not met because the differences in the treatment variants were already recognizable before sampling (conditional observation).

3. Results

During the vegetation period, the plant stand was observed once after the mechanical weeding was carried out (21 June 2021). It was seen that most of the wild plant species, especially the common tansy, were removed from between the maize rows but a large number of common tansy plants were still growing within the maize rows (Figure 4).

Figure 4. An impression of the maize plant stand within the treatment area "after wild plant cultivation", two days after the mechanical weeding was carried out (21 June 2021). While most of the common tansy plants and the other non-target species between the maize rows were destroyed, a few common tansy individuals survived (red arrows).

At harvest, just by looking at the plots from the field border, it was obvious that the overgrowth of common tansy had a clear impact on the growth of the maize (Figure 5). Thus, the maize plants in the plots where WPMs had previously been grown appeared significantly smaller and lighter than those in the control plots next to them, where there had previously been only grassland (Figure 5).

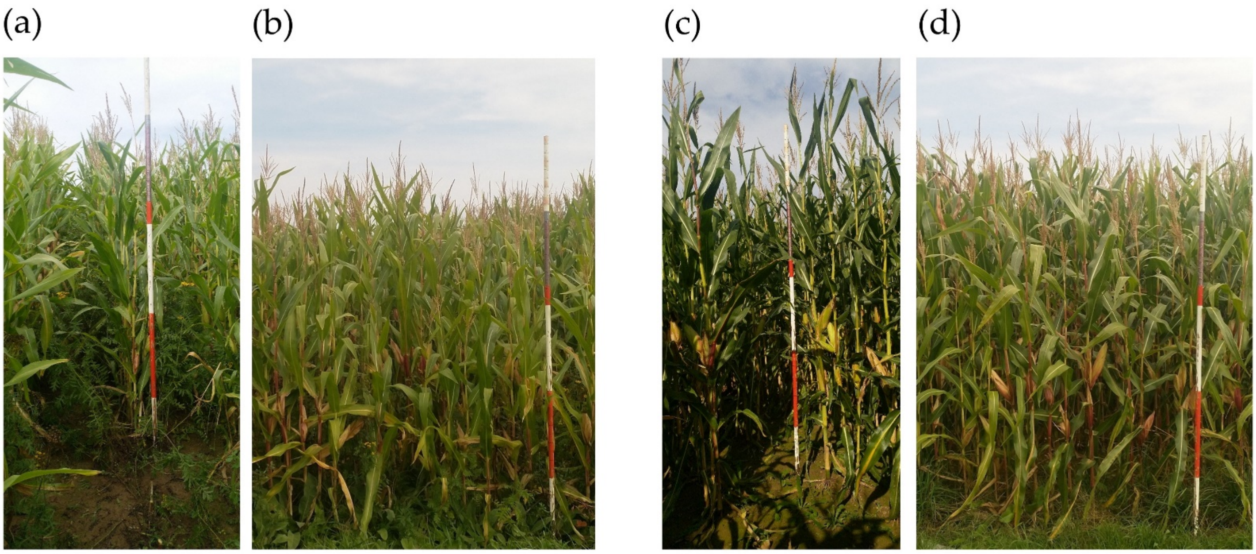

Figure 5. Impressions of the maize stands with (**a**,**b**) and without common tansy (**c**,**d**). For both treatments, views of inside the plant stand (**a**,**c**) and from the outside (**b**,**d**) are shown. One segment of the bar measures 0.5 m.

The visual impressions were confirmed by the measurements of the plant height, plant density and biomass yield characteristics at harvest (Tables 1 and 2, Figure 6a–c). This showed that common tansy had a significant ($p < 0.05$) negative influence on the growth height of maize, which averaged only 201.3 cm with common tansy and 265.3 cm without common tansy. However, the plant density of maize was not affected by common tansy (Table 1) and neither was the fresh matter yield of maize (Figure 6a) nor the total dry matter yield (Figure 6b).

Table 1. An overview of the morphological parameters of maize, common tansy and the total biomass per treatment. For each observation, the raw data, average values and standard deviations are shown.

