agronomy

MDPI

Review

Ecological Intensification of Food Production by Integrating Forages

José G. Franco [1,*], Marisol T. Berti [2], John H. Grabber [1], John R. Hendrickson [3], Christine C. Nieman [4], Priscila Pinto [5], David Van Tassel [6] and Valentín D. Picasso [5]

1 U.S. Dairy Forage Research Center, USDA-ARS, Madison, WI 53706, USA; john.grabber@usda.gov
2 Department of Plant Sciences, North Dakota State University, Fargo, ND 58104, USA; marisol.berti@ndsu.edu
3 Northern Great Plains Research Laboratory, USDA-ARS, Mandan, ND 58554, USA; john.hendrickson@usda.gov
4 Dale Bumpers Small Farms Research Center, USDA-ARS, Booneville, AR 72927, USA; christine.c.nieman@usda.gov
5 Department of Agronomy, University of Wisconsin-Madison, Madison, WI 53706, USA; ppinto@wisc.edu (P.P.); picassorisso@wisc.edu (V.D.P.)
6 The Land Institute, Salina, KS 67401, USA; vantassel@landinstitute.org
* Correspondence: jose.franco@usda.gov

Abstract: Forage crops have the potential to serve multiple functions, providing an ecological framework to sustainably intensify food production, i.e., ecological intensification. We review three categories of forages (annual forages, perennial forages, and dual-use perennial crops/forages) we believe hold the greatest promise for ecologically intensifying food production. Annual cover crops can provide additional forage resources while mitigating nutrient losses from agricultural fields when they are intercropped with, interseeded into, or following an annual crop, for instance. The integration of perennial forages either temporally, such as annual crop rotations that include a perennial forage phase, or spatially, such as the intercropping of perennial forages with an annual cash crop, provide weed suppression, soil quality, and yield and crop quality benefits. Dual-use crops/forages can provide forage and a grain crop in a single year while providing multiple ecological and economic benefits. However, tradeoffs in balancing multiple functions and limitations in reducing the risks associated with these practices exist. Advancing our understanding of these systems so we can overcome some of the limitations will play a critical role in increasing food production while promoting positive environmental outcomes.

Keywords: ecological intensification; multifunctional agriculture; ecosystem services; annual cover crops; annual forages; forage mixtures; perennial forages; intercropping; interseeding; dual-use crops/forages

Citation: Franco, J.G.; Berti, M.T.; Grabber, J.H.; Hendrickson, J.R.; Nieman, C.C.; Pinto, P.; Van Tassel, D.; Picasso, V.D. Ecological Intensification of Food Production by Integrating Forages. *Agronomy* **2021**, *11*, 2580. https://doi.org/10.3390/agronomy11122580

Academic Editor: Jerome H. Cherney

Received: 30 September 2021
Accepted: 15 December 2021
Published: 18 December 2021

1. Introduction

Globally, food demand from a growing population is projected to increase anywhere from 35% to 56% above recent (within the last 10 years) production levels by 2050 [1]. Concurrent with unprecedented food demand, wealth is also expected to increase, thus increasing per-capita consumption of high-protein and high-value foods, with the consumption of more livestock products being a major driver [2]. Most recently, the Agriculture Innovation Agenda of the United States Department of Agriculture (USDA) outlined benchmarks to increase agricultural production by 40% in the U.S. to meet the increasing demand [3]. Further, these production targets must be met while cutting the environmental footprint of U.S. agriculture in half by the year 2050 [3]. Increasing agricultural output per unit of land is one of the greatest challenges, not just for the global agricultural community, but for society as a whole [4,5].

The sustainable intensification (SI) of agriculture is a set of broad agricultural principles and technologies that may help us achieve production and environmental goals without expanding production outside of the current farm footprint, i.e., beyond arable land area currently utilized for food production, or on marginal lands so as to reduce competition with non-agricultural uses [6,7]. By its definition, SI is an increase in food production, kilocalories, or food energy from the same unit area of land or per unit of input resource (most often measured as crop or livestock yield output) with a concomitant reduction in negative environmental impact and/or enhancement in positive environmental benefits [5–11]. Though often used synonymously with SI, ecological intensification (EI) provides a framework that relies on the agroecological principles of synergies, biodiversity, efficiency, recycling, regulation, and resilience (to name a few) to achieve the goals of SI [12–14]. As such, the EI framework identifies agroecosystem characteristics, such as perenniality and diversity, that support these principles and lays the groundwork for their integration into current cropping systems with the goal of optimizing efficiencies and enhancing soil and crop benefits while also mitigating greenhouse gas (GHG) emissions [15]. In this paper we frame EI options using two agroecosystem axes (Figure 1): perenniality (i.e., continuous soil cover) and biodiversity (i.e., managed species richness). Integrating forages into agricultural systems may increase diversity, perenniality, or both, and therefore, move systems forward into EI. There is a growing body of research showing that long term agroecosystem properties such as resilience to climate extremes and stability of production are positively associated with diversity and perenniality [5].

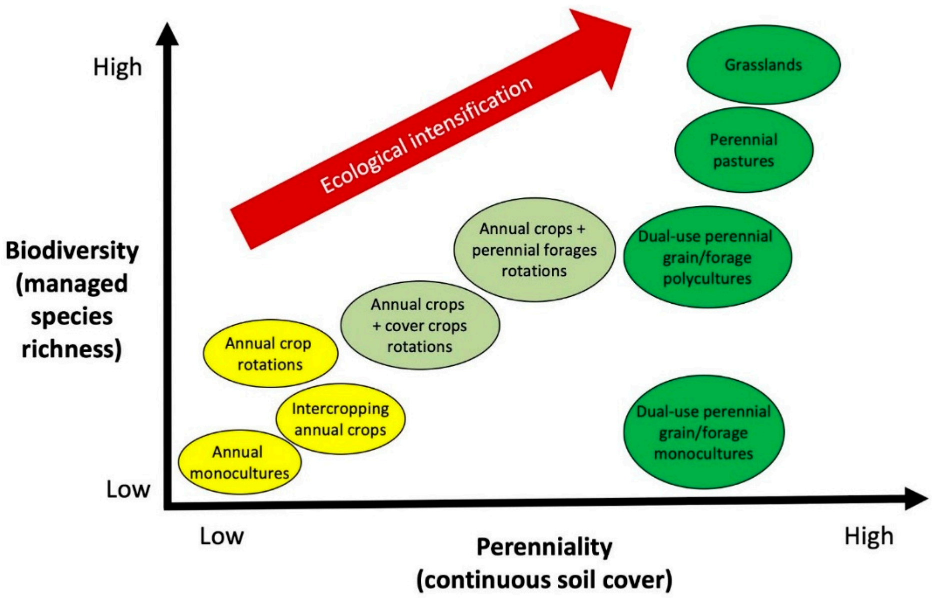

Figure 1. Multiple agricultural systems located in two axes of relative perenniality (i.e., continuous soil cover) and relative biodiversity (i.e., managed species richness). Colors correspond with annual systems (yellow), intermediate systems (light green), and perennial systems (dark green).

The introduction of diverse, multiple-use forages across the agricultural landscape provides opportunities to create multifunctional agroecosystems that utilize the EI framework. With an estimated 35–38% of the world's land area dedicated to agricultural production and evidence to suggest that the expansion of these areas has slowed and even decreased in developed countries over the last 25 years [2,16,17], there is every-increasing strain on existing cropland. There is a tremendous opportunity to optimize existing agricultural lands, and one approach we have at our disposal to achieve this is the wider adoption and integration of annual and perennial forages and dual-use perennial crops/forages. Diverse types of forages can mitigate negative environmental outcomes and enhance positive agronomic and ecological benefits while providing feed for livestock and food for human consumption.

When managed properly, the incorporation of perennial species, particularly diverse mixtures of species, across the landscape (e.g., perennial forages and grasslands), provides resounding benefits for building productive and resilient [5,18–21] agroecosystems that are also multidimensional, i.e., meet ecological and societal needs as well as being economically viable for growers [22]. There is evidence to suggest diverse crop rotations that include annual cover crops can provide multiple benefits [23–27] while also providing opportunities to provide additional forage sources for livestock [28–31]. Further, the grazing opportunities provided by annual, perennial, and dual-use crops/forages facilitate the integration of livestock in crop production systems. Integrated crop-livestock (ICL) systems have been identified as another approach that complements forage integration for sustainably intensifying crop production [32–38]. This approach to intensifying food production has the potential to increase calorie or energy output by producing both crops and livestock in the same unit of land area. It also stands to reason that with an increase in global meat and dairy consumption [2,39,40], integrated systems should play a key role in meeting both food production and environmental goals going forward.

In summary, forages may play a critical role in achieving the EI of food production and in meeting the goals set out by the USDA and the FAO and may be crucial to the re-coupling of crop and livestock production. Without doubt, there are food supply and waste issues entangled with socioeconomic and malnourishment issues that create additional barriers to meeting these societal challenges [7,41]. However, as critical as these issues are to future food production scenarios, they fall beyond the scope of this review. Rather, we focus our efforts on opportunities to, and examples of how, we can ecologically intensify crop and livestock production through the integration of (1) annual forages, (2) perennial forages, and (3) dual-use perennial crops/forages. We consider both spatial (e.g., intercropping or companion cropping) as well as temporal (e.g., diverse rotations that include forages to varying levels) integration strategies for introducing forages across the agricultural landscape.

2. Annual Forages

Annual forages play an important role in cropping system productivity, stability, diversity, and resiliency. In this section, we provide examples of the EI of cropping systems using annual forages. Planting annual forages after the harvest of cool-season cereals is common in areas where grazing beef cattle is frequent. Integrating annual cover crops in maize (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.)-based systems is more difficult due to the limited time to plant a second crop after harvest in cool, temperate climates, but may provide soil cover in addition to fall or spring forage production when successful (Figure 2). We summarize available research on intercropping and interseeding annual forages in maize-based systems. Finally, we describe research on the role of annual legumes interseeded into perennial pastures.

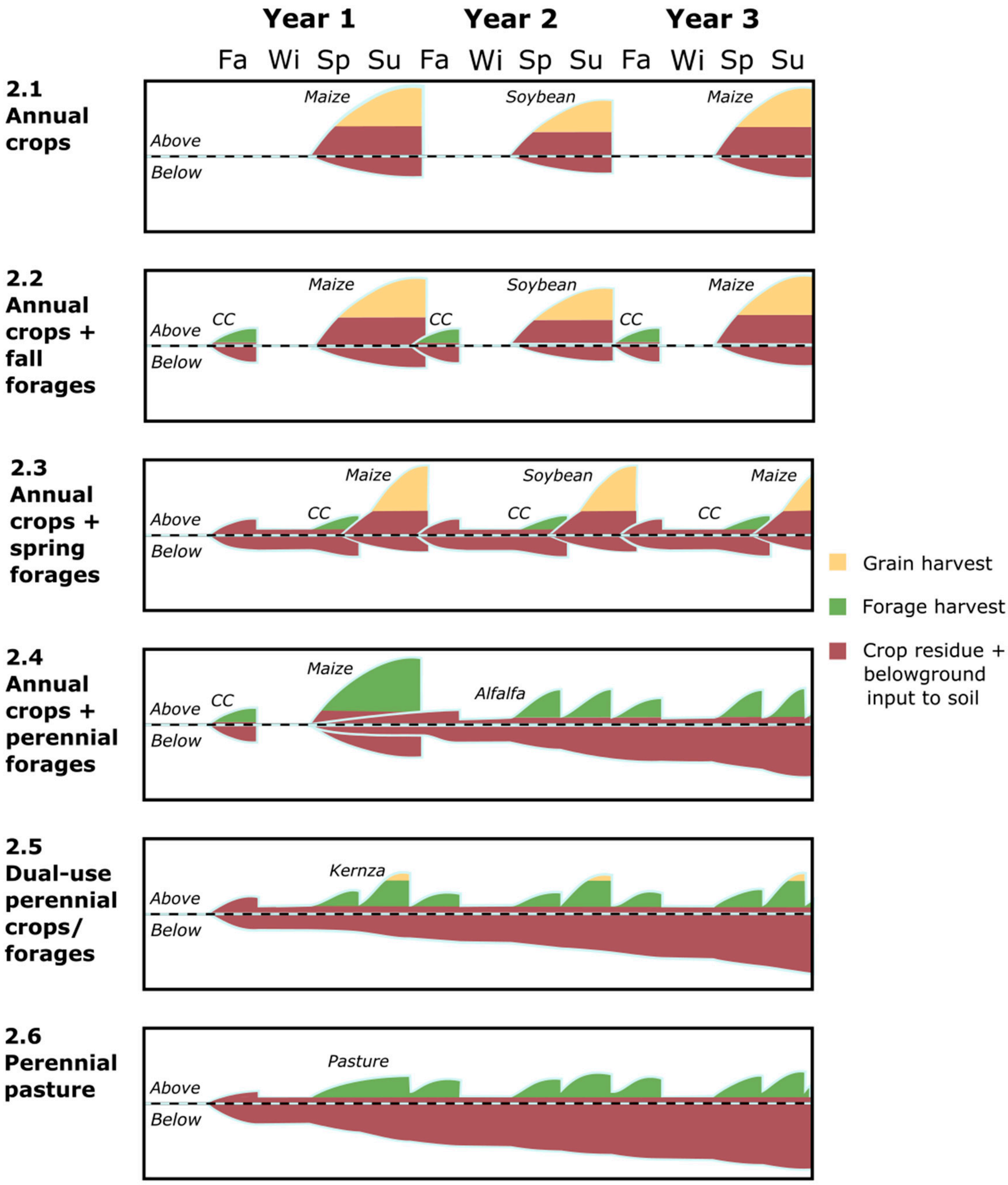

Figure 2. Conceptual representation of potential above- and below-ground productivity, ground cover, and soil inputs from an annual cropping system (**2.1**) compared to examples of systems discussed in this review. Systems include annuals crops with cover crops used for fall forage (**2.2**), annual crops with overwintering cover crops used for spring forage (**2.3**), annual crops with interseeded or intercropped perennial forages (**2.4**), dual-use perennial crops/forages such as Kernza (**2.5**), and perennial pasture (**2.6**) for reference. Root exploration in this figure was based on Thorup-Kristensen et al. [42].

2.1. Annual Forages after Cool-Season Cereals

Agricultural intensification strategies include both temporal and spatial components [43]. Temporal intensification is defined as increasing the number of crops in a cropping system in a given period of time [43]. Winter annual cover crops can be grown in the time between the harvest and planting of cash crops (double cropping), sharing part of the cash crop life cycle (relay cropping) or sharing the same life cycle as the cash crop (intercropping). Temporal intensification increases land use efficiency and profitability if the cover crop is grazed, while providing numerous ecosystem services [44].

