agriculture

MDPI

Communication

The Perennial Grain Crop *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey (Kernza™) as an Element in Crop Rotations: A Pilot Study on Termination Strategies and Pre-Crop Effects on a Subsequent Root Vegetable

Linda-Maria Dimitrova Mårtensson *, **Ana Barreiro** and **Jenny Olofsson**

Department of Biosystems and Technology, Swedish University of Agricultural Sciences, P.O. Box 190, 234 22 Lomma, Sweden; ana.barreiro.bujan@usc.es (A.B.); jennymaria.olofsson@gmail.com (J.O.)
* Correspondence: linda.maria.martensson@slu.se; Tel.: +46-40-41-51-29

Abstract: Intermediate wheatgrass (IWG) may benefit soil fertility in crop rotations. To investigate termination strategies, i.e., autumn ploughing (AP), autumn harrowing (AH) and spring harrowing (SH) on a five-year-old IWG stand, a pilot study was performed. After the treatments, beetroots were sown and the IWG plants were counted twice during the beetroot growing season. The number of IWG plants was highest (20) after the SH strategy, intermediate (14) after the AH, and lowest (3) after the conventional termination strategy, AP. After the first plant count, the plots were subject to mechanical weeding in the form of a stale seedbed (i.e., harrowing twice before sowing). At beetroot harvest, the number of IWG plants was low (3 in SH and AH, 0 in AP) and similar between the treatments. The beetroot production was highest after AP and lowest in SH, and intermediary in AH, which showed no difference from AP and SH. At beetroot harvest, the weed biomass did not differ between the termination strategies. The weeds were mainly annuals. There were no differences in soil bulk density between termination strategies. Our results show that shallow soil tillage is enough to terminate IWG, as long as it repeated. We suggest further studies that investigate the dynamics of crop sequences with IWG, and how to benefit from this crop in rotations.

Keywords: ploughing; cultivation; harrowing; crop rotation; crop sequence; Kernza

Citation: Dimitrova Mårtensson, L.-M.; Barreiro, A.; Olofsson, J. The Perennial Grain Crop *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey (Kernza™) as an Element in Crop Rotations: A Pilot Study on Termination Strategies and Pre-Crop Effects on a Subsequent Root Vegetable. *Agriculture* **2021**, *11*, 1175. https://doi.org/10.3390/agriculture11111175

Academic Editor: Manuel Ângelo Rosa Rodrigues

Received: 12 October 2021
Accepted: 15 November 2021
Published: 21 November 2021

1. Introduction

Perennial cereals, grain legumes and oilseed species represent a paradigm shift in agriculture and have the potential to contribute to increased sustainability of production systems [1]. A perennial cereal grain crop, such as intermediate wheatgrass (IWG; *Thinopyrum intermedium*), has been proven to contribute to decreased nitrogen leaching [2] and, thus, reduced coastal eutrophication [3], while contributing to the restoration of soil quality in terms of soil structure and fertility [4]. In organic crop rotations, the perennial component is essential in its function as a sanitation crop, breaking the life cycle of weeds [5], and contributes to the build-up of soil fertility and quality [6]. The ley crops are commonly the perennial component in organic crop rotations, and here the IWG crop may provide an alternative with its additional service to produce human-consumable seeds.

In organic crop production, non-chemical termination strategies need to be applied to a perennial herbaceous crop. In crop rotations, ley fields are often ploughed [7] in the transition from a perennial to an annual crop in a rotation or before the ley is re-established (or renewed) [8]. Ploughing can have positive effects on soil structure but negative effects on soil organic matter content [9], active soil microbial biomass [10], earthworm occurrence [11], and thus the fertility and quality of the soil [12]. Furthermore, weed management in organic production mainly relies on mechanical soil perturbation, where the creation of a false seedbed distorts the weeds before the establishment of the main crop [13], while row harrowing controls the weeds in the already established crops [14]. There are different strategies for crop termination, from deep ploughing to more superficial soil cultivation techniques that can alter the nutrient distribution in the soil profile differently [15].