Treatment	Height (cm)		Number of Stems per m^2	
	Common Tansy	**Maize**	**Common Tansy**	**Maize**
Maize Control		274		10.7
		246		8.0
		276		7.1
		265.3 ± 13.7		8.6 ± 1.5
Maize After WPM	120	218	28.4	8.0
	122	210	28.4	9.8
	114	176	60.4	8.9
	118.7 ± 3.4	201.3 ± 18.2	39.1 ± 15.1	8.9 ± 0.7

Table 2. The raw data, average values and standard deviations of the fresh matter yields (FMYs) of common tansy and maize and the total biomass (maize + common tansy) per treatment. For the total biomass, the dry matter content (DMC) and dry matter yield (DMY) are also shown.

Treatment	FMY (Mg ha^{-1})			DMC (%)	DMY (Mg ha^{-1})
	Common Tansy	**Maize**	**Total**	**Total**	**Total**
Maize Control		71.8	71.8	42.1	30.2
		39.4	39.4	33.1	13.0
		63.7	63.7	42.3	26.9
		58.3 ± 13.7	58.3 ± 13.7	39.1 ± 4.3	23.4 ± 7.4
Maize After WPM	8.6	36.8	45.4	40.7	18.5
	9.6	29.2	38.9	37.6	14.6
	13.8	18.2	32.0	41.4	13.3
	10.7 ± 2.2	28.1 ± 7.6	38.8 ± 5.5	39.9 ± 1.6	15.5 ± 2.2

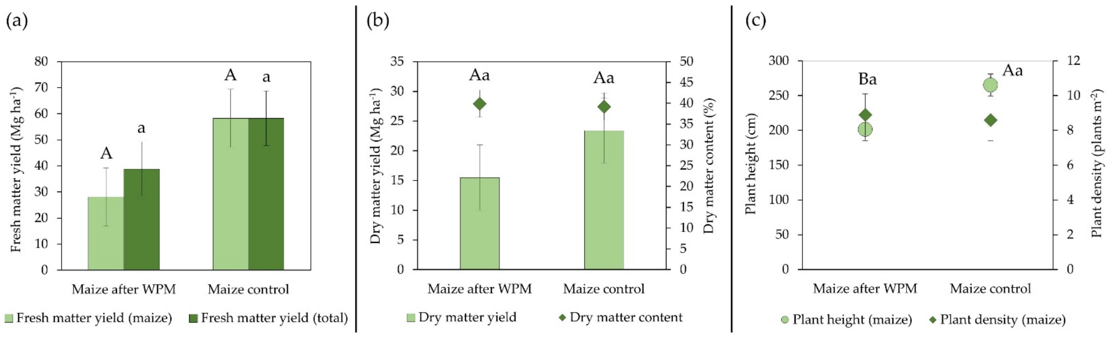

Figure 6. The results of the statistical analyses (estimates and standard errors) of the fresh matter yield components (**a**), total dry matter yield and dry matter content (**b**) and plant height and plant density (**c**) of the maize at harvest on 14 September 2021. "Maize after WPM" denotes the area where wild plant mixtures (WPMs) were grown during the years of 2013 to 2018. "Maize control" denotes the area that was cultivated with grassland (four-cut regime). Upper case letters denote significant ($p < 0.05$) differences between the treatments of fresh matter yield (maize) (**a**), total dry matter yield (**b**) and plant height (**c**). Lower case letters denote the other respective parameters shown in (**a**–**c**).

4. Discussion

Generally, it was shown that the results of the field experiment demonstrated a very high variation due to the low number of replicates (n = 3) and the small sample area (1.13 m^2). For *Miscanthus* and willow, for example, a sample area of 3 m^2 and 9 m^2 is required, respectively, to account for 90% of the variances [39,40]. Thus, the preliminary results of this study should be approved by field experiments at a larger scale with larger sample areas and a higher number of replicates. This would allow for a more realistic representation of the variances of the quantitative and qualitative traits of the plants. For example, common tansy had a much higher share of the total fresh matter yield in one of the three replicates (Table 2) despite it being a little smaller than in the other two replicates (Table 1). This was mainly due to the much higher plant density in that replicate, showing how important it is to consider the plant density of common tansy (or any other wild plant species that could regrow after removing WPM cultivation) more in future investigations.