Growing annual cover crops in double cropping after a cereal crop with the intent to provide forage for grazing in the fall, winter, or spring ahead of the following year's cash crop has been reported [44–46]. Legumes, grasses, brassicas, or mixtures have plenty of time to grow after a cool-season cereal crop, producing up to 4 Mg ha^{-1} of forage depending upon the location, soil moisture, species, and soil fertility [44,47]. For example, faba bean (*Vicia faba* Roth) and pea (*Pisum sativum* L.) can provide late-fall grazing without affecting maize yield the following season [45]. Fall weaned calves can have an average daily gain between 0.6 to 1.1 kg by grazing fall planted oat (*Avena sativa* L.) [44].

2.2. Intercropped Annual Forages

Intercropping of cereals with legumes in forage production is used commonly to increase forage yield and nutritive value, improve land use efficiency [48], and increase profitability per unit land area [49,50]. Almost all studies conducted in legume-cereal intercropping (barley (*Hordeum vulgare* L.)-pea, oat-pea, and oat-barley) have shown forage yield advantages compared with a corresponding monoculture [51].

The complementary effects of intercropping pea with cereals such as spring wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), oat, and spring triticale (× *Triticosecale* Witt.) are enhanced when component crop phenology and growth period was different. Cereals dominate mixtures and have a greater contribution to the total forage yield [52], while pea and other legumes can increase the crude protein of the forage [50]. Increased forage yield and nutritive value associated with intercropping may be related to changes in root development and distribution, often leading to increased nutrient and water use efficiency [53]. Pea-barley intercropping induced deeper roots in the cereal and faster lateral root growth in both species compared with the sole crops [54].

2.3. Interseeded Annual Forages into Maize to Improve Grazing Value of Maize Stover

Although maize harvested for grain does not provide a large enough window for fall grazing, interseeding of cover crops into standing maize to increase the nutritional value of maize stover can be an alternative establishment method. Interseeding turnips (*Brassica rapa* L.) into standing maize has been shown to increase in vitro dry matter digestibility (IVDMD) of sweet maize stover and increased ADG [55]. Similarly, Villalobos and Brummer [56] reported that interseeded cover crops at V6 growth stage in irrigated maize increased crude protein content and fiber digestibility for the maize stalks-cover crop mixture in the fall compared with maize stalks alone.

2.4. Winter Cover Crops for Spring Forage

There has been increasing interest in the use of winter cover crops following maize (either for silage or for grain) and soybean in regions where water quality is a major concern. Winter cover crops can scavenge excess nutrients from agricultural fields, thus reducing nitrate leaching [57–59]. This is particularly important in systems where manure applications are common [59]. However, there is relatively less known about the use of overwintering cover crops as spring forages in colder climates. Winter cover crops can provide additional economic value and incentive for producers to adopt this practice. Winter cereal cover crops can be successfully utilized as a spring forage source [60–62]. The impacts on the subsequent cash crop can be variable, however. For instance, cover crops such as winter cereal rye (*Secale cereale* L.) may have a negative impact on the subsequent alfalfa (*Medicago sativa* L.) crop [63]. Thus, more research is needed to investigate the benefits of utilizing overwintering cover crops for spring forage and timing of termination to balance productivity and nutritive value with the impact on the cash crop.

2.5. Intercropping Annual Warm-Season Crops to Increase Value of Maize Silage

Silage maize production in the U.S. is very intensive and depletes soils from water and nutrients, resulting in a negative impact on the environment. Integrating other forage crops via intercropping with maize can alleviate its negative environmental footprint by decreasing nutrient losses to water and GHG emissions and increasing carbon storage and biodiversity. Several examples of intercropping in maize to increase nutritive value have been reported. Silage maize intercropped with forage sorghum [*Sorghum bicolor* (L.) Moench.] did not decrease forage yield and nutritive value in North Dakota, USA [64]. Further, sunnhemp (*Crotalaria juncea* L.) and cowpea [*Vigna unguiculata* (L.) Walp.] intercropped in silage maize has been shown to increase crude protein without decreasing total silage yield [65].

Crimson clover (*Trifolium incarnatum* L.) interseeded into maize 10 to 20 days after maize emergence can establish successfully, but may result in competition with the maize crop [66]. Interseeded crimson clover may compete for soil water with maize, especially at a seeding rate of 22 kg ha^{-1}, resulting in decreased maize grain yield [67]. However, crimson clover with adequate moisture and rainfall during the growing season has been shown to have less of an effect on maize grain yield [66].

Intercropping silage maize and sunflower (*Helianthus annuus* L.) can increase forage nutritive value (fiber, fat, and protein content) compared with the sole crops [51]. Anil et al. [51] found that maize produced high dry matter yield and sunflower silage was higher in fat and crude protein in comparison with silage maize. Further, lactating cow intake on intercropping silage maize and sunflower was similar to intake on silage maize alone, but increased milk production was observed with silage produced from mixtures.

2.6. Annual Forages Seeded into Perennial Pasture

Annual forages seeded into perennial crops or pastures can serve many functions from improving forage production, nutritive value, and lengthening the grazing season, to preventing nutrient leaching and soil erosion that may occur with annual only systems. In the mid-south USA, also known as the fescue belt, annual species may also be used to mitigate the effects of endophyte infected (E+) tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.]. Tall fescue is a cool-season grass species heavily utilized by beef farmers for grazing in the mid-South. Infected tall fescue is tolerant of continuous grazing and has digestibility and protein levels that allow cattle to outperform those on warm-season species [68]. However, E+ tall fescue is also responsible for substantial losses in beef production because toxic alkaloids cause breeding inefficiencies in cows and reduced growth in growing livestock [69]. Therefore, producers have adopted mitigation strategies such as overseeding warm-season perennial pastures with winter annuals and incorporating clovers.

In areas such as the lower mid-South U.S., winter annuals can be used to replace E+ tall fescue and extend the grazing season into fall and winter, when small grains, annual ryegrass (*Lolium multiflorum* Lam.), or clovers are sod-seeded into perennial pastures dominated by warm-season species, namely bermudagrass [*Cynodon dactylon* (L.) Pers]. Although winter grains are less productive when sod-seeded into warm-season perennials compared with a prepared seed-bed [70,71], and the success of establishment and subsequent animal performance may vary [72–74], this practice increases land use efficiency [75] and, thus, may contribute to the sustainable intensification of beef production systems in the mid-South. Bermudagrass has a winter dormancy period of nearly seven months [76]; by interseeding with annual grasses and legumes in the fall, pastures can be grazed nearly year-round and spring forages can take advantage of ample rainfall. Other benefits for these systems are improved animal gains compared with E+ tall fescue [73,74], improved gain when clovers are interseeded [77,78], spring weed control [79], and economic advantages (increased average daily gain, gain per acre [80], or input costs of annual seeding were recovered by improved animal gain [81].

Interseeding legumes into tall fescue is widely recommended by extension specialists for toxic fescue pastures [82]. Greater proportions of legumes generally result in greater animal performance [83], which is generally attributed to the greater intakes on legumes [84]. For toxic fescue pastures, legumes create a dilution effect, and this method has been generally adopted by producers [82]. Lusby et al. [85] observed improvement in carcass weights for steers grazing E+ tall fescue and white clover (*Trifolium repens* L.) and McMurphy et al. [86] observed improvements in cattle gain in red clover (*Trifolium pratense* L.) and E+ tall fescue; improvements in both studies were attributed to a dilution effect. However, Beck et al. [87] observed increases in cattle gain on E+ tall fescue and non-toxic endophyte (E−) tall fescue with clover inclusion, indicating that gain improvements were not due to dilution, but likely the increased intake and performance that occur on pasture with clovers. Hoveland et al. [88] also identified that legumes minimally improve gains, but persistence of the legumes in E+ tall fescue pastures is low.

Despite inconclusive effects of legume contributions to animal gain in E+ tall fescue, red clover has recently been of interest because of physiological mechanisms for mitigating tall fescue toxicosis. Red clover contains phytoestrogenic compounds called isoflavones [89]. Ergovaline from ergot alkaloids in E+ tall fescue cause vasoconstriction through binding of amide receptors [90,91] which contributes to heat stress and loss of circulation that results in "fescue foot", causing lameness and eventual gangrene if symptoms are severe and circulation is not restored. Isoflavones have been shown to relax the vasculature [92,93], even in livestock consuming E+ tall fescue seed [94,95]. Aiken et al. [95] infused the rumen of goats consuming endophyte-infected tall fescue with 30 mg of biochanin A (an isoflavone) and observed vasorelaxation with a return to normal pulse rate [95]. Therefore, there is potential that overseeding E+ tall fescue with red clover and consumption of red clover may promote vasorelaxation and could aid in the mitigation of tall fescue toxicosis symptoms. However, the minimum inclusion amount of biochanin A in a diet or red clover in infected tall fescue pastures has not been determined.

2.7. The Role of Annual Forages in Achieving Ecological Intensification

Annual forage crops integrated into annual or perennial cropping systems as double crops, intercrops, or overseeded crops, can increase total land productivity while reducing negative impacts to the environment. Temporal or spatial (intercropping) integration of annual forages into existing systems provides additional food and feed. This is measured as the land equivalent ratio (LER) defined as "an index of intercropping advantage and a reflection of the degree of interspecific competition or facilitation in an intercropping system" [96]. An LER greater than 1.0 means that annual crops integrated in between or into the same life cycle of two crops produce more than each crop in monoculture [54]. Resources are used more efficiently when two crops are grown together in comparison to a sole crop [54], and in non-forage species it has been shown that physiological stress can be reduced in some component crops [97]. Harvesting annual forage crops for biofuel and feed generally increases availability without affecting soil properties and crop yields [98].

Cover crops, which can be utilized for forage to provide a value-added product, can reduce the yield of the following cash crop in water-limited environments; however, integrating livestock and grazing the cover crops can offset the short-term impact on yield on the following crop [21]. Overwintering cover crops can recycle nutrients and prevent them for leaching or running off in the fall or spring [57,99–102]. Winter annual cover crops such as winter cereal rye, winter triticale, and winter wheat provide soil protection in the fall and spring, reduce nutrient leaching, and can also provide a spring forage, while cover crops that winter-kill only provide soil erosion control in the fall and may contribute further to nutrient leaching over the winter [103]. Reduction of soil erosion by wind and water by using cover crops has also been reported extensively in literature [102,104–106].

Annual cover crops can increase soil organic carbon (SOC) if not grazed, but if grazed may decrease SOC [46]. In general, grazing of cover crops and cover crops in maize residue do not affect GHG fluxes, but there is some indication that GHG emissions are lower when the cover crop is a grass species compared with a legume [30]. Further, grazing of cover crops such as in ICL systems may increase farm profitability [46].

From a biodiversity perspective, maize grown in monoculture does not provide food resources for small vertebrates and arthropods. However, intercropping maize with annual forage legumes such as sweetclover (*Melilotus officinalis* L.) and common vetch (*Vicia sativa* Roth) has been shown to increase insect biodiversity [107].

2.8. Annual Forages: Limitations and Knowledge Gaps

Extensive research has demonstrated the numerous benefits of integrating annual cover crops and forages in annual cropping and perennial pasture systems, but there are a number of limitations associated with their implementation. The main limitations to adoption of ecological intensification practices include: livestock not available in the area, cost of seeds, limited crop insurance coverage, profitability, availability of equipment (particularly a no-till drill for pasture based producers), failure to establish the annual forage in intercropping or relay cropping, and low production of the annual forage (particularly concerning sod-seeded legumes). In some cases, these limitations cause such variability in success, even under research conditions, that producers are hesitant to adopt these strategies. For example, legume inclusion in endophyte-infected tall fescue research does not guarantee an increase in animal gain [108], leaving producers unsure about whether to adopt the practice because of additional risk associated with seed and establishment costs.

The research gaps associated with the limitations described above are mainly related to the establishment of annual cover crops to be utilized as forage in intercropping or relay cropping. Establishment methods, the role of soil water availability, and the estimation of ecosystem services in cropping systems that include annual forages is needed. Additional research on selection of appropriate annual forages and forage mixtures that provide resilient systems, such that establishment and subsequent production risks may be minimized is also needed. Further research on the benefits of legume inclusion, especially potential of specific legumes to reduce effects of tall fescue toxicosis is also needed. In addition, more plant breeding work is needed to develop winter-hardy varieties of legume and brassica cover crops to reduce nutrient leaching during the winter months and to also provide additional spring forage. As previously mentioned, more research is also required to determine the impacts of grazing or forage harvest timing of overwintering cover crops on subsequent cash crop pest management and yield. Farmers' adoption of these practices will likely increase if risk of establishment could be reduced or better defined. Research indicating the long-term successes, failures, and economic consequences may also benefit producers in understanding the level of risk and reward associated with annual forage integration in their systems.

3. Perennial Forages

Adding perennial forages to annual cropping systems can provide multiple benefits. Forages can be incorporated either as a multi-year phase in the crop rotation or intercropped into existing annual crops. These two approaches can be combined in cases where perennial forages are intercropped into annual crops during their establishment year and then the established perennials are used for forage production in the subsequent years (Figure 2). Either practice has been shown to reduce the need for additional, purchased inputs, improve soil quality parameters, and increase crop yields. Despite these advantages, management challenges remain to improve the efficiency of the systems. The following two sections review the state of knowledge regarding benefits and challenges of incorporating perennials into annual cropping systems.

3.1. Perennial Forages in Annual Crop Rotations

Soil benefits are one of the most widely researched benefits of including a perennial forage phase in annual crop rotations. A 38-year study comparing an annual crop rotation to a rotation with 4 years of annual crops followed by 4 years of a pasture found greater particulate organic carbon at the 20–40 and 40–60 cm soil depths with the rotation that included pasture [109]. Similarly, Gamble et al. [110] found greater SOC when a perennial forage phase was added to an annual crop rotation. Besides improving carbon sequestration, adding a perennial can improve other aspects of soil quality. Liebig [111] compared

4 years of forages in a semi-arid part of North Dakota, USA, with continuous annual spring wheat production and found that forages mitigated soil acidification, reduced bulk density and increased water-stable aggregation in soil particles. A comparison of wheat grown after an annual forage, subterranean clover, (*Trifolium subterraneum* L.) or the perennial forage, alfalfa, found greater rooting depth for wheat after alfalfa [112]. However, including a perennial phase in a crop rotation can negatively impact greenhouse gas flux. Tan et al. [113] found greater N_2O emissions when maize followed orchardgrass (*Dactylis glomerata* L.) compared with continuous maize and a rotation containing a perennial hay mix of timothy (*Phleum pratense* L.), rough fescue (*Festuca campestris* Rydb.) and smooth brome (*Bromus inermis* Leyss) had greater CO_2 emissions than an annual crop rotation in Canada [114]. Other studies, however, have not shown differences in greenhouse gas emissions between an annual and an annual-perennial crop rotation [115].