In order to benefit from the multiple functions offered by perennial cereal grain crops, such as IWG, research on management methods at the cropping system level is of significant importance to be able to know the impacts of the perennial crop within crop rotations otherwise dominated by annuals. Research on crop rotational effects of IWG is still limited. This short communication reports the results from a pilot study on three different termination strategies after five years of IWG production and the pre-crop effects on the cash crop beetroot (*Beta vulgaris* subsp. *vulgaris*). When terminating five-year-old IWG stands, we hypothesize that undesired re-occurring growth of IWG will be lower and deeper than after more shallow soil perturbation. Furthermore, we hypothesize that the yield of the subsequent root vegetable, beetroot, in addition to weed growth, will be highest after spring cultivation, second highest after autumn cultivation and lowest after the autumn ploughing.

2. Materials and Methods

The experimental site, located at the SITES Research Station Lönnstorp, SLU, in Alnarp (55.65° N, 13.06° E), has a fertile sandy loam soil, with a soil pH_{H2O} (0–30 cm) of 7.3 and 0.9% soil organic matter content. Soil nutrient conditions for the site correspond to 51 mg kg^{-1} of aluminum lactate extractable P, 0.36 g kg^{-1} total P, 65 mg kg^{-1} aluminum lactate extractable K, and 1.4 g kg^{-1} total K [16]. The average temperature is 9 °C and the average precipitation is 500 mm [17]. Seeds of intermediate wheatgrass were accessed from the Cycle 3 germplasm of the perennial grain-breeding program of The Land Institute of Salinas, KS [18]. The IWG sole crop was established in 2015. A solid fertilizer (YaraMila 27-3-3) was applied corresponding to 40 kg NPK ha^{-1} y^{-1} (corresponding to 11 kg N, 0.52 kg P, and 1.0 kg K ha^{-1} y^{-1}) and harvested annually in August or September.

The IWG crop was harvested for the last time on 16 September 2019 and cut down to approximately 10 cm 1 October 2019 (Table 1). The experiment was laid out in a complete randomized block design with three treatments (Figure 1) and four blocks. All plots were approximately 3 m wide and 12 m long (i.e., 36 m^2). The three termination strategies were repeated in four linearly located blocks resulting in a total experimental area of 423 m^2 (36 by 12 m). The conventional autumn ploughing (Kverneland ES KKE8-85-200) was performed to a 25 cm soil depth. The rotary disc autumn and spring harrowing were performed to a 7 cm soil depth, using a Väderstad Carrier Disc harrow (NZA 600, Väderstad, Väderstad, Sweden). In the three termination treatments, weed management was undertaken using a stale seedbed (Bond and Grundy 2001), which was done by harrowing to 10 cm soil depth (Cultus 350, Väderstad, Sweden). Beetroot were sown on 3 June and the weed management in the beetroots was done by row harrowing twice in July. No fertilizers or agrochemicals were used. Despite the unfavorable conditions posed to beetroot, no further weeding was undertaken to enable visual detection of the potential resprouting of IWG after the different termination treatments.

The number of IWG plants was counted in two 0.25 m^2 subplots in each experimental plot on 26 June and 21 September 2020 (Table 1). The sub-plots followed a stratified design placed at the midline of each plot 3 m from each side (Figure 1). Similarly, the beetroots were hand-harvested for assessment on 21 September 2020 in two 0.25 m^2 subplots in each experimental plot. The number and total fresh weight of beetroots were determined, where the average weight per beetroot was used as a quality indicator for industry beetroot. The weed species occurring were identified and the weed biomass was sampled in two 0.25 m^2 subplots in each experimental plot on 21 September 2020.

The soil was sampled on 14–15 September 2019 (prior to the establishment of the experiment) and 28–30 September 2020 (after the experiment) for analysis on the bulk density at the 0–10, 10–20 and 30–40 cm soil depths (Table 1). The 20–30 cm depth was excluded because it represented the depth of the plough pan. For the bulk density sampling at the surface level (0–10 cm), plant cover was cut to the soil surface level avoiding compaction and without disturbing the soil. For the bulk density sampling at the second (10–20 cm) and third (30–40 cm) depths, the soil was carefully excavated to a depth that allowed sampling. At each level, a soil sample was carefully taken using a metal cylinder (10 cm in height and 10 cm in diameter) after excavation to the desired depth. The bulk density (g cm^{-3}) was calculated as the ratio of net weight of the dry soil (dried at 105 °C for 24 h) and the volume of the soil sample for the three sampled soil levels.