Additionally, there were no significant differences between the maize biomass yields for the different treatments, but it was notably lower in the area where WPMs were cultivated in the years of 2013 to 2018. With a more accurate estimation of the variances, this difference may be significant. Thus, the hypothesis was not confirmed. However, the preliminary results of this study already indicate the decline in biomass yield that can be caused by the regrowth of wild plant species, such as common tansy (Figure 6a,b).

This study did not consider effects on biomass quality other than the DMC and yet, they are significant in terms of biomass utilization (e.g., biogas production). This is because wild plant species, such as the common tansy, are known to have a lower ensilage suitability [41] and a lower substrate-specific methane yield than maize [27,28]. From this, it can be assumed that any share of the total biomass of wild plants, such as the common tansy, could cause a decrease in biomass quality where biogas production is concerned [29].

To circumvent this problem of decreased biomass quality for biogas production purposes, it would be worthwhile to investigate whether another type of use could be suitable. Other biomass utilization pathways, such as combustion or bioethanol production, require biomass quality criteria that are different from those of biogas production [18,41]. The high lignin content and the low content of water-soluble sugars in the biomass both lower the suitability of WPMs for biogas production [41] but can increase the suitability of the biomass for combustion [42–44].

However, biomass for combustion use must be harvested much later (in the winter), which would result in the renewed seed maturity of common tansy and a further spread of this wild plant within the stand (Figure 7). This would be harmless from an ecological point of view, as common tansy is a native wild plant species in central Europe [25,27]. In fact, extending the flowering period of common tansy would be fundamentally positive in terms of the ecosystem function of supporting pollinator insects. This is because the supply of flowering crops in modern agricultural landscapes is very limited [45], especially in the late summer to fall period, and it is then that many wild bee and bumblebee species rely on food to prepare their larvae for winter [46–48]. However, the common tansy seed accumulation in the soil would be unfavorable to the cultivation of annual arable crops, again reducing the yield of agricultural products (grains, tubers, etc.) and possibly also their quality. Hence, a higher input of labor energy and resources would be required to cope with common tansy in subsequent years.