Including a forage phase can also alter weed communities. Eighty three percent of producers in Manitoba and Saskatchewan, Canada observed weed control benefits of including forages in a crop rotation [18]. In organic cropping systems, adding a perennial phase may increase diversity and reduce the number of broadleaf seeds in the weed seedbank [116]. For example, using alfalfa followed by a cereal crop resulted in weed communities that were different from continuous cereal fields [117]. Meiss et al. [118] suggested that frequent cutting of alfalfa shifted weed communities away from upright and climbing broad-leaved plants but favored weed species with reproductive organs closer to the ground such as grasses and perennial broad-leaves with rosettes. However, the shifting of weed communities provides evidence of the importance of considering a perennial phase in weed management strategies [118].

Franco et al. [20] pointed out that adding a perennial phase to an annual crop rotation could have a positive, neutral, or negative impact on subsequent crop production. Some differences may be related to the aridity of the site as was suggested for a comparison of crop yields after different pasture types in Australia [119]. Generally, yield responses have been positive [20] with 71% of producers in the provinces of Manitoba and Saskatchewan reporting higher grain yields after perennial forages than following annual crops [18]. Besides providing yield increases, perennial forages also have the potential to maintain yields without external inputs. Franco et al. [20] found spring wheat yields after 3–4 year of alfalfa were higher than fertilized spring wheat but also that these yield benefits continued for up to 4 years after alfalfa and 5 years after an alfalfa—intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey] mixture.

There is little published on how the addition of perennials can affect subsequent crop quality. Clemensen et al. [120] reported comparable spring wheat protein and mineral concentrations between unfertilized spring wheat grown after perennial forages and fertilized spring wheat. Their data also suggested that incorporating alfalfa into the crop rotation could enhance spring wheat protein but may lower zinc concentration. Despite the lack of direct comparisons of crop quality in systems with and without perennials, there are some suggestions that perennials can enhance crop quality. For example, perennials have been demonstrated to increase soil organic matter [121,122] and increases in soil organic matter have been linked to increased crop quality [123].

Little is known about how the yield stability of perennial forages compares to annual crops. An evaluation of maize yields following four different crop rotations in Pennsylvania, USA, resulted in coefficients of variation (CV), a measure of stability, ranging from 21 to 28% [124]. However, in a comparison of different dryland crop rotations in the more arid, central Great Plains of Colorado, USA, Nielsen and Vigil [125] found CVs ranging from 30–69% depending on crop rotation. The CV for perennial switchgrass (*Panicum virgatum* L.) dry matter yield was reported to be around 19% in Oklahoma, USA [126] and ranged between 7–24% for perennial grass biomass yields in Sweden [127]. Grover et al. [124] reported the lowest CVs for maize yields when four years of alfalfa was rotated with four years of maize.

3.2. Perennial Forages Intercropped or Interseeded with Annual Crops

Growing perennial legumes in crop rotations improves yield of maize and other annual row crops, lowers inputs of fertilizer nitrogen, reduces pest populations, improves labor usage during the growing season, increases soil quality and carbon storage, reduces nitrate leaching, soil erosion, and nutrient runoff, and provides forage that enhances ruminate livestock production [128,129]. In a northern temperate climate of the U.S., establishment year yields of spring-seeded forage legumes are low, often being one-half that of subsequent full production years [130,131] and this has contributed to maize silage becoming the primary source of forage for ruminant livestock [128].

Two approaches have been pursued for utilizing perennial forages interseeded or intercropped with maize. One approach aims to bypass the low yielding establishment year of forage legumes by interseeding them into a relatively high-yielding maize companion crop. In this system, the forage legume serves as a cover crop during its establishment in maize and then it is brought into full forage production in subsequent years. A second approach utilizes perennial legumes or grasses as so-called "living mulch" for the production of maize or other annual crops. In these systems, the primary purpose of the living mulch is to provide year-round and long-term ground cover while forage production is usually a secondary consideration.

Successful establishment of forage legumes in a maize-silage companion crop for subsequent forage production appears to be highly dependent on management practices, growth environment, and the developmental characteristics and yield potential of maize. Multi-year studies in Wisconsin, USA demonstrated that alfalfa establishment in maize silage is favored by early interseeding prior to the V2 stage of maize using normal alfalfa seeding rates, and by planting maize at moderate maize populations to lessen competition and allow some penetration of direct sunlight to alfalfa seedlings following maize canopy closure [132–135]. Establishment of interseeded alfalfa in Wisconsin was further enhanced by planting a suitable variety [136] and by treating seedlings with the gibberellin inhibitor prohexadione followed by fungicide and insecticide to promote root growth and overall plant health [132–134,136]. A similar study conducted in North Dakota had similar results to those of Grabber [132] but application of prohexadione did not improve alfalfa survival [137]. In a multistate study with maize for grain instead of silage, alfalfa was established successfully while growing maize [138]. Several options for controlling weeds have also been developed for interseeding systems utilizing glyphosate-resistant and non-GMO alfalfa and maize [139]. Alfalfa variety selection and agrichemical use is of little consequence, however, if establishment is carried out under conditions that favor an open maize canopy, relatively low yields of maize, and low pressure from weeds, disease, or insects [133,135,136,139]. Red clover (*Trifolium pratense* L.) has typically been interseeded into maize at the V4 to V6 stage as a short-term cover crop, and although establishment can be inconsistent, it can in some years produce high yields of forage the following year [140]. Improved establishment and subsequent forage production of red clover interseeded into maize might be obtained by implementing many of the agrichemical treatments and improved management practices described above for interseeded alfalfa. Applying adequate nitrogen fertilizer [141] and delaying interseeding until maize emergence can lessen the adverse impacts of interseeded legumes on maize silage yields.

A number of studies have examined intercropping of maize or other annual crops in living mulches (also referred to as perennial groundcovers) of kura clover (*Trifolium ambiguum* Bieb.), white clover (*Trifolium repens* L), crownvetch (*Coronilla varia* L.), alfalfa, and various forage or turf-type perennial grasses [96,142–147]. To be successful, perennial forages utilized as living mulch should have good persistence during long-term intercropping and possess growth characteristics and be managed in a manner that minimizes direct competition with the primary annual crop. Depending on seedling vigor, perennial forages are usually sown several months or up to a year prior to intercropping to ensure good establishment and their long-term persistence as living mulches [148]. Once established, perennial forages are typically severely suppressed in early spring with herbicides and then narrow strips are killed preferably with tillage to lessen their direct competitive effects of the living mulch and create a seed bed for planting the annual crop [149]. Suppression and strip tillage of legume living mulches stimulates N mineralization to a degree that applications of nitrogen fertilizer can be reduced or eliminated for maize [150,151]. The long-term persistence of the living mulch by planting maize in wider rows and using narrower strips of killed mulch [145], and likely by alternating intercropping with periods of perennial forage production to restore stand vigor. Persistence is also enhanced if the perennial much has the ability to spread vegetatively via rhizomes or stolons or reseeding [148]. Living mulch systems usually reduce maize yields relative to monocropped maize, especially if precipitation is limited [96,140,142–147], but yield reductions can be partially alleviated through use of drought-tolerant hybrids [152].

3.3. The Role of Perennial Forages in Achieving Ecological Intensification

Perennial forages can provide multiple supporting and regulating ecosystem services. Depending on the forage, perennials can improve crop yield, enhance soil health, N_2 fixing, N credits for the next crop, pollinators and wildlife habitat, below-ground biodiversity, water retention in the soil, and mitigation of nitrate leaching and phosphorous (P) run-off [97,111,153–157]. Perennial forages can mitigate soil acidity and reduce bulk density, while increasing particulate organic matter and water stable aggregates [111]. Alfalfa, for example, can control erosion and enhance soil structure, due to its deep root system and increase in SOC [156,158]. Soil stability was enhanced, and surface sediment run-off was shown to decrease when alfalfa was included in the cropping system [159]. Alfalfa can also benefit crop quality as unfertilized spring wheat following alfalfa had greater crude protein than fertilized spring wheat in one study [120].

Rainfall simulator studies demonstrated that interseeded legumes and living mulches reduce loss of sediment and total soil phosphorus from cropland by up to 90 percent and increase water infiltration into soil relative to solo-seeded maize [157,160–162]. Interseeded legumes and living mulches are also effective scavengers of residual soil nitrate following maize production [140,141,163]. Interseeded alfalfa also suppresses weeds in maize [139]. When successfully established, first year dry matter yields of interseeded alfalfa are approximately two-fold greater than conventionally spring-seeded alfalfa but gains in alfalfa forage production are often partially offset by reductions in the yield of the maize companion crop [132–134,137,138]. Nonetheless, recent economic analysis found that alfalfa-maize silage rotations utilizing forage interseeding should increase annualized net returns by 7 to 33% relative to rotations using conventional spring establishment of alfalfa [164]. Similarly, Berti et al. [137] determined alfalfa intercropped with maize had higher net returns than a silage-maize followed by a spring-seeded alfalfa sequence. Full realization of these benefits will, however, require reliable and cost-effective establishment of forage legumes while maintaining relatively high yields of the maize companion crop. Due to lower maize yields, living mulch systems appear to be less profitable than monocropped maize, but the economic outcome can be improved if the living mulch can also be used as a forage source, permit greater harvest and utilization of maize stover, or provide longer-term benefits that increase cropland productivity [148,150].

3.4. Perennial Forages: Limitations and Knowledge Gaps

The benefits of incorporating perennial forages into crop rotations have been well articulated [18,165]. However, there is a need to develop best management practices for integrating perennial forages into cropping rotations across agroecosystems. For example, there has been research on the impacts of different perennial forages and forage mixtures on crop yields [97], soil quality parameters [111], and crop quality [120], but a more extensive evaluation that incorporates different forage species and species mixtures across environmental gradients is needed. There have been studies on the best tillage management system to convert from perennials to annual [166] and the impact of annual crops on subsequent perennial establishment and yield [167], but more in-depth evaluations are needed to achieve a mechanistic understanding of these critical management decisions and the economic benefits associated with these systems. In more semi-arid regions, there is a need to understand how environmental factors such as precipitation impact conversion into and out of perennial forages and the subsequent crop sequence needed to maximize the benefits of perennial forages over time.

Adoption of legume interseeding and living mulches by producers has been limited because these systems require greater management effort, can require greater inputs or specialized equipment, and can increase risk of yield loss relative to annual monocropping systems. Thus, implementation of these systems in the landscape will require new approaches for improving their productivity and profitability, and may require greater support through conservation cost sharing programs and coverage by crop insurance programs. Even when utilizing all currently recommended practices, establishment of interseeded legumes in maize or long-term survival of living mulches can be poor if growth conditions favor full canopy closure and especially high yields of maize, severe disease and insect damage, and vigorous competition from summer annual grass or other weeds. Other remaining challenges to interseeded legume or living mulch systems includes damage from rutting and compaction of wet soil during maize harvest, competition between crops for moisture and nutrients under certain production conditions and weed avoidance responses that reduce maize yields. Research that overcomes these challenges will help to foster greater implementation of perennial legume interseeding and living mulch systems on farms.

4. Dual-Use Perennial Crops/Forages

Perennial forages that can also produce a grain crop in the same year, i.e., dual-use crops/forages, provide ecological benefits associated with perennials (Figure 2) while providing a grain crop that does not require yearly planting and intensive use of purchased inputs. Dual-use perennial crops/forages are often developed from hybrids between annual grains and perennial native species that are adapted to regional growing conditions and can tolerate periods of limited rainfall. These perennial crops are better able to utilize resources more efficiently while requiring fewer nutrient inputs in some cases. In this section, we provide two specific examples of perennial crops being developed and how their integration in a landscape dominated by annual, input-intensive crops may provide multiple benefits, including forage production, that may effectively advance the EI framework. Tradeoffs between forage and grain production and among ecosystem services may exist, however.

4.1. Dual-Use Cereals

Kernza intermediate wheatgrass is a novel perennial grain and forage crop with the potential to provide multiple ecosystem services. Through its continuous above-ground productivity, i.e., perenniality, Kernza reduces annual weed populations [168], protects soil from erosion, and increases pollinators and insect diversity [169]. Kernza's perennial nature also leads to a reduction in nutrient leaching [170,171], an increase in the SOC pool and other beneficial soil properties [172], and improvements in biota linked to high soil quality [169,172]. Therefore, Kernza can recover ecosystem services that usually are lost due to annual grain agriculture [173,174]. This transition to more sustainable agriculture is usually the main motivation for early-adopter growers [175,176].

In addition to environmental benefits, growing Kernza as a dual-use perennial crop provides two sources of income to farmers: forage and grain. Kernza grain is highly valued by the market for making baked goods and beer [177,178] and demand is growing from environmentally conscious consumers [179]. In its first year, Kernza grain yield in the North Central US varies from 112 to 1150 kg ha^{-1} with large declines usually observed the following years (Table 1). Some practices are recommended to avoid Kernza grain decline such as increasing N fertilization [180,181], widening row spacing [182], post-harvest management practices (e.g., defoliation [182,183], stand-thinning [183,184], or chopping and burning [183], but thus far results have been highly variable. In contrast, first year Kernza forage harvest varies from 3243 to 11,753 kg ha^{-1} in summer but also shows a slow decline over time (Table 1). Kernza forage's nutritive value is low in summer [185] but could replace straw in high-starch dairy diets to maintain proper rumen function [186] or could produce biomass for the production of biofuel. High-quality forage harvest varies from 500 to 3900 kg ha^{-1} in spring and from 75 to 3900 kg ha^{-1} in fall [185,187,188]. Both spring and fall-harvested Kernza forage have high nutritive value and are suitable for lactating beef cows, dairy cows, and growing heifers [185]. All of these commercial uses of Kernza can relieve the economic disparity between perennial grain and annual cereal systems [189].

Table 1. Grain and summer forage yields of Kernza intermediate wheatgrass in the first year and older stands (second, third or fourth year) across different US locations. Single values show published means while ranges show minimum and maximum published means for each study.