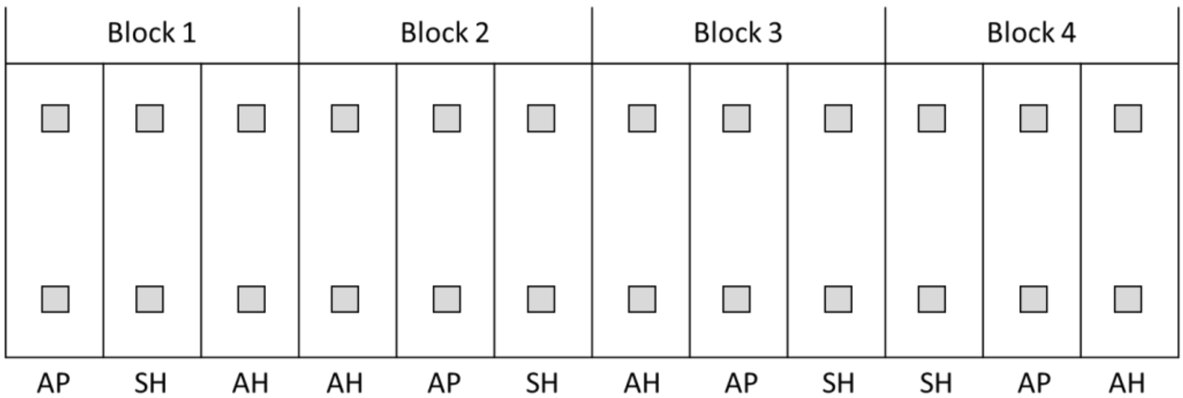

Figure 1. The experimental design with four blocks in a linear arrangement with 12 plots with three randomly located treatments AP: autumn ploughing, AH: autumn harrowing, and SH: spring harrowing for termination of the IWG crop. Small grey squares indicate the approximate position of the squared frames used for sampling. Illustration not according to scale.

Table 1. Overview of the dates for the management, treatments and sampling in the pilot project. Abbreviations: IWG = intermediate wheatgrass, Bulk dens = soil bulk density. Superscripts A = plant count and B = biomass sampling.

Year	Month	Day	Crop	Management	Treatment	Sampling
2019	August	14–15	IWG			Bulk dens
	September	16		Harvest	All	
	October	1		Cutting	All	
		2		Harrowing (7 cm)	Autumn harrowing (AH)	
		11		Ploughing (25 cm)	Autumn ploughing (AP)	
2020	April	23		Harrowing (7 cm)	Spring harrosing (SH)	
		27		Mechanical weed management (10 cm)	All	
	May	18		Mechanical weed management (10 cm)	All	
	June	2		Mechanical weed management (10 cm)	All	
		3	Beetroot	Sowing	All	
		26				IWG [A]
	July	10		Mechanical weed management: Row-harrowing	All	
		23		Mechanical weed management: Row-harrowing	All	
	September	21		Harvest	All	IWG [A], weeds [A,B]
	September	28–30				Bulk dens

Statistics

The effects of termination strategy on IWG reoccurrence, converted into square meter -based units (reoccurrence per m^2), beetroot production and weed biomass, and converted into hectare-based units (tons per hectare and kg per hectare), were analyzed using a factorial design with block as a random factor and termination strategy as fixed factors in a univariate ANOVA with Tukey's post hoc test at the $p < 0.05$ level of significance (IBM Statistics SPSS software). The treatment effect on soil bulk density was analyzed using an independent samples *t*-test at the $p < 0.05$ level of significance (IBM Statistics SPSS software, IBM Corp, Released 2019, IBM SPSS Statistics for Windows Version 26.0, Armonk, NY, USA) with year as the factor.