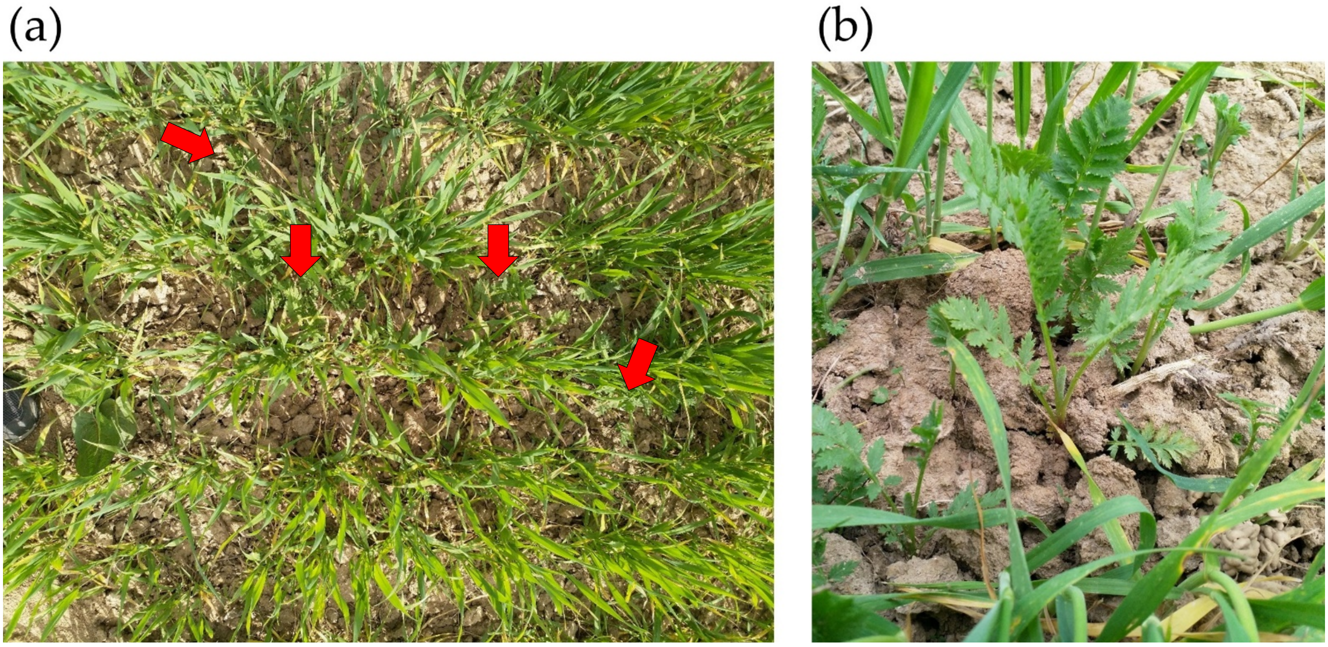

Figure 7. Observations of common tansy in winter wheat from above (**a**) (red arrows indicate a few individuals of the common tansy) and close-up (**b**). Photos were taken on 21 April 2022.

In this study, it was not possible to carry out different weed management strategies. In the future, it should be investigated whether, for example, the preparation of a false seedbed [49] (seedbed preparation followed by another seedbed preparation a few weeks later) in combination with a later sowing date of maize would lead to a reduction in the spread of the common tansy. Any additional costs for further tillage could then be compensated by a higher biomass yield of maize (and a better biogas substrate quality), which would be enabled by the lower competitive pressure from common tansy (Figure 6a). More weed-competitive crops, such as fiber hemp [50] or sunflower, could also be tested instead of maize, provided that common tansy does not impede the harvesting procedure, for example, by further reducing the working speed of the harvester, which is already low in the case of sunflower cultivation (5 km/h) [51].

Furthermore, the regrowth from the second year of WPM cultivation also deserves a closer look. This is because it was shown in the spring of 2022 that common tansy germinated in winter wheat (which followed the silage maize cultivation in 2021) (Figure 7a,b) and could perhaps cause a certain reduction in the grain yield of the winter wheat. Here, the use of living mulch could be worth trying as Hiltbrunner et al. [52] found that living mulch, i.e., a mixture of white clover (*Trifolium repens* L.), subterranean clover (*Trifolium subterraneum* L.) and birdsfoot trefoil (*Lotus corniculatus* L.), helped to control dicotyledonous weeds in an organic farming system.

In non-organic farming systems that allow the use of synthetic–chemical pesticides, it would make sense to test the use of herbicides. In winter cereals, for example, there are a number of herbicides that have a broad spectrum of activity against dicotyledonous weeds [53]. However, conventional non-organic farming systems were not considered in this study as the trend in the future is more likely to be toward farming systems in which the use of at least synthetic–chemical pesticides is prohibited, such as organic farming or mineral-ecological farming [54].

5. Conclusions

The preliminary results of this study showed that the regrowth of common tansy has the potential to notably reduce the biomass yield and quality of silage maize in an organic farming system. Therefore, it is a very important topic that needs to be dealt with in more comprehensive studies (e.g., large-scale field trials) in the future. Two possible solutions were identified as needing to be addressed: (i) making the best use of the substrate mixture of maize and the common tansy, e.g., in biogas production, and (ii) increasing the weeding intensity so as to decrease the share of the total biomass of common tansy as much as possible. Other utilization pathways that are linked with a winter harvest, such as combustion or bioethanol production, would not make any sense for arable crops. Thus, in order to reintroduce an organic crop rotation of annual arable crops, there is probably no way around yield and quality losses due to the regrowth of certain wild plant species, such as the common tansy, in the first year.

It remains to be seen how low-intensity tillage approaches could also effectively help to reduce the regrowth of WPMs. This would be important in terms of reducing the mineralization of the soil carbon stocks that build up over the years by WPMs. Thus, the lower the tillage intensity (when removing WPMs), the better the climate change mitigation effects of WPM cultivation. This would add up to a wide range of beneficial ecosystem functions being caused by successful WPM cultivation and enable more sustainable biomass production that is not only biodiversity friendly but also contributes to climate change mitigation. The more knowledge that can be gained about this issue of the reintegration of arable crops after WPM cultivation, the greater the likelihood that (i) farmers will choose to cultivate WPMs and (ii) the corresponding agricultural policy regulations will be better adapted, for example, with regard to the duration, amount and framework conditions of the support measures.

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Conflicts of Interest: The author declares no conflict of interest.

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