		Grain Yield (kg ha^{-1})		Vegetative Biomass (kg ha^{-1})		
Location		**First Year**	**Older Stands**	**First Year**	**Older Stands**	**Ref.**
Colorado	Fort Collins	724	3	11,753	1808	[188]
Kansas	Salina	526	71	4098	4696	[188]
Michigan	Hickory Corners	112–157	1390–1662	3881–4984	12,202–17,131	[170]
Minnesota	Crookston/Roseau	452–1150	32–986	4037–8421	738–11,638	[180,190]
	Lamberton/Waseca		33–1110		4684–13,161	[190]
	Morris		107–809		4373–10,379	[190]
	Saint Paul	535–876	183–664	9697–10,200	6604–8200	[181,182,188]
New York	Aurora/Ithaca	1043	134–219	4723	4059–7290	[184,188]
Wisconsin	Arlington	446–902	105–479	6607	4666–5690	[181,188,191]
	Lancaster/Montfort	143–203	59–326	6141	3183–19,495	[183,185]
Ohio	S. Charleston/Wooster	651–758	36–655	3243–6069	2337–6040	[188]

Other dual-use cereals under development through wide-hybridization of annual grains and perennial relatives include perennial rice, perennial wheat (wheat X intermediate wheatgrass), and perennial sorghum [15,173].

4.2. Dual-Use Oilseeds

The genus *Silphium* includes several long-lived, deep-rooted sunflower relatives native to the central and eastern regions of the U.S. The drought tolerance of these species was noted by the botanist John Weaver [192] during the droughts of the Dust Bowl era. Although these forbs are coarse with stiff stalks and resinous, often hirsute leaves, early naturalists also noted that cattle often feed on silphium plants first when introduced to new prairie pastures [193]. Since that time, the largest, fastest-growing species, *Silphium perfoliatum* L. (cup plant) was adopted in central and northern Europe as a forage with dry matter yields ranging from 2–32 Mg ha^{-1} and crude protein content of 4.9–15% [194]. The forage value of this species has also been appreciated in Chile because it remains productive during the dry season when other (presumably more shallowly rooted) species are dormant or stressed [195]. *Silphium integrifolium* (silflower) also produces high-quality forage whether fresh or ensiled [196].

In recent years, the majority of research on cup plant has focused on its potential as a substitute for maize in biogas production in Europe, especially Germany [197–199]. While maize is somewhat higher yielding than cup plant, diversification of bioenergy feedstocks in agricultural landscapes is generally desirable and cup plant is perceived as providing more ecosystem services than maize [198]. The key differences between these highly productive species result from differences in pollination biology and life history. First, the perennial habit of cup plant and other perennial energy crops reduces the need for tillage (compared with annual crops), and this protects soil from erosion and degradation [200], allows for the development of a litter layer, and changes the amount of root biomass allowing, for example, higher populations of earthworms to develop [201,202]. Second, because it is insect-pollinated, cup plant provides a greater range and quantity of floral resources than wind-pollinated maize [203]. Cup plant compared favorably with insect-pollinated annual crops such as rapeseed (*Brassica napus* L.) and sunflower [203]. The long flowering season and relatively high production of nectar makes cup plant attractive as a bee pasture crop, with estimates as high as 200 kg of honey production per hectare [204].

In parallel to the growth of interest in and literature about cup plant as a perennial biomass crop that has increased in Europe in recent years, interest and research on the closely related silflower as a perennial oilseed grain crop has grown in the Americas [205,206]. The native range of silflower is westwards shifted compared with cup plant. Silflower but not cup plant is found in the Central and southern Great Plains of the U.S. (https://plants.usda.gov/home, accessed on 15 September 2021), suggesting that the two species differ in tolerance to hot, dry, windy conditions common on the Great Plains, while cup plant may better tolerate wet soils and humid conditions of the Atlantic coastal states of the U.S. In the Great Plains, cup plant establishes more rapidly and achieves greater biomass in the first few years than silflower, but declines in yield more rapidly and does not tolerate competition with intercrops such as tall fescue as well. In Kansas, the former is markedly more disease resistant than the latter, but the situation is reversed for resistance to foliar insect herbivores (Van Tassel, personal observations). Together, these suggest that crops developed from these two species may be targeted for different macro-environments based on precipitation and drought stress.

Under scenarios of planetary climate destabilization, crops in previously humid regions may be exposed to episodic drought and heat, while those in drier regions may face episodic flooding. For this reason, and to attempt to combine insect and disease resistance in a single breeding population, hybrids between these two species have been made. Hybrids are easily obtained but the fertility of hybrids varies widely, depending on the particular pair of parents mated (Van Tassel, personal observations). Intermating hybrids produces populations segregating for many characters. However, it remains to be seen if it is possible to develop a population with the potential for both high biomass and high oilseed production.

An all-purpose crop with the biomass energy yield of cup plant and the large seeds and higher seed yield of silflower may ultimately not be possible due to sink competition between vegetative and reproductive sinks. However, a variety with intermediate traits might make an excellent forage crop. Faster growth and disease resistance from cup plant is highly desirable, and the larger seeds and drought resistance of silflower would improve stand establishment and persistence. Genetic improvement of both cup plant and silflower is in its infancy and genetic and genomic resources are being developed [199,207]. Progress has been made in understanding the genetic basis of self-compatibility [208], the physiology and ecophysiology of germination [209–211].

Two other crops with both oilseed and forage potential are spiny, thistle-like perennials native to the Mediterranean: cardoon (*Cynara cardunculus* L.) and akkoub (*Gundelia tournefortii* L.). Intriguingly, both were traditionally used as vegetable delicacies but, being members of the aster family, also have oil-rich seeds. As with *S. perfoliatum* in northern and central Europe, *Cynara cardunculus* is being developed primarily as a bioenergy crop for southern Europe. However, there is also interest in the seeds as a source of biodiesel, biomass waste products as a source of industrial or pharmaceutical chemicals and stems as feedstock for paper production (reviewed recently by Barbosa et al. [212]). Where stems are used for paper or as solid fuel, the foliage "waste" has been found to be safe and nutritious enough to be used as livestock fodder [212]. As the inflorescences have historically been used in the cheesemaking process as a curdling agent, this plant can truly be said to be multifunctional.

Further east in the Mediterranean, *Gundelia* has long been appreciated as a vegetable and prepared similarly to artichokes (*Cynara*) for traditional dishes. It has been used medicinally and there is some evidence that the seeds were harvested and used as a source of vegetable oil in ancient times [213,214]. In some parts of the Mediterranean, the seeds are toasted and eaten as a snack [215]. Although the plants are spiny and avoided by grazing sheep, leading to an increase in the *Gundelia* population in some heavily grazed regions [216], herders have traditionally gathered and dried *Gundelia* as feed for goats, sheep, and camels when other fodder was scarce [217]. Surprisingly, given its unpalatable appearance, animals performed similarly when alfalfa in a standard ration was replaced by ground *Gundelia* [218]. In Palestine, where access to wild stands of *Gundelia* is becoming difficult, entrepreneuring farmers are beginning to propagate it from seed and produce it as a vegetable under cultivation, representing an early stage of agronomic domestication [219]. Other workers in the region have speculated that this valuable vegetable could also be domesticated as an oilseed [220].

4.3. The Role of Dual-Use Crops/Forages in Achieving Ecological Intensification

While the ecological benefits of perennial forages and grains relative to annuals have been widely discussed and tested [221], the benefits of dual purpose vs. single purpose perennial crops are less obvious. An economic analysis comparing hypothetical perennial wheat with annual wheat in Australia found that using perennial wheat as a dual-purpose cereal grain and forage crop increased profitability under scenarios in which yields of perennial wheat lagged behind the yield of annual wheat [189]. The ability of perennial wheat to regrow following grain harvest enabled farmers to graze their sheep flocks during a season when purchased feeds were otherwise needed. The general principle here is that new grain crops take many cycles of breeding to catch up to the yields of standard grain crops, but that multiple economic uses could allow them to be adopted by farmers earlier in the process.

From the perspective of introducing a new perennial forage, more breeding for increased seed production could reduce the cost of seed and increased seed size could make it easier to handle and improve seedling vigor. It is less clear whether breeding for forage traits could also result in improved traits that would help grain producers. Disease and pest resistance would be an example of breeding that would benefit both forage and grain cultivar development equally. Breeding for improved palatability and nutritive value to livestock could reduce pest herbivore resistance-contrary to the goals of grain breeders-although examples of this tradeoff are difficult to find in the literature.

Species with multifunctionality may attract a greater number and diversity of researchers. This in turn could help close knowledge gaps faster compared with single-purpose species. For example, basic agronomic, genomic, and physiological research should benefit all applied researchers for a given species. Whether the species is to be used as a forage or as a grain or energy crop, breaking seed dormancy, seedling vigor, plant nutrition, and plant protection are common needs; genomic and genetic resources (maps, reference genomes, and marker platforms) can be shared by multiple crop improvement communities.

4.4. Dual-Use Crops/Forages: Limitations and Knowledge Gaps

A major knowledge gap preventing wider use of dual-purpose oilseeds and legumes is the lack of broadly replicated protocols for maximizing production of both forage and other products such as oilseed or legume grains. Waiting for seed crops to mature and dry in the field will mean a reduction in the forage nutritive value of the crop residues compared with harvesting forage earlier in the season. Biomass harvest early in the season, on the other hand, may reduce grain production when the crop re-grows. Except for very early forage harvest dates (when yield of forage will be low), forcing silflower to regrow from cut stalks significantly reduced grain yield [197]. At the moment, the safest way to use perennial oilseeds in multiple ways may be to alternate between uses. Farmers may decide whether to harvest at peak forage production in years when forage prices are high or wait and harvest oilseed grain when vegetable oil demand (locally or internationally) is high. One advantage of this kind of management rotation may be that harvesting a perennial at different stages of development in different years could disrupt the life cycle of specialist herbivores or other parasites. For example, the *Silphium* specialist moth *Eucosma* oviposits very specifically on immature *Silphium* seed heads and the larvae grow rapidly in size within the heads. Later, they descend and feed on the rhizomes of *Silphium*, causing a lot of damage to the whole plant. Forage harvesting just after heading could disrupt this moth's life cycle [196].

In addition to tradeoffs between forage and grain harvests in a single year, it remains to be seen if seed production traits being improved through selective breeding are negatively correlated with traits preferred for forage breeding. Will it be necessary to breed separate forage and grain varieties? An example of a potential conflict between these two breeding ideotypes is plant height. Tall plants may produce greater forage yield, but semi-dwarfing stature may be preferred for grain production. Shorter plants may be less prone to lodging and may be able to allocate a greater amount of scarce carbon or nitrogen resources to seed filling.

If perennial dual-use crops are meant to increase diversity in agricultural systems, mixtures (or intercrops, or polycultures) are needed to add diversity in space (given that diversity over time is limited by the perenniality). This brings a series of questions that are currently major knowledge gaps for developing perennial dual-use systems: Which species and cultivars optimize grain yield, forage yield, and nutritive value? How many species are needed? When and how should be planted? Furthermore, breeding crops for perennials mixtures may require that the evaluations are conducted in the target environment, i.e., in mixtures per se [222]. This opens up a challenging field of research combining breeding and agroecology for designing optimal diverse perennial systems.

5. Conclusions

In this review, we categorized forages into three broad categories, annual, perennial, and dual-use crops/forages, and provided examples for how each of these forage types can provide an applied, ecological framework for intensifying food production. There are a number of dimensions (or ecosystem services) within the EI framework addressed in this review, including provisioning of forage and grain production, soil and water quality benefits, agronomic pest management and biodiversity, as well as potential economic advantages. To summarize our findings, we provide a comparison of each forage type's contribution to a suite of EI dimensions and the magnitude of that contribution relative to the other forage types discussed in this review in Table 2. The magnitude with which each forage type can provide these services is dependent on how successfully forages can be integrated into an annual cropping or perennial pasture system, and tradeoffs may exist in providing more of one or more services over others.

This paper was not intended to provide a systematic review of all systems that possess the potential to meet sustainable intensification goals; rather we limited our review to areas we believe hold the greatest promise and discussed some of the limitations and knowledge gaps associated with each. For instance, the role of forages, specifically tannin-containing forages, on mitigating GHG emissions derived from livestock nor their impact on animal health and performance were discussed. Further, the selection and placement of each forage type across the landscape will be critical for addressing environmental concerns based on landscape characteristics. In summary, given that the specialization of agriculture has led to decoupling of animal and crop components, forages, in their many facets, provide a unique opportunity to re-couple these components and address both food production needs and environmental concerns.

Table 2. A comparison of each forage type (annual, perennial, dual-use) and their contributions to dimensions of ecological intensification (EI) when integrated into annual crop production and pasture-based systems. The magnitude of contribution of each forage type to achieving EI within a given dimension is indicated by the "+" symbol, with "+++" indicating the highest magnitude and "+" indicating the lowest.

Dimension of Ecological Intensification *	Annual Forages	Perennial Forages	Dual-Use Crops/Forages
Increase in forage production	++	+++	++
Increase in grain production	+	++	+++
Increase in soil quality	++	+++	+++
Increase in soil carbon	++	+++	+++
Reduction of soil erosion	++	+++	+++
Reduction of nutrient leaching/ improvement in water quality	++	+++	+++
Suppression of weeds & other agronomic pests	+++	++	++
Increase in managed biodiversity †	+–+++	+–+++	+–+++
Increase in associated biodiversity	+	++	++
Economic benefits	++	++	+++

* The magnitude by which each forage type can impact each dimension will vary based on a number of factors such as mixture diversity, component species, soil and environmental factors, and success of establishment; † Managed biodiversity, i.e., controlled species richness, can vary depending on species diversity and combinations.

Author Contributions: Conceptualization, J.G.F. and V.D.P.; Investigation, J.G.F., M.T.B., J.H.G., J.R.H., C.C.N., P.P., D.V.T., V.D.P.; Data collection, J.G.F., M.T.B., J.H.G., J.R.H., C.C.N., P.P., D.V.T., V.D.P.; Writing—original draft preparation, J.G.F., M.T.B., J.H.G., J.R.H., C.C.N., P.P., D.V.T.; Writing—review and editing, J.G.F., M.T.B., J.H.G., J.R.H., C.C.N., P.P., D.V.T., V.D.P.; Visualization, J.G.F., P.P., V.D.P.; Supervision, J.G.F., M.T.B., V.D.P. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partially supported by AFRI Sustainable Agricultural Systems Coordinated Agricultural Project (SAS-CAP) grant no. 2020-68012-31934 from the USDA National Institute of Food and Agriculture.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

Disclaimer: Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply either recommendation or endorsement by the U.S. Department of Agriculture. The USDA is an equal opportunity provider and employer.