3. Results

The number of IWG plants in the summer (Jun 2020) was highest after the SH strategy, intermediate after the AH, and lowest after the AP termination strategy (F = 40.8 (df = 2) $p < 0.001$; Figure 2A). However, later in the growing season (Sep 2020) the number of IWG plants was low, i.e., on average two plants m^{-2} per treatment, with no difference between the treatments.

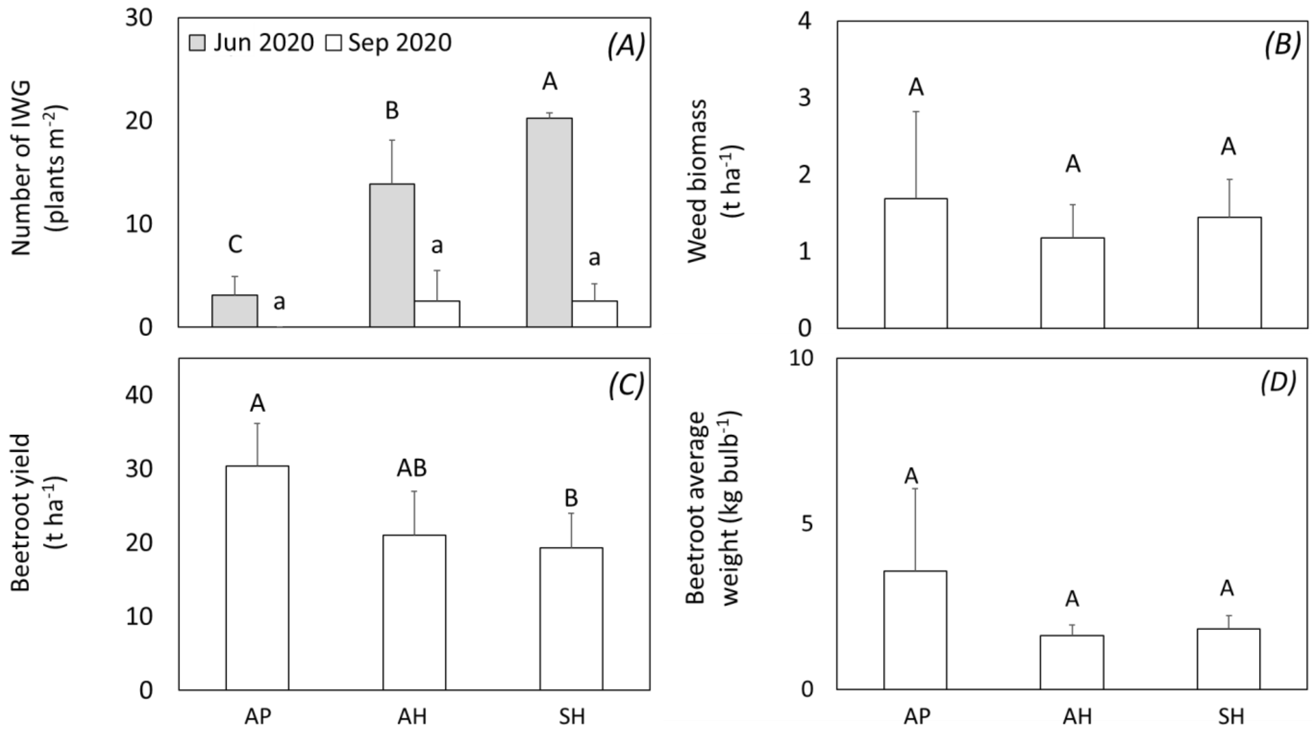

Figure 2. Number of IWG plant individuals per square meter in June and September 2020: (**A**), the weed biomass (**B**), the yield of beetroot (**C**) and average bulb weight (**D**) in September 2020. Data are presented as means (N = 4) with standard error deviations. Different lower-case letters indicate the significant difference in number of IWG in April 2020. Different upper-case letters indicate significant differences in September 2020 between the different strategies for terminating Kernza (AP, autumn ploughed; AH, autumn harrowing; SH, spring harrowing).