References

1. Van Dijk, M.; Morley, T.; Rau, M.L.; Saghai, Y. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nat. Food* **2021**, *2*, 494–501. [CrossRef]
2. Alexandratos, N.; Bruinsma, J. World Agriculture toward 2030/2050: The 2012 Revision. Food and Agriculture Organization of the United Nations. ESA Working Paper no. 12-03. Available online: http://www.fao.org/3/ap106e/ap106e.pdf (accessed on 1 July 2021).
3. United States Department of Agriculture. USDA Engages Public for Input on Agriculture Innovation Agenda (Press Release No. 0210.20). Available online: https://www.usda.gov/media/press-releases/2020/04/01/usda-engages-public-input-agriculture-innovation-agenda (accessed on 1 July 2021).
4. Kremen, C.; Merenlender, A.M. Landscapes that work for biodiversity and people. *Science* **2018**, *362*, eaau6020. [CrossRef]
5. Sanford, G.R.; Jackson, R.D.; Booth, E.G.; Hedtcke, J.L.; Picasso, V. Perenniality and diversity drive output stability and resilience in a 26-year cropping systems experiment. *Field Crop. Res.* **2021**, *263*, 108071. [CrossRef]
6. Smith, P. Delivering food security without increasing pressure on land. *Glob. Food Secur.* **2013**, *2*, 18–23. [CrossRef]
7. Pretty, J.; Bharucha, Z.P. Sustainable intensification in agricultural systems. *Ann. Bot.* **2014**, *114*, 1571–1596. [CrossRef] [PubMed]
8. Royal Society. *Reaping the Benefits: Science and the Sustainable Intensification of Global Agricultur*; The Royal Society: London, UK, 2009.

9. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327*, 812–818. [CrossRef] [PubMed]
10. Pretty, J. Intensification for redesigned and sustainable agricultural systems. *Science* **2018**, *362*, eaav0294. [CrossRef]
11. Spiegal, S.; Bestelmeyer, B.T.; Archer, D.W.; Augustine, D.J.; Boughton, E.H.; Cavigelli, M.A.; Clark, P.E.; Derner, J.D.; Duncan, E.W.; Hapeman, C.J.; et al. Evaluating strategies for sustainable intensification of US agriculture through the Long-Term Agroecosystem Research Network. *Environ. Res. Lett.* **2018**, *13*, 034031. [CrossRef]
12. Tittonell, P. Ecological intensification of agriculture-sustainable by nature. *Curr. Opin. Environ. Sustain.* **2014**, *8*, 53–61. [CrossRef]
13. Barrios, E.; Herren, B.G.; Bicksler, A.; Siliprandi, E.; Brathwaite, R.; Moller, S.; Batello, C.; Tittonell, P. The 10 elements of Agroecology; enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosyst. People* **2020**, *16*, 230–247. [CrossRef]
14. Wezel, A.; Herren, B.G.; Kerr, R.B.; Barrios, E.; Goncalves, A.L.R.; Sinclair, F. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev.* **2020**, *40*, 40. [CrossRef]
15. Crews, T.; Cox, T.; De Haan, L.; Damaraju, S.; Jackson, W.; Nabukalu, P.; Van Tassel, D.; Wang, S. New roots for ecological intensification. *CSA News* **2014**, *59*, 16–18. [CrossRef]
16. Ausubel, J.H.; Wernick, I.K.; Waggoner, P.E. Peak farmland and the prospect for land sparing. *Popul. Dev. Rev.* **2013**, *38*, 221–242. [CrossRef]
17. Ustaoglu, E.; Williams, B. Determinants of urban expansion and agricultural land conversion in 25 EU countries. *Environ. Manage.* **2017**, *60*, 717–746. [CrossRef]
18. Entz, M.H.; Bullied, W.J.; Katepa-Mupondwa, F. Rotational benefits of forage crops in Canadian prairie cropping systems. *J. Prod. Agric.* **1995**, *8*, 521–529. [CrossRef]
19. Cates, A.M.; Ruark, M.D.; Hedtcke, J.L.; Posner, J.L. Long-term tillage, rotation and perennialization effects on particulate and aggregate soil organic matter. *Soil Tillage Res.* **2016**, *155*, 371–380. [CrossRef]
20. Franco, J.G.; Duke, S.E.; Hendrickson, J.R.; Liebig, M.A.; Archer, D.W.; Tanaka, D.L. Spring wheat yields following perennial forages in a semiarid no-till cropping system. *Agron. J.* **2018**, *110*, 2408–2416. [CrossRef]
21. Sprunger, C.D.; Martin, T.; Mann, M. Systems with greater perenniality and crop diversity enhance soil biological health. *Agric. Environ. Lett.* **2020**, *5*, e20030. [CrossRef]
22. Reynolds, J.; Bell, M.A.; Grace, J.; Gratton, C.; Jackson, R.D.; Keeley, K.O.; Mayerfeld, D. An agroecological vision of perennial agriculture. *Agroecol. Sustain. Food Syst.* **2021**, *45*, 1470–1479. [CrossRef]
23. Snapp, S.S.; Swinton, S.M.; Labarta, R.; Mutch, D.; Black, J.R.; Leep, R.; Nyiraneza, J.; O'Neil, K. Evaluating cover crops for benefits, costs and performance within cropping systems niches. *Agron. J.* **2005**, *97*, 322–332. [CrossRef]
24. Blanco-Canqui, H.; Holman, J.D.; Schlegel, A.J.; Tatarko, J.; Shaver, T.M. Replacing fallow with cover crops in a semiarid soil: Effects on soil properties. *Soil Sci. Soc. Am. J.* **2013**, *77*, 1026–1034. [CrossRef]
25. Schipanski, M.E.; Barbercheck, M.; Douglas, M.R.; Finney, D.M.; Haider, K.; Kaye, J.P.; Kemanian, A.R.; Mortensen, D.A.; Ryan, M.R.; Tooker, J.; et al. A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agric. Syst.* **2014**, *125*, 12–22. [CrossRef]
26. Florence, A.M.; Higley, L.G.; Drijber, R.A.; Francis, C.A.; Lindquist, J.L. Cover crop mixture diversity, biomass productivity, weed suppression, and stability. *PLoS ONE* **2019**, *14*, e0206195. [CrossRef]
27. Mallinger, R.E.; Franco, J.G.; Prischmann-Voldseth, D.A.; Prasifka, J.R. Annual cover crops for managed and wild bees: Optimal plant mixtures depend on pollinator enhancement goals. *Agric. Ecosyst. Environ.* **2019**, *273*, 107–116. [CrossRef]
28. Sanderson, M.; Johnson, H.; Hendrickson, J. Cover crop mixtures grown for annual forage in a semi-arid environment. *Agron. J.* **2018**, *110*, 525–534. [CrossRef]
29. Planisich, A.; Utsumi, S.A.; Larripa, M.; Galli, J.R. Grazing of cover crops in integrated crop-livestock systems. *Animal* **2021**, *15*, 100054. [CrossRef] [PubMed]
30. Singh, N.; Abagandura, G.O.; Kumar, S. Short-term grazing of cover crops and maize residue impacts on soil greenhouse gas fluxes in two Mollisols. *J. Environ. Qual.* **2020**, *49*, 628–639. [CrossRef]
31. Kelly, C.; Schipanski, M.E.; Tucker, A.; Trujillo, W.; Holman, J.D.; Obour, A.K.; Johnson, S.K.; Brummer, J.E.; Haag, L.; Fonte, S.J. Dryland cover crop soil health benefits are maintained with grazing in the U.S. High and Central Plains. *Agric. Ecosyst. Environ.* **2021**, *313*, 107358. [CrossRef]
32. Hilimire, K. Integrated crop/livestock agriculture in the United States: A review. *J. Sustain. Agric.* **2011**, *35*, 376–393. [CrossRef]
33. Ryschawy, J.; Choisis, N.; Choisis, J.P.; Joannon, A.; Gibon, A. Mixed crop-livestock systems: An economic and environmental-friendly way of farming? *Animal* **2012**, *6*, 1722–1730. [CrossRef]
34. Lemaire, G.; Franzluebbers, A.; de Faccio Carvalho, P.C.; Dedieu, B. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agric. Ecosyst. Environ.* **2014**, *190*, 4–8. [CrossRef]
35. Sulc, R.M.; Franzluebbers, A.J. Exploring integrated crop-livestock systems in different ecoregions of the United States. *Eur. J. Agron.* **2014**, *57*, 21–30. [CrossRef]
36. Hendrickson, J.R. Crop-livestock integrated systems for more sustainable agricultural production: A review. *CABI Rev.* **2020**, *15*, 1–11. [CrossRef]
37. Schut, A.G.T.; Cooledge, E.C.; Moraine, M.; van de Ven, G.W.J.; Jones, D.L.; Chadwick, D.R. Reintegration of crop-livestock systems in Europe: An overview. *Front. Agric. Sci. Eng.* **2020**, *8*, 111–129. [CrossRef]

38. Smart, A.J.; Redfearn, D.; Mitchell, R.; Wang, T.; Zilverberg, C.; Bauman, P.J.; Derner, J.D.; Walker, J.; Wright, C. *Forum*: Integration of crop-livestock systems: An opportunity to protect grasslands from conversion to cropland in the US Great Plains. *Rangel. Ecol. Manag.* **2020**, in press. [CrossRef]
39. Henchion, M.; McCarthy, M.; Resconi, V.C.; Troy, D. Meat consumption: Trends and quality matters. *Meat Sci.* **2014**, *98*, 561–568. [CrossRef] [PubMed]
40. Stoll-Kleemann, S.; O'Riordan, T. The sustainability challenges of our meat and dairy diets. *Environ. Sci. Policy Sustain. Dev.* **2015**, *57*, 34–48. [CrossRef]
41. Rockström, J.; Steffen, W.; Noone, K.; Persson, A.; Chapin, F.S., III; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. A safe operating space for humanity. *Nature* **2009**, *461*, 472–475. [CrossRef]
42. Thorup-Kristensen, K.; Halberg, N.; Nicolaisen, M.; Olesen, J.E.; Crews, T.E.; Hinsinger, P.; Kirkegaard, J.; Pierret, A.; Dresboll, D.B. Digging deeper for agricultural resources, the value of deep rooting. *Trends Plant Sci.* **2020**, *25*, 406–417. [CrossRef]
43. Heaton, E.A.; Schulte, L.A.; Berti, M.; Langeveld, H.; Zegada-Lizarazu, W.; Parrish, D.; Monti, A. Managing a second-generation crop portfolio through sustainable intensification: Examples from the USA and the EU. *Biofuels Bioprod. Biorefin.* **2013**, *7*, 701–714. [CrossRef]
44. Drewnoski, M.; Parsons, J.; Blanco, H.; Redfearn, D.; Hales, K.; MacDonald, J. Forages and pastures symposium: Cover crops in livestock production: Whole-system approach. Can cover crops pull double duty: Conservation and profitable forage production in the Midwestern United States? *J. Anim. Sci.* **2018**, *96*, 3503–3512. [CrossRef] [PubMed]
45. Andersen, B.J.; Samarappuli, D.P.; Wick, A.; Berti, M.T. Faba bean and pea can provide late-fall forage grazing without affecting maize yield the following season. *Agronomy* **2020**, *10*, 80. [CrossRef]
46. Tobin, C.; Singh, S.; Kumar, S.; Wang, T.; Sexton, P. Demonstrating Short-term impacts of grazing and cover crops on soil health and economic benefits in an integrated crop-livestock system in South Dakota. *Open J. Soil Sci.* **2020**, *10*, 109–136. [CrossRef]
47. Samarappuli, D.P.; Johnson, B.L.; Kandel, H.; Berti, M.T. Biomass yield and nitrogen content of annual energy/forage crops preceded by cover crops. *Field Crop. Res.* **2014**, *167*, 31–39. [CrossRef]
48. Li, L.; Sun, J.; Zhang, F.; Guo, T.; Smith, F.A.; Smith, S.E. Root distribution and interactions between intercropped species. *Oecologia* **2006**, *147*, 280–290. [CrossRef]
49. Hauggaard-Nielsen, H.; Jornsgaard, B.; Kinane, J.; Jensen, E.S. Grain legume-cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. *Renew. Agric. Food Syst.* **2007**, *23*, 3–12. [CrossRef]
50. Strydhorst, S.; King, J.R.; Lopetinsky, K.J.; Harker, K.N. Forage potential of intercropping barley with faba bean, lupin, or field pea. *Agron. J.* **2008**, *100*, 182–190. [CrossRef]
51. Anil, L.; Park, J.; Phipps, R.H.; Miller, F.A. Temperate intercropping of cereal for forage: A review of the potential for growth and utilization with particular reference to the UK. *Grass Forage Sci.* **1998**, *53*, 301–317. [CrossRef]
52. Sarunaite, L.; Deveikyte, I.; Arlauskiene, A.; Kadziuliene, Z.; Maiksteniene, S. Pea and spring cereal intercropping systems: Advantages and suppression of broad-leaved weeds. *Pol. J. Environ. Stud.* **2013**, *22*, 541–551.
53. Zhang, G.; Zhang, C.; Yang, Z.; Dong, S. Root distribution and N acquisition in an alfalfa and corn intercropping system. *J. Agric. Sci.* **2013**, *5*, 128. [CrossRef]
54. Hauggaard-Nielsen, H.; Ambus, P.; Jensen, E.S. Interspecific competition, N use and interference with weeds in pea-barley intercropping. *Field Crop. Res.* **2001**, *70*, 101–109. [CrossRef]
55. Lauriault, L.M.; Guldan, S.J.; Popiel-Powers, F.G.; Steiner, R.L.; Martin, C.A.; Heyduck, R.F.; Falk, C.L.; Petersen, M.K.; May, T. Relay intercropping with cover crops improved autumn forage potential of sweet maize stover. *Agriculture* **2018**, *8*, 103. [CrossRef]
56. Villalobos, L.; Brummer, J.E. Interseeding cool-season forages into corn to increase yield and quality of residue grazed in the fall. *Proc. West. Sect. Am. Soc. Anim. Sci.* **2015**, *66*, 268–271.
57. Dabney, S.M.; Delgado, J.A.; Reeves, D.W. Using winter cover crops to improve soil and water quality. *Commun. Soil Sci. Plant Anal.* **2001**, *32*, 1221–1250. [CrossRef]
58. Shah, S.; Hookway, S.; Pullen, H.; Clarke, T.; Wilkinson, S.; Reeve, V.; Fletcher, J.M. The role of cover crops in reducing nitrate leaching and increasing soil organic matter. *Asp. Appl. Biol.* **2017**, *134*, 243–251.
59. Everett, L.A.; Wilson, M.L.; Pepin, R.J.; Coulter, J.A. Winter rye cover crop with liquid manure injection reduces spring soil nitrate but not maize yield. *Agronomy* **2019**, *9*, 852. [CrossRef]
60. Coblentz, W.K.; Akins, M.S.; Kalscheur, K.F.; Brink, G.E.; Cavadini, J.S. Effects of growth stage and growing degree day accumulations on triticale forages: 1. Dry matter yield, nutritive value, and in vitro dry matter disappearance. *J. Dairy Sci.* **2018**, *101*, 8965–8985. [CrossRef]
61. Coblentz, W.K.; Akins, M.S.; Kalscheur, K.F.; Brink, G.E.; Cavadini, J.S. Effects of growth stage and growing degree day accumulations on triticale forages: 2. In vitro disappearance on neutral detergent fiber. *J. Dairy Sci.* **2018**, *101*, 8986–9003. [CrossRef]
62. Landry, E.; Janovicek, K.; Lee, E.A.; Deen, W. Winter cereal cover crops for spring forage in temperate climates. *Agron. J.* **2019**, *111*, 217–223. [CrossRef]
63. Adhikari, L.; Mohseni-Moghadam, M.; Missaoui, A. Allelopathic effects of cereal rye on weed suppression and forage yield in alfalfa. *Am. J. Plant Sci.* **2018**, *9*, 685–700. [CrossRef]
64. Samarappuli, D.; Berti, M.T. Intercropping forage sorghum with maize is a promising alternative to maize silage for biogas production. *J. Clean. Prod.* **2018**, *194*, 515–524. [CrossRef]

65. La Guardia Nave, R.; Corbin, M.D. Forage warm-season legumes and grasses intercropped with corn as an alternative for corn silage production. *Agronomy* **2018**, *8*, 199. [CrossRef]
66. Abdin, O.; Bruce, E.; Coulman, D.; Cloutier, M.A.; Faris, J.; Zhou, X.; Smith, D.L. Yield and yield components of maize interseeded with cover crops. *Agron. J.* **1998**, *90*, 63–68. [CrossRef]
67. Parr, M.; Grossman, J.M.; Reberg-Horton, S.C.; Brinton, C.; Crozier, C. Nitrogen delivery from legume cover crops in no-till organic maize production. *Agron. J.* **2011**, *103*, 1578–1590. [CrossRef]
68. Kallenbach, R.L.; Crawford, R.J., Jr.; Massie, M.D.; Kerley, M.S.; Bailey, N.J. Integrating bermudagrass into tall fescue-based pasture systems for stocker cattle. *J. Anim. Sci.* **2012**, *90*, 387–394. [CrossRef] [PubMed]
69. Stuedemann, J.A.; Hoveland, C.S. Fescue endophyte: History and impact on animal agriculture. *J. Prod. Agric.* **1988**, *1*, 39–44. [CrossRef]
70. Utley, P.R.; Marchant, W.H.; McCormick, W.C. Evaluation of annual grass forages in prepared seedbeds and overseeded into perennial sods. *J. Anim. Sci.* **1976**, *42*, 16–20. [CrossRef]
71. Moyer, J.L.; Coffey, K.P. Forage quality and production of small grains interseeded into bermudagrass sod or grown in monoculture. *Agron. J.* **2000**, *92*, 748–753. [CrossRef]
72. Coffey, K.P.; Coblentz, W.K.; Montgomery, T.G.; Shockey, J.D.; Bryant, K.J.; Francis, P.B.; Rosenkrans, C.F., Jr.; Gunter, S.A. Growth performance of stocker calves backgrounded on sod-seeded winter annuals or hay and grain. *J. Animal Sci.* **2002**, *80*, 926–932. [CrossRef]
73. Beck, P.A.; Gunter, S.A.; Lusby, K.S.; West, C.P.; Watkins, K.B.; Hubbell, D.S., III. Animal performance and economic comparison of novel and toxic endophyte tall fescues to cool-season annuals. *J. Anim. Sci.* **2008**, *86*, 2043–2055. [CrossRef]
74. Gunter, S.A.; Lusby, K.S.; Hubbell, D.S., III. Tall fescue for backgrounding in preparation for small-grain or Bermudagrass pasture. *Prof. Anim. Sci.* **2005**, *21*, 93–96. [CrossRef]
75. Moyer, J.L.; Coffey, K.P.; Brazle, F.K.; Schneider, J.E.; Coppock, C.E.; DelCurto, T. Forage intake, diet quality, and performance of stocker cattle grazing interseeded or monocultured rye and bermudagrass. *Prof. Anim. Sci.* **1995**, *11*, 67–73. [CrossRef]
76. Ball, D.M.; Hoveland, C.S.; Lacefield, G.D. *Southern Forages*, 3rd ed.; Potash and Phosphate Institute and the Foundation for Agronomic Research: Norcross, GA, USA, 2002.
77. Hoveland, C.S.; Anthony, W.B.; McGuire, J.A.; Starling, J.G. Beef cow-calf performance on coastal bermudagrass overseeded with winter annual clovers and grasses. *Agron. J.* **1978**, *70*, 418–420. [CrossRef]
78. Gunter, S.A.; Whitworth, W.A.; Montgomery, T.G.; Beck, P.A. Cool-season annual pastures with clovers to supplement wintering beef cows nursing calves. *J. Anim. Sci. Biotechnol.* **2012**, *3*, 25. [CrossRef]
79. Hoveland, C.S.; Evers, G.W. Arrowleaf, crimson and other annual clovers. *Forages* **1995**, *1*, 249–260.
80. Beck, P.A.; Hubbell, D.S.; Watkins, K.B.; Gunter, S.A.; Daniels, L.B. Performance of stocker cattle grazing cool-season annual grass mixtures in northern Arkansas. *Prof. Anim. Sci.* **2005**, *21*, 465–473. [CrossRef]
81. Hill, G.M.; Utley, P.R.; McCormick, W.C. Evaluation of cow-calf systems using ryegrass sod-seeded in perennial pastures. *J. Anim. Sci.* **1985**, *61*, 1088–1094. [CrossRef]
82. Roberts, C.; Andrae, J. Public Education on Tall Fescue Toxicosis. Neotyphodium in Cool-Season Grasses. 2005. Available online: https://onlinelibrary.wiley.com/doi/10.1002/9780470384916.ch18 (accessed on 1 July 2021).
83. Nieman, C.C.; Albrecht, K.A.; Schaefer, D.M. Temporal composition of alfalfa–grass pastures and productivity response of Holstein steers. *Agron. J.* **2019**, *111*, 686–693. [CrossRef]
84. Minson, D.J. *Forage in Ruminant Nutrition*; Academic Press: San Diego, CA, USA, 1990.
85. Lusby, K.S.; McMurphy, W.E.; Strasia, C.A.; Smith, S.C.; Muntz, S.H. Effects of fescue endophyte and interseeded clovers on subsequent finishing performance of steers. *J. Prod. Agric.* **1990**, *3*, 103–105. [CrossRef]
86. McMurphy, W.E.; Lusby, K.S.; Smith, S.C.; Muntz, S.H.; Strasia, C.A. Steer performance on tall fescue pasture. *J. Prod. Agric.* **1990**, *3*, 100–102. [CrossRef]
87. Beck, P.A.; Haque, M.; Biermacher, J.T.; Hopkins, A.A.; Hubbell, D.S.; Hess, T. Impact of clover additions to toxic or nontoxic endophyte-infected tall fescue on animal performance and economics of stocker programs. *Prof. Anim. Sci.* **2012**, *28*, 433–442. [CrossRef]
88. Hoveland, C.S.; McCann, M.A.; Bouton, J.H. Influence of endophyte, alfalfa, and grazing pressure on steer performance and plant persistence of Jesup tall fescue. *J. Prod. Agric.* **1997**, *10*, 546–550. [CrossRef]
89. Melchior, E.A.; Myer, P.R. Fescue toxicosis and its influence on the rumen microbiome: Mitigation of production losses through clover isoflavones. *J. Appl. Anim. Res.* **2018**, *46*, 1280–1288. [CrossRef]
90. Rhodes, M.; Paterson, J.; Kerley, M.; Garner, H.; Laughlin, M. Reduced blood flow to peripheral and core body tissues in sheep and cattle induced by endophyte-infected tall fescue. *J. Anim. Sci.* **1991**, *69*, 2033–2043. [CrossRef]
91. Aiken, G.; Piper, E.; Miesner, C. Influence of protein supplementation and implant status on alleviating fescue toxicosis. *J. Anim. Sci.* **2001**, *79*, 827–832. [CrossRef]
92. Nevala, R.; Korpela, R.; Vapaatalo, H. Plant derived estrogens relax rat mesenteric artery in vitro. *Life Sci.* **1998**, *63*, 95–100. [CrossRef]
93. Simoncini, T.; Fornari, L.; Mannella, P.; Caruso, A.; Garibaldi, S.; Baldacci, C.; Genazzani, A.R. Activation of nitric oxide synthesis in human endothelial cells by red clover extracts. *Menopause* **2005**, *12*, 69–77. [CrossRef]

94. Jia, Y.; Harmon, D.L.; Flythe, M.D.; Klotz, J.L. Interaction of isoflavones and endophyte-infected tall fescue seed extract on vasoactivity of bovine mesenteric vasculature. *Front. Nutr.* **2015**, *2*, 1–10. [CrossRef]
95. Aiken, G.E.; Flythe, M.D.; Kagan, I.A.; Ji, H.; Bush, L.P. Mitigation of ergot vasoconstriction by clover isoflavones in goats (*Capra hircus*). *Front. Vet. Sci.* **2016**, *3*, 1–10. [CrossRef] [PubMed]
96. Zhang, G.; Yang, Z.; Dong, S. Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system. *Field Crop. Res.* **2011**, *124*, 66–73. [CrossRef]
97. Franco, J.G.; King, S.R.; Volder, A. Component crop physiology and water use efficiency in response to intercropping. *Eur. J. Agron.* **2018**, *93*, 27–39. [CrossRef]
98. Blanco-Canqui, H.; Ruis, S.J.; Proctor, C.A.; Creech, C.F.; Drewnoski, M.E.; Redfearn, D.D. Harvesting cover crops for biofuel and livestock production: Another ecosystem service? *Agron. J.* **2020**, *112*, 2373–2400. [CrossRef]
99. Kaspar, T.C.; Jaynes, D.B.; Parkin, T.B.; Moorman, T.B.; Singer, J.W. Effectiveness of oat and rye cover crops in reducing nitrate losses in drainage water. *Agric. Water Manage.* **2012**, *110*, 25–33. [CrossRef]
100. Kladivko, E.J.; Kaspar, T.C.; Jaynes, D.B.; Malone, R.W.; Singer, J.; Morin, X.K.; Searchinger, T. Cover crops in the upper midwestern United States: Potential adoption and reduction of nitrate leaching in the Mississippi River Basin. *J. Soil Water Conserv.* **2014**, *69*, 279–291. [CrossRef]
101. Blanco-Canqui, H. Cover crops and water quality. *Agron. J.* **2018**, *110*, 1633–1647. [CrossRef]
102. Peterson, A.T.; Berti, M.T.; Samarappuli, D. Intersowing cover crops into standing soybean in the US upper Midwest. *Agronomy* **2019**, *9*, 264. [CrossRef]
103. Morris, A.H.; Isbell, S.A.; Saha, D.; Kaye, J.P. Mitigating nitrogen pollution with under-sown legume-grass cover crop mixtures in winter cereals. *J. Environ. Qual.* **2020**, *50*, 324–335. [CrossRef] [PubMed]
104. Wall, G.J.; Pringle, E.A.; Sheard, R.W. Intercropping red clover with silage maize for soil erosion control. *Can. J. Soil Sci.* **1991**, *71*, 137–145. [CrossRef]
105. Mohammed, Y.A.; Patel, S.; Matthees, H.L.; Lenssen, A.W.; Johnson, B.L.; Wells, M.S.; Forcella, F.; Berti, M.T.; Gesch, R.W. Soil nitrogen in response to interseeded cover crops in maize-soybean production systems. *Agronomy* **2020**, *10*, 1439. [CrossRef]
106. Cecchin, A.; Pourhashem, G.; Gesch, R.W.; Lenssen, A.W.; Mohammed, Y.A.; Patel, S.; Berti, M.T. Environmental trade-offs of relay-cropping winter cover crops with soybean in a maize-soybean cropping system. *Agric. Syst.* **2021**, *189*, 103062. [CrossRef]
107. Schulz, V.S.; Schumann, C.; Weisenburger, S.; Müller-Lindenlauf, M.; Stolzenburg, K.; Möller, K. Row-intercropping maize (*Zea mays* L.) with biodiversity-enhancing flowering-partners-effect on plant growth, silage yield, and composition of harvest material. *Agriculture* **2020**, *10*, 524. [CrossRef]
108. Gadberry, M.S.; Hawley, J.; Beck, P.A.; Jennings, J.A.; Kegley, E.B.; Coffey, K.P.; Bill, E. Kunkle interdisciplinary beef symposium: A meta-analysis of research efforts aimed at reducing the impact of fescue toxicosis on cattle weight gain and feed intake. *J. Anim. Sci.* **2015**, *93*, 5496–5505. [CrossRef]
109. Gentile, R.M.; Martino, D.L.; Entz, M.H. Influence of perennial forages on subsoil organic carbon in a long-term rotation study in Uruguay. *Agric. Ecosyst. Environ.* **2005**, *105*, 419–423. [CrossRef]
110. Gamble, A.V.; Howe, J.A.; Balkcom, K.B.; Wood, C.W.; DiLorenzo, N.; Watts, D.B.; van Santen, E. Soil organic carbon storage and greenhouse gas emissions in a grazed perennial forage–crop rotation system. *Agrosyst. Geosci. Environ.* **2019**, *2*, 1–9. [CrossRef]
111. Liebig, M.A.; Hendrickson, J.R.; Franco, J.G.; Archer, D.W.; Nichols, K.; Tanaka, D.L. Near-surface soil property responses to forage production in a semiarid region. *Soil Sci. Soc. Am. J.* **2018**, *82*, 223–230. [CrossRef]
112. Ward, P.R.; Dunin, F.X.; Micin, S.F. Water use and root growth by annual and perennial pastures and subsequent crops in a phase rotation. *Agric. Water Manag.* **2002**, *53*, 83–97. [CrossRef]
113. Tan, I.Y.S.; Van Es, H.M.; Duxbury, J.M.; Melkonian, J.J.; Schindelbeck, R.R.; Geohring, L.D.; Hively, W.D.; Moebius, B.N. Single-event nitrous oxide losses under maize production as affected by soil type, tillage, rotation, and fertilization. *Soil Tillage Res.* **2009**, *102*, 19–26. [CrossRef]
114. Taylor, A.M.; Amiro, B.D.; Fraser, T.J. Net CO_2 exchange and carbon budgets of a three-year crop rotation following conversion of perennial lands to annual cropping in Manitoba, Canada. *Agric. For. Meteorol.* **2013**, *182*, 67–75. [CrossRef]
115. Tenuta, M.; Amiro, B.D.; Gao, X.; Wagner-Riddle, C.; Gervais, M. Agricultural management practices and environmental drivers of nitrous oxide emissions over a decade for an annual and an annual-perennial crop rotation. *Agric. For. Meteorol.* **2019**, *276*, 107636. [CrossRef]
116. Wortman, S.E.; Francis, C.A.; Lindquist, J.L. Cover crop mixtures for the western Corn Belt: Opportunities for increased productivity and stability. *Agron. J.* **2012**, *104*, 699–705. [CrossRef]
117. Ominski, P.D.; Entz, M.H.; Kenkel, N. Weed suppression by Medicago sativa in subsequent cereal crops: A comparative survey. *Weed Sci.* **1999**, *47*, 282–290. [CrossRef]
118. Meiss, H.; Médiène, S.; Waldhardt, R.; Caneill, J.; Bretagnolle, V.; Reboud, X.; Munier-Jolain, N. Perennial lucerne affects weed community trajectories in grain crop rotations. *Weed Res.* **2010**, *50*, 331–340. [CrossRef]
119. Dear, B.S.; Sandral, G.A.; Virgona, J.M.; Swan, A.D. Yield and grain protein of wheat following phased perennial grass, lucerne, and annual pastures. *Aust. J. Agric. Res.* **2004**, *55*, 775–785. [CrossRef]
120. Clemensen, A.K.; Grusak, M.A.; Duke, S.E.; Hendrickson, J.R.; Franco, J.G.; Archer, D.W.; Roemmich, J.N.; Liebig, M.A. Perennial forages influence mineral and protein concentrations in annual wheat cropping systems. *Crop. Sci.* **2021**, *61*, 2080–2089. [CrossRef]