The beetroot production was highest after the AP termination strategy and lowest in the SH strategy, and the AH was intermediate, but with no difference from the two other strategies (F = 4.75 (df = 2) $p < 0.05$; Figure 2B). The beetroot average size did not differ between termination strategies (Figure 2C). At beetroot harvest, the weed biomass was high in all treatments, but did not differ between the termination strategies. The occurring weed species in the experiment were the annuals *Capsella bursa-pastoris* (sometimes bi-annual), *Chenopodium* sp., *Fallopia convolvulus*, *Papaver* sp., *Persicaria lapathifolia*, *Polygonum aviculare*, *Senecio vulgaris*, *Solanum nigrum*, *Stellaria media*, *Tripleurospermum perforatum*, and *Viola arvensis*;

the perennials *Cirsium arvensis*, *Sonchus arvensis*, and *Veronica chamaedrys*; and an unidentified grass species.

In the SH strategy, the soil bulk density was higher after the experimental period (Sep 2020), than before (Sep 2019) (t = −3.512 (df = 6) $p < 0.05$; Figure 3C). No other differences were detected in bulk density before and after the experimental period (Figure 3A,B).

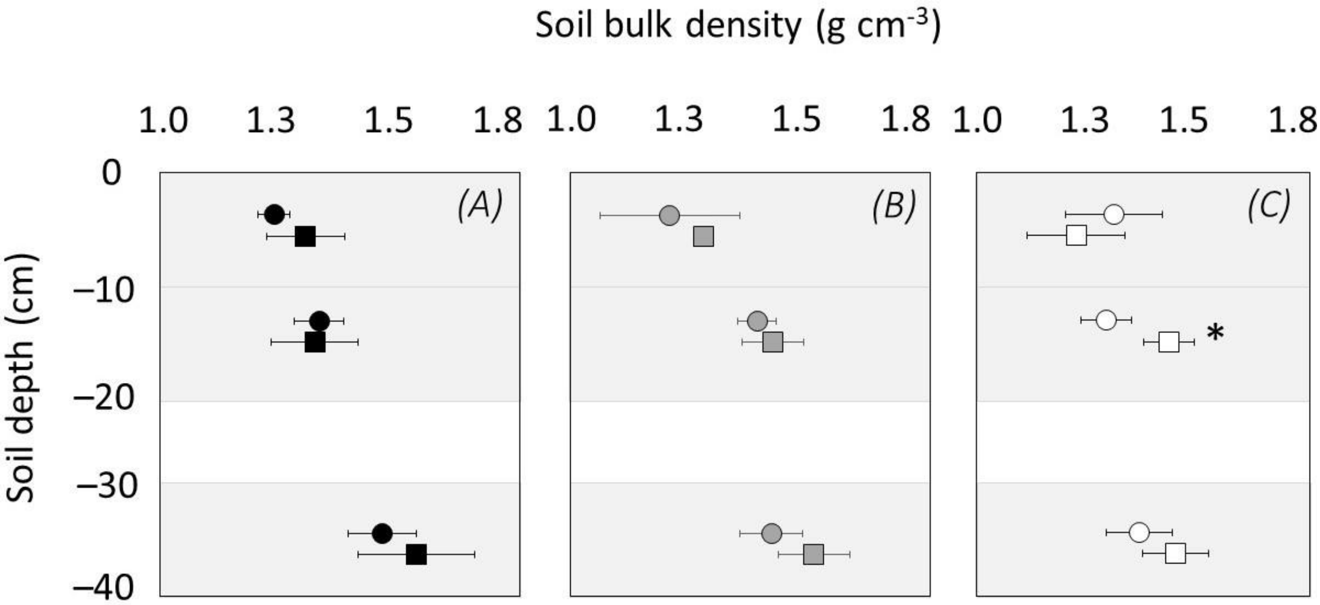

Figure 3. Soil bulk density (g cm^{-3}) at 0–10, 10–20 and 30–40 cm depth in the autumn ploughed (**A**), the autumn cultivated (**B**) and the spring cultivated (**C**) treatments in September 2019 (circles) and 2020 (squares). Data are presented as means (N = 4) with standard error deviations. Asterisks (*) indicate significant difference between 2019 and 2020 within soil depth and treatment.