121. Crews, T.E.; Rumsey, B.E. What agriculture can learn from native ecosystems in building soil organic matter: A review. *Sustainability* **2017**, *9*, 578. [CrossRef]
122. Kantola, I.B.; Masters, M.D.; DeLucia, E.H. Soil particulate organic matter increases under perennial bioenergy crop agriculture. *Soil Biol. Biochem.* **2017**, *113*, 184–191. [CrossRef]
123. Wood, S.A.; Tirfessa, D.; Baudron, F. Soil organic matter underlies crop nutritional quality and productivity in smallholder agriculture. *Agric. Ecosyst. Environ.* **2018**, *266*, 100–108. [CrossRef]
124. Grover, K.K.; Karsten, H.D.; Roth, G.W. Corn grain yields and yield stability in four long-term cropping systems. *Agron. J.* **2009**, *101*, 940–946. [CrossRef]
125. Nielsen, D.C.; Vigil, M.F. Wheat yield and yield stability of eight dryland crop rotations. *Agron. J.* **2018**, *110*, 594–601. [CrossRef]
126. Fuentes, R.; Taliaferro, C. *Biomass Yield Stability of Switchgrass Cultivars. Trends in New Crops and New Uses*; Janick, J., Whipkey, A., Eds.; ASHS Press: Alexandria, VA, USA, 2002; pp. 276–282. Available online: https://hort.purdue.edu/newcrop/ncnu02/v5-276.html (accessed on 15 September 2021).
127. Halling, M.A. Yield stability of *Festulolium* and perennial ryegrass in southern and central Sweden. *Grassl. Sci. Eur.* **2012**, *17*, 118–120.
128. Olmstead, J.; Brummer, E.C. Benefits and barriers to perennial forage crops in Iowa corn and soybean rotations. *Renew. Agric. Food Syst.* **2008**, *23*, 97–107. [CrossRef]
129. Martin, N.P.; Russelle, M.P.; Powell, J.M.; Sniffen, C.J.; Smith, S.I.; Tricarico, J.M.; Grant, R.J. Invited review: Sustainable forage and grain crop production for the US dairy industry. *J. Dairy Sci.* **2017**, *100*, 9479–9494. [CrossRef]
130. Hall, M.H.; Hebrock, N.S.; Pierson, P.E.; Caddel, J.L.; Owens, V.N.; Sulc, R.M.; Undersander, D.J.; Whitesides, R.E. The effects of glyphosate-tolerant technology on reduced alfalfa seeding rates. *Agron. J.* **2010**, *102*, 911–916. [CrossRef]
131. Stranger, T.F.; Lauer, J.G.; Chavas, J.-P. The profitability and risk of long-term cropping systems featuring different rotations and nitrogen rates. *Agron. J.* **2008**, *100*, 105–113.
132. Grabber, J.H. Prohexadione-calcium improves stand density and yield of alfalfa interseeded into silage corn. *Agron. J.* **2016**, *108*, 726–735. [CrossRef]
133. Osterholz, W.R.; Renz, M.J.; Lauer, J.G.; Grabber, J.H. Prohexadione-calcium rate and timing effects on alfalfa interseeded into silage corn. *Agron. J.* **2018**, *110*, 85–94. [CrossRef]
134. Osterholz, W.R.; Dias, J.L.C.S.; Grabber, J.H.; Renz, M.J. PRE- and POST-applied herbicide options for alfalfa interseeded with corn silage. *Weed Technol.* **2021**, *35*, 263–270. [CrossRef]
135. Grabber, J.H.; Smith, D.L.; Osterholz, W.R.; Renz, M. Establishment and first year yield of interseeded alfalfa as influenced by corn plant density and treatment with prohexadione, fungicide and insecticide. *Agronomy* **2021**, *11*, 2343. [CrossRef]
136. Grabber, J.H.; Osterholz, W.R.; Riday, H.; Cassida, K.A.; Williamson, J.A.; Renz, M. Differential survival of alfalfa varieties interseeded into corn silage. *Crop. Sci.* **2021**, *61*, 1797–1808. [CrossRef]
137. Berti, M.T.; Lukaschewsky, J.; Samarappuli, D.P. Intercropping alfalfa into silage maize can be more profitable than maize silage followed by spring-seeded alfalfa. *Agronomy* **2021**, *11*, 1196. [CrossRef]
138. Berti, M.T.; Cecchin, A.; Samarappuli, D.P.; Patel, S.; Lenssen, A.W.; Moore, K.J.; Wells, S.S.; Kazula, M.J. Alfalfa established successfully in intercropping with corn in the US Midwest. *Agronomy* **2021**, *11*, 1676. [CrossRef]
139. Osterholz, W.R.; Ruark, M.D.; Renz, M.; Grabber, J.H. Benefits of alfalfa interseeding include reduced residual soil nitrate pools following corn production. *Agric. Environ. Lett.* **2021**, *6*, e20053. [CrossRef]
140. Grabber, J.H.; Jokela, W.E.; Lauer, J.G. Soil nitrogen and forage yields of corn grown with clover or grass companion crops and manure. *Agron. J.* **2014**, *106*, 952–961. [CrossRef]
141. Osterholz, W.R.; Ruark, M.D.; Renz, M.J.; Grabber, J.H. Interseeding alfalfa into corn silage increases corn N fertilizer demand and increases system yield. *Agron. Sustain. Dev.* **2021**, *41*, 1–3. [CrossRef]
142. Duiker, S.W.; Hartwig, N.L. Living mulches of legumes in imidazolinone-resistant corn. *Agron. J.* **2004**, *96*, 1021–1028. [CrossRef]
143. Zemenchik, R.A.; Albrecht, K.A.; Boerboom, C.M.; Lauer, J.G. Maize production with kura clover as a living mulch. *Agron. J.* **2000**, *92*, 698–705. [CrossRef]
144. Martin, R.C.; Greyson, P.R.; Gordon, R. Competition between corn and a living mulch. *Can. J. Plant Sci.* **1999**, *79*, 579–586. [CrossRef]
145. Sanders, Z.P.; Andrews, J.S.; Saha, U.K.; Vencill, W.; Lee, R.D.; Hill, N.S. Optimizing Agronomic Practices for Clover Persistence and Corn Yield in a White Clover-Corn Living Mulch System. *Agron. J.* **2017**, *109*, 2025–2032. [CrossRef]
146. Flynn, E.S.; Moore, K.J.; Singer, J.W.; Lamkey, K.R. Evaluation of grass and legume species as perennial ground covers in corn production. *Crop. Sci.* **2013**, *53*, 611–620. [CrossRef]
147. Bartel, C.A.; Banik, C.; Lenssen, A.W.; Moore, K.J.; Laird, D.A.; Archontoulis, S.V.; Lamkey, K.R. Establishment of perennial groundcovers for maize-based bioenergy production systems. *Agron. J.* **2017**, *109*, 822–835. [CrossRef]
148. Schlautman, B.; Bartel, C.; Diaz-Garcia, L.; Fei, S.; Flynn, S.; Haramoto, E.; Moore, K.J.; Raman, D.R. Perennial groundcovers: An emerging technology for soil conservation and the sustainable intensification of agriculture. *Emerg. Top. Life Sci.* **2021**, *5*, 337–347. [CrossRef]
149. Dobbratz, M.; Baker, J.M.; Grossman, J.; Wells, M.S.; Ginakes, P. Rotary zone tillage improves corn establishment in a kura clover living mulch. *Soil Tillage Res.* **2019**, *189*, 229–235. [CrossRef]

150. Alexander, J.R.; Baker, J.M.; Venterea, R.T.; Coulter, J.A. Kura clover living mulch reduces fertilizer N requirements and increases profitability of maize. *Agronomy* **2019**, *9*, 432. [CrossRef]
151. Andrews, J.S.; Sanders, Z.P.; Cabrera, M.L.; Saha, U.K.; Hill, N.S. Nitrogen dynamics in living mulch and annual cover crop corn production systems. *Agron. J.* **2018**, *110*, 1309–1317. [CrossRef]
152. Ziyomo, C.; Albrecht, K.A.; Baker, J.M.; Bernardo, R. Corn performance under managed drought stress and in a kura clover living mulch intercropping system. *Agron J.* **2013**, *105*, 579–586. [CrossRef]
153. Carter, P.R.; Sheaffer, C.C. Alfalfa response to soil water deficits. Growth, forage quality, yield, water use, and water-use efficiency. *Crop. Sci.* **1983**, *23*, 669–675. [CrossRef]
154. Sulc, R.M.; Tracy, B.F. Integrated crop-livestock systems in the US Maize Belt. *Agron. J.* **2007**, *99*, 335–345. [CrossRef]
155. Power, A.G. Ecosystem Services and Agriculture: Tradeoffs and Synergies. 2010. Available online: http://rstb.royalsocietypublishing.org/content/365/1554/2959.short (accessed on 14 September 2021).
156. Dell, C.J.; Gollany, H.T.; Adler, P.R.; Skinner, R.H.; Polumsky, R.W. Implications of observed and simulated soil carbon sequestration for management options in maize-based rotations. *J. Environ. Qual.* **2018**, *47*, 617–624. [CrossRef] [PubMed]
157. Osterholz, W.R.; Renz, M.J.; Jokela, W.E.; Grabber, J.H. Interseeded alfalfa reduces soil and nutrient runoff losses during and after corn silage production. *J. Soil Water Conser.* **2019**, *74*, 85–90. [CrossRef]
158. Niu, Y.; Luo, Z.; Cai, L.; Coulter, J.A.; Zhang, Y.; Berti, M. Continuous monoculture of alfalfa and annual crops influence soil organic matter and microbial communities in the rainfed loess plateau of China. *Agronomy* **2020**, *10*, 1054. [CrossRef]
159. Wu, S.; Wu, P.; Feng, H.; Merkley, G.P. Effects of alfalfa coverage on runoff, erosion and hydraulic characteristics of overland flow on loess slope plots. *Front. Environ. Sci. Eng. China* **2011**, *5*, 76–83. [CrossRef]
160. Siller, A.R.; Albrecht, K.A.; Jokela, W.E. Soil erosion and nutrient runoff in corn silage production with kura clover living mulch and winter rye. *Agron. J.* **2016**, *108*, 989–999. [CrossRef]
161. Grabber, J.H.; Jokela, W.E. Off-season groundcover and runoff characteristics of perennial clover and annual grass companion crops for no-till corn fertilized with manure. *J. Soil Water Conserv.* **2013**, *68*, 411–418. [CrossRef]
162. Kleinman, P.J.A.; Salon, P.; Sharpley, A.N.; Saporito, L.S. Effect of cover crops established at time of corn planting on phosphorus runoff from soils before and after dairy manure application. *J. Soil Water Conserv.* **2005**, *60*, 311–322.
163. Ochsner, T.E.; Albrecht, K.A.; Schumacher, T.W.; Baker, J.M.; Berkevich, R.J. Water balance and nitrate leaching under corn in kura clover living mulch. *Agron. J.* **2010**, *102*, 1169–1178. [CrossRef]
164. Osterholz, W.R.; Renz, M.J.; Grabber, J.H. Alfalfa establishment by interseeding with silage corn projected to increase profitability of corn silage-alfalfa rotations. *Agron. J.* **2020**, *112*, 4120–4132. [CrossRef]
165. Entz, M.; Baron, V.; Carr, P.M.; Meyer, D.W.; Smith, S.R.; McCaughey, W.P. Potential of forages to diversify cropping systems in the Northern Great Plains. *Agron. J.* **2002**, *94*, 240–250. [CrossRef]
166. Hendrickson, J.R.; Tanaka, D.L.; Liebig, M.A. Tillage and grazing impact on annual crop yields following conversion from perennial grass to annual crops. *Crop. Manag.* **2014**, *13*, 1–7. [CrossRef]
167. Schmer, M.R.; Hendrickson, J.R.; Liebig, M.A.; Johnson, H.A. Perennial plant establishment and productivity can be influenced by previous annual crops. *Agron. J.* **2017**, *109*, 1423–1432. [CrossRef]
168. Zimbric, J.W.; Stoltenberg, D.E.; Picasso, V.D. Effective weed suppression in dual-use intermediate wheatgrass systems. *Agron. J.* **2020**, *112*, 2164–2175. [CrossRef]
169. Glover, J.D.; Culman, S.W.; DuPont, S.T.; Broussard, W.; Young, L.; Mangan, M.E.; Mia, J.G.; Crews, T.E.; DeHaan, L.R.; Buckley, D.H.; et al. Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability. *Agric. Ecosyst. Environ.* **2010**, *137*, 3–12. [CrossRef]
170. Culman, S.W.; Snapp, S.; Ollenburger, M.; Basso, B. Soil and water quality rapidly responds to the perennial grain Kernza wheatgrass. *Agron J.* **2013**, *105*, 735–744. [CrossRef]
171. 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.* **2019**, *272*, 63–73. [CrossRef]
172. Culman, S.W.; DuPont, S.T.; Glover, J.D.; Buckley, D.H.; Fick, G.W.; Ferris, H.; Crews, T.E. Long-term impacts of high-input annual cropping and unfertilized perennial grass production on soil properties and belowground food webs in Kansas, USA. *Agric. Ecosyst. Environ.* **2010**, *137*, 13–24. [CrossRef]
173. Crews, T.E.; Carton, W.; Olsson, L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Glob. Sustain.* **2018**, *1*, e9. [CrossRef]
174. De Oliveira, G.; Brunsell, N.A.; Crews, T.E.; DeHaan, L.R.; Vico, G. Carbon and water relations in perennial Kernza (*Thinopyrum intermedium*): An overview. *Plant Sci.* **2020**, *295*, 110279. [CrossRef] [PubMed]
175. Lanker, M.; Bell, M.; Picasso, V.D. Farmer perspectives and experiences introducing the novel perennial grain Kernza intermediate wheatgrass in the US Midwest. *Renew. Agric. Food Syst.* **2019**, *35*, 653–662. [CrossRef]
176. Wayman, S.; Debray, V.; Parry, S.; David, C.; Ryan, M.R. Perspectives on perennial grain crop production among organic and conventional farmers in France and the United States. *Agriculture* **2019**, *9*, 244. [CrossRef]
177. Marti, A.; Bock, J.E.; Pagani, M.A.; Ismail, B.; Seetharaman, K. Structural characterization of proteins in wheat flour doughs enriched with intermediate wheatgrass (*Thinopyrum intermedium*) flour. *Food Chem.* **2016**, *194*, 994–1002. [CrossRef] [PubMed]
178. DeHaan, L.R.; Ismail, B.P. Perennial cereals provide ecosystem benefits. *Cereal Foods World* **2017**, *62*, 278–281. [CrossRef]