4. Discussion

Mechanical intervention to terminate perennial herbaceous crops is a common practice to fulfil the requirements in organic production where synthetic chemicals are prohibited [7,19]. Generally, tillage is required to control perennial rhizomatous grass weeds [20]. As hypothesized, our results show that a deeper cultivation strategy is initially more successful at terminating a stand of IWG. Targeting full termination of the IWG crop, the reduction in IWG individuals over time proves the need for repeated interventions, such as creating stale seedbeds before establishing the subsequent main crop. Because this result was equally evident after all termination methods, more shallow cultivation would be possible and sufficient to terminate the perennial if such management provides larger benefits in terms of soil fertility [21,22]. More shallow soil perturbation strategies have been demonstrated to improve the soil quality and fertility [23,24], thus offering an alternative and avoiding the negative effects resulting from ploughing [9–12]. The shallow soil perturbation strategies presume that remaining rhizomes from IWG are not aggressive enough to regenerate the crop. This needs to be further studied.

Contrary to our second hypothesis, the subsequent root vegetable, beetroot, benefitted from the ploughed treatment, which could be a result of a suitable soil structure provided by the deeper and more intensive perturbation. At the 10–20 cm soil depth, a slightly higher soil bulk density was seen in the two cultivated treatments, which concurs with the slightly lower average bulb weight indicating some difficulty for the root crop to thrive. However, because no differences in soil bulk density between treatments were statistically proven, we conclude that other factors of soil quality also affect beetroot production. One of these factors may be a variation in the availability of subsoil nutrients for the plant, favoring yield [25]. Indeed, the level of pest damage on beetroots was perceived to be higher in conventional termination, i.e., autumn ploughing, and there is a need for further research with regard to subsequent crop performance, and soil quality and fertility, after the termination of an IWG stand. Beetroot has been found to have a higher yield, and to grow more and deeper roots, when cultivated under organic, controlled traffic farming [26], which can be attributed to the improved soil quality in comparison to the random traffic farming. The values of yields obtained in this experiment were reactively low compared with commercial beetroot production under organic conditions, which vary widely (28–53 t ha^{-1}) depending on the genotype [27]. This low yield is most likely related to the lack of fertilizer application and, possibly, to suboptimal weeding strategies to enable data collection.

All the treatments in this pilot experiment resulted in large weed biomass, which clearly demonstrates a potent seedbank at the site [28]. The weed species were mainly annuals, indicating the change of conditions when the perennial crop was terminated, with reduced interspecific competition allowing the annuals to enter the scene of light and other resources. In terms of *Chenopodium* sp., *P. lapathifolia*, *S. vulgaris*, *S. nigrum*, and *T. perforatum*, their ability to grow a large biomass in a short period [29] was also noticed at field inspection. We suggest that thorough investigations of the weed development after terminating IWG stands are undertaken to better plan for weed management in the subsequent crop. In this particular experiment, we allowed the weeds to flourish due to being able to gain an insight into the weed development after terminating IWG. Thus, the large weed biomass does not resemble a commercial production where more production-oriented weeding practices would have been performed. However, the dominance of annuals, in relation to perennial weeds, indicates a high competitive ability of IWG towards species with a similar life strategy. Furthermore, IWG may be able to modulate the efficiency of the seedbank, in line with evidence from no-till systems regulating the abundance of suitable sites for weed establishment [30].

5. Conclusions

We conclude that only shallow soil tillage is sufficient to terminate IWG if it is followed by repeated harrowing to create the stale seedbed following the general practices for organic production in northern Europe. We also conclude that IWG may provide a suitable pre-crop for beetroot. We suggest further studies to better understand the dynamics of crop sequences with IWG, and how to best benefit from the crop in rotations otherwise dominated by annual crops.

Author Contributions: Conceptualization, L.-M.D.M.; methodology, L.-M.D.M.; formal analysis, L.-M.D.M., J.O. and A.B.; investigation, L.-M.D.M., J.O. and A.B.; resources, L.-M.D.M.; data curation, L.-M.D.M.; writing—original draft preparation, L.-M.D.M.; writing—review and editing, J.O. and A.B.; visualization, L.-M.D.M.; supervision, L.-M.D.M.; project administration, L.-M.D.M.; funding acquisition, L.-M.D.M. and J.O. All authors have read and agreed to the published version of the manuscript.

Funding: Funding for this student work was gratefully received from Partnership Alnarp, Swedish University of Agricultural Sciences.

Acknowledgments: This study was made possible by the Swedish Infrastructure for Ecosystem Science (SITES), in this case, SITES Lönnstorp Research Station at SLU. SITES receives funding through the Swedish Research Council under the grant no 2017-00635. In particular, Ryan Davidson, research engineer, Eamon Gallagher, technician, and Erik Rasmusson, station manager, are acknowledged for valuable discussions, experiment management and field assistance. Johannes Albertsson is acknowledged for internal manuscript review.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. FAO. *Perennial Crops for Food Security*; FAO Expert Workshop: Rome, Italy, 2013.
2. Culman, S.W.; Snapp, S.S.; Ollenburger, M.; Basso, B.; DeHaan, L.R. Soil and Water Quality Rapidly Responds to the Perennial Grain Kernza Wheatgrass. *Agron. J.* **2013**, *105*, 735–744. [CrossRef]
3. Jungers, J.M.; DeHaan, L.H.; Mulla, D.J.; Sheaffer, C.C.; Wyse, D.L. Reduced nitrate leaching in a perennial grain crop compared to maize in the Upper Midwest, USA. *Agric. Ecosyst. Environ.* **2018**, *272*, 63–73. [CrossRef]
4. Sprunger, C.D.; Culman, S.; Peralta, A.L.; DuPont, S.T.; Lennon, J.T.; Snapp, S. Perennial grain crop roots and nitrogen management shape soil food webs and soil carbon dynamics. *Soil Biol. Biochem.* **2019**, *137*, 107573. [CrossRef]
5. Dominschek, R.; Arrobas, A.; Barroso, M.; Lang, R.; De Moraes, A.; Sulc, R.M.; Schuster, M.Z. Crop rotations with temporary grassland shifts weed patterns and allows herbicide-free management without crop yield loss. *J. Clean. Prod.* **2021**, *306*, 127140. [CrossRef]
6. Watson CAAtkinson, D.; Gosling, P.; Jackson, L.R.; Rayns, F.W. Managing soil fertility in organic farming systems. *Soil Use Manag.* **2002**, *18*, 239–247. [CrossRef]
7. Vellinga, T.; Dasselaar, A.V.D.P.-V.; Kuikman, P. The impact of grassland ploughing on CO_2 and N_2O emissions in the Netherlands. *Nutr. Cycl. Agroecosystems* **2004**, *70*, 33–45. [CrossRef]
8. Reinsch, T.; Loges, R.; Kluß, C.; Taube, F. Effect of grassland ploughing and reseeding on CO_2 emissions and soil carbon stocks. *Agric. Ecosyst. Environ.* **2018**, *265*, 374–383. [CrossRef]
9. Alcántara, V.; Don, A.; Well, R.; Nieder, R. Deep ploughing increases agricultural soil organic matter stocks. *Glob. Chang. Biol.* **2016**, *22*, 2939–2956. [CrossRef]
10. Alvarez, C.R.; Álvarez, R. Short-term effects of tillage systems on active soil microbial biomass. *Biol. Fertil. Soils* **2000**, *31*, 157–161. [CrossRef]
11. Chen, X.; Liang, A.; Wu, D.; McLaughlin, N.B.; Jia, S.; Zhang, S.; Zhang, Y.; Huang, D. Tillage-induced effects on organic carbon in earthworm casts through changes in their physical and structural stability parameters. *Ecol. Indic.* **2021**, *125*, 107521. [CrossRef]
12. Peigné, J.; Lefevre, V.; Vian, J.-F.; Fleury, P. Conservation Agriculture in Organic Farming: Experiences, Challenges and Opportunities in Europe. In *Conservation Agriculture*; Springer: Cham, Switzerland, 2014; pp. 559–578. [CrossRef]
13. Bond, W.; Grundy, A.C. Non-chemical weed management in organic farming systems. *Weed Res.* **2001**, *41*, 383–405. [CrossRef]