179. Lazaroiu, G.; Andronie, M.; Uta, C.; Hurloiu, I. Trust management in organic agriculture: Sustainable consumption behavior, environmentally conscious purchase intention, and healthy food choices. *Front. Public Health* **2019**, *7*, 340. [CrossRef]
180. Fernandez, C.W.; Ehlke, N.; Sheaffer, C.C.; Jungers, J.M. Effects of nitrogen fertilization and planting density on intermediate wheatgrass yield. *Agron. J.* **2020**, *112*, 4159–4170. [CrossRef]
181. Sakiroglu, M.; Picasso, V.; Dong, C.; Hall, M.B.; Jungers, J.M. How does nitrogen and forage harvest affect belowground biomass and nonstructural carbohydrates in dual-use Kernza intermediate wheatgrass? *Crop Sci.* **2020**, *60*, 2562–2573. [CrossRef]
182. Hunter, M.C.; Sheaffer, C.C.; Culman, S.W.; Jungers, J.M. Effects of defoliation and row spacing on intermediate wheatgrass I: Grain production. *Agron. J.* **2020**, *112*, 1748–1763. [CrossRef]
183. Pinto, P.; De Haan, L.; Picasso, V. Post-harvest management practices impact on light penetration and kernza intermediate wheatgrass yield components. *Agronomy* **2021**, *11*, 442. [CrossRef]
184. Law, E.P.; Pelzer, C.J.; Wayman, S.; DiTommaso, A.; Ryan, M.R. Strip-tillage renovation of intermediate wheatgrass (*Thinopyrum intermedium*) for maintaining grain yield in mature stands. *Renew Agric. Food Syst.* **2020**, *36*, 321–327. [CrossRef]
185. Favre, J.R.; Munoz, T.; Combs, D.K.; Wattiaux, M.A.; Picasso, V.D. Forage nutritive value and predicted fiber digestibility of Kernza intermediate wheatgrass in monoculture and in mixture with red clover during the first production year. *Anim. Feed. Sci. Technol.* **2019**, *258*, 114298. [CrossRef]
186. Mazzenga, A.; Gianesella, M.; Brscic, M.; Cozzi, G. Feeding behavior, diet digestibility, rumen fluid and metabolic parameters of beef cattle fed total mixed rations with a stepped substitution of wheat straw with maize silage. *Livest. Sci.* **2009**, *122*, 16–23. [CrossRef]
187. Hunter, M.C.; Sheaffer, C.C.; Culman, S.W.; Lazarus, W.F.; Jungers, J.M. Effects of defoliation and row spacing on intermediate wheatgrass II: Forage yield and economics. *Agron. J.* **2020**, *112*, 1862–1880. [CrossRef]
188. Pugliese, J.Y. Above- and Belowground Response to Managing Kernza (*Thinopyrum intermedium*) as a Dual-Use Crop for Forage and Grain. 2017. Available online: https://etd.ohiolink.edu/apexprod/rws_olink/r/1501/10?clear=10&p10_accession_num=osu1494000853982965 (accessed on 1 July 2021).
189. Bell, L.W.; Byrne, F.; Ewing, M.A.; Wade, L.J. A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system. *Agric. Syst.* **2008**, *96*, 166–174. [CrossRef]
190. Tautges, N.E.; Jungers, J.M.; Dehaan, L.R.; Wyse, D.L.; Sheaffer, C.C. Maintaining grain yields of the perennial cereal intermediate wheatgrass in monoculture v. bi-culture with alfalfa in the Upper Midwestern USA. *J. Agric. Sci.* **2018**, *156*, 758–773. [CrossRef]
191. Zimbric, J.W.; Stoltenberg, D.E.; Picasso, V.D. Strategies to reduce plant height in dual-use intermediate wheatgrass cropping systems. *Agron. J.* **2020**, *113*, 1563–1573. [CrossRef]
192. Weaver, J.E.; Stoddart, L.A. Response of the prairie to the great drought of 1934. *Ecology* **1935**, *16*, 612–629. [CrossRef]
193. Leopold, A. *A Sand County Almanac*; Oxford University Press: Oxford, UK, 1968; ISBN 01950077785-62-311-7.
194. Peni, D.; Stolarski, M.J.; Bordiean, A.; Krzyżaniak, M.; Devowski, M. *Silphium perfoliatum*—A herbaceous crop with increased interest in recent years for multi-purpose use. *Agriculture* **2020**, *10*, 640. [CrossRef]
195. Pichard, G. Manejo, producción, y características nutricionales del silfo (*Silphium perfoliatum*) en climas templados del sur de Chile. *Cien. Inv. Agric.* **2012**, *39*, 61–77. [CrossRef]
196. Vilela, A.E.; González-Paleo, L.; Ravetta, D.A.; Murrell, E.G.; van Tassel, D.L. Balancing forage production, seed yield, and pest management in the perennial sunflower *Silphium integrifolium* (Asteraceae). *Agronomy* **2020**, *10*, 1471. [CrossRef]
197. Cumplido-Marin, L.; Graves, A.R.; Burgess, P.J.; Morhart, C.; Paris, P.; Jablonowsk, N.D.; Facciotto, G.; Bury, M.; Martens, R.; Nahm, M. Two novel energy crops: *Sida hermaphrodita* (L.) Rusby and *Silphium perfoliatum* L.-state of knowledge. *Agronomy* **2020**, *10*, 928. [CrossRef]
198. Von Cossel, M.; Amarysti, C.; Wilhelm, H.; Priya, N.; Winkler, B.; Hoerner, L. The replacement of maize (*Zea mays* L.) by cup plant (*Silphium perfoliatum* L.) as biogas substrate and its implications for the energy and material flows of a large biogas plant. *Biofuels Bioprod. Biorefin.* **2020**, *14*, 152–179. [CrossRef]
199. Wever, C.; Höller, M.; Becker, L.; Biertümpfel, A.; Köhler, J.; van Inghelandt, D.; Westhoff, P.; Pude, R.; Pestsova, E. Towards high-biomass yielding bioenergy crop *Silphium perfoliatum* L.: Phenotypic and genotypic evaluation of five cultivated populations. *Biomass Bioenergy* **2019**, *124*, 102–113. [CrossRef]
200. Grunwald, D.; Panten, K.; Schwarz, A.; Bischoff, W.A.; Schittenhelm, S. Comparison of maize, permanent cup plant and a perennial grass mixture with regard to soil and water protection. *GCB Bioenergy* **2020**, *12*, 694–705. [CrossRef]
201. Emmerling, C.; Ruf, T.; Audu, V.; Werner, W.; Udelhoven, T. Earthworm communities are supported by perennial bioenergy cropping systems. *Eur. J. Soil Biol.* **2021**, *105*, 103331. [CrossRef]
202. Schorpp, Q.; Schrader, S. Earthworm functional groups respond to the perennial energy cropping system of the cup plant (*Silphium perfoliatum* L.). *Biomass Bioenergy* **2016**, *87*, 61–68. [CrossRef]
203. Mueller, A.L.; Biertümpfel, A.; Friedritz, L.; Power, E.F.; Wright, G.A.; Dauber, J. Floral resources provided by the new energy crop, *Silphium perfoliatum* L. (Asteraceae). *J. Apic. Res.* **2019**, *59*, 232–245. [CrossRef]
204. Teleuţă, A.; Coşman, S.; Ababii, V. Introduction of *Silphium perfoliatum* L. and its utilization possibilities. In *Conservation of Plant Diversity*; Gradina Botanica (Institut): Chișinău, Moldova, 2012; Volume 2, pp. 262–268. ISBN 978-997.
205. Vilela, A.; González-Paleo, L.; Turner, K.; Peterson, K.; Ravetta, D.; Crews, T.E.; Van Tassel, D. Progress and bottlenecks in the early domestication of the perennial oilseed *Silphium integrifolium*, a sunflower substitute. *Sustainability* **2018**, *10*, 638. [CrossRef]

206. Van Tassel, D.L.; Albrecht, K.A.; Bever, J.D.; Boe, A.A.; Brandvain, Y.; Crews, T.E.; Gansberger, M.; Gerstberger, P.; Gonzalez-Paleo, L.; Hulke, B.S.; et al. Accelerating *Silphium* domestication: An opportunity to develop new crop ideotypes and breeding strategies informed by multiple disciplines. *Crop Sci.* **2017**, *57*, 1274–1284. [CrossRef]
207. Raduski, A.R.; Herman, A.; Pogoda, C.; Dorn, K.M.; Van Tassel, D.L.; Kane, N.; Brandvain, Y. Patterns of genetic variation in a prairie wildflower, *Silphium integrifolium*, suggest a non-prairie origin and locally adaptive variation. *Am. J. Bot.* **2021**, *108*, 145–158. [CrossRef]
208. Reinert, S.; Price, J.H.; Smart, B.C.; Pogoda, C.S.; Kane, N.C.; Van Tassel, D.L.; Hulke, B.S. Mating compatibility and fertility studies in an herbaceous perennial Aster undergoing de novo domestication to enhance agroecosystems. *Agron. Sustain. Dev.* **2020**, *40*, 27. [CrossRef]
209. Reinert, S.; Money, K.L.; Rockstad, G.B.G.; Kane, N.C.; Van Tassel, D.L.; Hulke, B.S. Two contrasting laboratory methods improve *Silphium integrifolum* Michx. Germination rate to agronomically acceptable levels. *Euphytica* **2018**, *214*, 156. [CrossRef]
210. Von Gehren, P.; Gansberger, M.; Mayr, M.; Liebhard, P. The effect of sowing date and seed pretreatments on establishment of the energy plant Silphium perfolatium by sowing. *Seed Sci. Technol.* **2016**, *44*, 310–319. [CrossRef]
211. Schiffner, S.; Jungers, J.M.; Van Tassel, D.; Smith, K.P.; Sheaffer, C.C. Seeding date affects seed and biomass yield of *Silphium integrifolium* Michx. (silflower). *Nativ. Plants J.* **2021**, *22*, 30–44. [CrossRef]
212. Barbosa, C.H.; Andrade, M.A.; Vilarinho, F.; Castanheira, I.; Fernando, A.L.; Loizzo, M.R.; Silva, A.S. A new insight on cardoon: Exploring new uses besides cheese making with a view to zero waste. *Foods* **2020**, *9*, 564. [CrossRef]
213. Savard, M.; Nesbitt, M.; Gale, R. Archaeobotanical evidence for early Neolithic diet and subsistence at M'lefaat (Iraq). *Paléorient* **2003**, *29*, 93–106. [CrossRef]
214. Hind, N. 763. *Gundelia tournefortii*. *Curtis's Bot. Mag.* **2013**, *30*, 114–138. [CrossRef]
215. Yazdanshen, H.; Tavili, A.; Arzani, H.; Azarnivand, H. Traditional *Gundelia tournefortii* usage and its habitat destruction in Tiran va Karvan district in Iran's Isfahan province. *Ecologia* **2016**, *6*, 19–25. [CrossRef]
216. Khojasted, F.; Chahouki, M.A.Z. Spatial patterns and coexistence of the native forb, *Psathyrostachys fragilis* (Asteracea) and the native invader, *Gundelia tournefortii* (Poaceae) in a semi-arid rangeland of Iran. *Pol. J. Ecol.* **2013**, *61*, 373–377.
217. Karabulut, A.; Ozgur Ozcan, C.; Kamalak, A.; Canbolat, O. Comparison of the nutritive value of a turkey native forage, tumbleweed hay (*Gundelia tournefortii* L.), wheat straw and alfalfa hay using in situ and in vitro measurements with sheep. *Arch. Latinoam. Prod. Anim.* **2006**, *14*, 78–83.
218. Dehghani-Samani, A.; Madreseh-Ghahfarokhi, S.; Dehghani-Samani, A. Evaluation of performance rate, some hematological and biochemical parameters in Iranian Afshari breed fattened sheep fed diet containing gundelia (*Gundelia tournefortii* L.). *Iraqi J. Vet. Sci.* **2019**, *33*, 33–38. [CrossRef]
219. Van Tassel, D.L.; Tesdell, O.; Schlautman, B.; Rubin, M.J.; DeHaan, L.R.; Crews, T.E.; Streit Krug, A. New food crop domestication in the age of gene editing: Genetic, agronomic and cultural change remain co-evolutionarily entangled. *Front. Plant Sci.* **2020**, *11*, 789. [CrossRef]
220. Khanzadeh, F.; Khodaparast, M.H.H.; Elhami Rad, A.H.; Rahmani, F.R. Physiochemical properties of *Gundelia tournefortii* L. seed oil. *J. Agric. Sci. Technol.* **2012**, *14*, 1535–1542.
221. Sanderson, M.A.; Adler, P.R. Perennial forages as second generation bioenergy crops. *Int. J. Mol. Sci.* **2008**, *9*, 768–788. [CrossRef]
222. Mortenson, J.S.; Waldron, B.L.; Larson, S.R.; Jensen, K.B.; DeHaan, L.R.; Peel, M.D.; Peel, M.D.; Creech, J.E. Quantitative trait loci (QTL) for forage traits in intermediate wheatgrass when grown as spaced-plants versus monoculture and polyculture swards. *Agronomy* **2019**, *9*, 580. [CrossRef]