14. Melander, B.; Rasmussen, I.A.; Bàrberi, P. Integrating physical and cultural methods of weed control— examples from European research. *Weed Sci.* **2005**, *53*, 369–381. [CrossRef]
15. Duiker, S.W.; Beegle, D.B. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. *Soil Tillage Res.* **2006**, *88*, 30–41. [CrossRef]
16. Lönnstorp Field Research Station. Soil Data from Lönnstorp. SITES Data Portal. 2021. Available online: https://data.fieldsites.se/portal/ (accessed on 10 November 2021).
17. Swedish Meteorological and Hydrological Institute. 2021. Available online: www.smhi.se (accessed on 1 October 2021).
18. Zhang, X.; Sallam, A.; Gao, L.; Kantarski, T.; Poland, J.; DeHaan, L.; Wyse, D.L.; Anderson, J.A. Establishment and Optimization of Genomic Selection to Accelerate the Domestication and Improvement of Intermediate Wheatgrass. *Plant Genome* **2016**, *9*, 1–18. [CrossRef] [PubMed]
19. KRAV 2021. *Regler för KRAV-Certifierad Produktion Utgåva*; KRAV Ekonomisk Förening: Uppsala, Sweden, 2021.
20. Ringselle, B.; Bertholtz, E.; Magnuski, E.; Brandsæter, L.O.; Mangerud, K.; Bergkvist, G. Rhizome Fragmentation by Vertical Disks Reduces Elymus repens Growth and Benefits Italian Ryegrass-White Clover Crops. *Front. Plant Sci.* **2018**, *8*, 2243. [CrossRef]
21. Shokati BAhangar, A.G. Effect of conservation tillage on soil fertility factors: A review. *Int. J. Biosci.* **2014**, *4*, 144–156.
22. Young, M.D.; Ros, G.H.; de Vries, W. Impacts of agronomic measures on crop, soil, and environmental indicators: A review and synthesis of meta-analysis. *Agric. Ecosyst. Environ.* **2021**, *319*, 107551. [CrossRef]
23. Krauss, M.; Berner, A.; Perrochet, F.; Frei, R.; Niggli, U.; Mäder, P. Enhanced soil quality with reduced tillage and solid manures in organic farming–a synthesis of 15 years. *Sci. Rep.* **2020**, *10*, 1–12. [CrossRef]
24. Meurer, K.H.; Haddaway, N.R.; Bolinder, M.A.; Kätterer, T. Tillage intensity affects total SOC stocks in boreo-temperate regions only in the topsoil—A systematic review using an ESM approach. *Earth-Sci. Rev.* **2017**, *177*, 613–622. [CrossRef]
25. Schneider, F.; Don, A.; Hennings, I.; Schmittmann, O.; Seidel, S.J. The effect of deep tillage on crop yield—What do we really know? *Soil Tillage Res.* **2017**, *174*, 193–204. [CrossRef]
26. Hefner, M.; Labouriau, R.; Nørremark, M.; Kristensen, H.L. Controlled traffic farming increased crop yield, root growth, and nitrogen supply at two organic vegetable farms. *Soil Tillage Res.* **2019**, *191*, 117–130. [CrossRef]
27. Yasaminshirazi, K.; Hartung, J.; Groenen, R.; Heinze, T.; Fleck, M.; Zikeli, S.; Graeff-Hönninger, S. Agronomic Performance of Different Open-Pollinated Beetroot Genotypes Grown Under Organic Farming Conditions. *Agronomy* **2020**, *10*, 812. [CrossRef]
28. Buhler, D.D.; Hartzler, R.G.; Forcella, F. Implications of weed seedbank dynamics to weed management. *Weed Sci.* **1997**, *45*, 329–336. [CrossRef]
29. Grime, J.P. Primary strategies in plants. *Trans. Bot. Soc. Edinb.* **1979**, *43*, 151–160. [CrossRef]
30. Gallandt, E.R. How can we target the weed seedbank? *Weed Sci.* **2006**, *54*, 588–596. [CrossRef]