Legume Cover Crops as One of the Elements of Strategic Weed Management and Soil Quality Improvement. A Review

Anna Kocira [1,*] **, Mariola Staniak** [2] **, Marzena Tomaszewska** [1] **, Rafał Kornas** [1] **,
Jacek Cymerman** [1] **, Katarzyna Panasiewicz** [3] **and Halina Lipińska** [4]

[1] Institute of Agricultural Sciences, State School of Higher Education in Chełm, Pocztowa 54,
    22-100 Chełm, Poland; mtomaszewska@pwsz.chelm.pl (M.T.); rkornas@pwsz.chelm.pl (R.K.);
    jcymerman@pwsz.chelm.pl (J.C.)
[2] Department of Forage Crop Production, Institute of Soil Science and Plant Cultivation—State Research Institute,
    Czartoryskich 8, 24-100 Puławy, Poland; mstaniak@iung.pulawy.pl
[3] Agronomy Department, Poznań University of Life Sciences, Dojazd 11, 60-632 Poznań, Poland;
    katarzyna.panasiewicz@up.poznan.pl
[4] Department of Grassland and Landscape Forming, University of Life Sciences in Lublin, Akademicka 13,
    20-950 Lublin, Poland; halina.lipinska@up.lublin.pl
* Correspondence: akocira@pwsz.chelm.pl; Tel.: +48-82-565-8895

check for updates

Abstract: The benefits of conservation practices increased the interest of farmers in the cultivation of cover crops (CCs). This review aims to present and analyze the state of the art on the cultivation of legume CCs, including their importance in protecting crops against weeds, as well as their effects on organic matter and nitrogen content in the soil, physical and biological properties of the soil, and its erosion. The multi-purpose character of legume CCs is visible in their positive effect on reducing weed infestation, but also on the soil: reducing its compaction and erosion, improving its structural and hydraulic properties, increasing the content of organic matter and activity of soil microorganisms, or increasing its nitrogen content due to symbiotic N_2 fixing. This review demonstrates that a wider use of legume CCs in organic farming is needed. The benefits of legume CCs for successive crops in these cultivation conditions, both in terms of inhibiting weed populations and improving fertility and soil properties, also need to be identified. Further research is also needed to determine the potential impact of legume CCs on the improvement of the quality of degraded soils, or those with less favorable physicochemical properties.

Keywords: legume cover crop; weed control; organic matter; nitrogen; soil physical and biological properties; soil erosion

1. Introduction

Currently, more and more attention is paid to production systems based on managing natural resources in such a way as to ensure that the needs of contemporary and future generations are met. This trend fits well with conservation agriculture, which aims to protect, improve and more efficiently use natural resources through the integrated management of soil, water, and biological resources, in combination with external inputs. This approach contributes to environmental protection, but also improves agricultural production and maintains it at a high level [1].

All the benefits of conservation practices increased farmers' interest in the cultivation of cover crops (CCs) [2]. CCs are defined as non-cash crops that can be grown before or together with the main crops to keep the soil covered with vegetation for as long as possible—even all year round [3]. CCs have

a positive effect on agroecosystems by reducing soil erosion and nitrate leaching, increasing water infiltration and maintaining soil moisture. They also suppress weeds and reduce the occurrence of pests, nematodes and various soil pathogens, and improve soil quality, e.g., by increasing the content of organic matter and the availability of nutrients [4–13]. Species used as CCs plants should produce a lot of biomass, which is important for uniform coverage of the soil surface. Moreover, their C:N ratio should be balanced, and they should be resistant to rapid decomposition, thus protecting the soil, even from the early stages of growth and development of the main crop [14,15]. The soil exposure promotes weed infestation, increases susceptibility to erosion, while high C:N can extract nitrogen from the system, reducing its availability to successive plants [16]. Cover crops can be introduced into plant production systems by: (i) cultivation during the off-season and destruction before main crop cultivation—a common practice in annual growing systems; (ii) cultivation with the main crop for a part, or all of its growing season as living mulch—a common practice in perennial growing systems [17].

The CCs that are most commonly used in farming belong to families *Fabaceae*, *Brassicaceae*, and *Poaceae*. Due to the varied growth rate, the amount of biomass produced, the uniformity of the soil cover and the C:N ratio, they play a different role in the main crop. Numerous studies confirm that legume CCs improve soil quality and thus provide more favorable conditions for the growth, development and yielding of main crops, while playing a significant role in reducing weed infestation [12,18–25]. In addition to ecosystem services, legumes are also a rich source of protein in human and animal nutrition. However, the use of these plants without prior thermal treatment may be limited by the presence of anti-nutritional and toxic factors such as proteolytic inhibitors, phytohemagglutinins, lathyrogens, cyanogenetic compounds, compounds causing favism, and factors affecting digestibility and saponins [26].

This review aims to present and analyze the state of the art on the cultivation of legume Ccs, including their importance in protecting crops against weeds, their effect on organic matter and nitrogen content in the soil, as well as physical and biological properties of the soil, and its erosion.

2. Effect of Legume CCs on Weed Control

CCs are an essential tool in the integrated management of weeds, including those resistant to herbicides. They provide a competitive advantage, contributing to the good condition of the soil and inhibiting weed infestation [17,27–29]. Oerke [30] reports that weeds are one of the most important factors contributing to the reduction of the yield, by up to 34%. The estimated yield loss caused by weeds is up to two times higher than the loss caused by other pests (insects, pathogens), which amount to approximately 8% to 10% [27]. The large difference between the potential and actual estimates of crop loss due to weeds indicates that current weed control is relatively effective [31].

The weed management system is based on information on interactions between plants, including the competitive ability of the main crops on various stages of their development to inhibit weed growth and expansion [32]. CCs introduced into the cultivation of the main plant contribute to the reduction of weed infestation by preventing seed germination and emergence of weed seedlings. Thus, they limit the growth and development of weeds and reduce the number of seeds in the weed seed bank in the soil (by increasing seed predation, limiting seed recruitment) [33,34].

Appropriate selection of crop species, and even varieties, often has a decisive impact on the level of weed infestation control [35,36]. Characteristic features such as growth rates [37], rapid germination, early above-ground growth and vigor [38], shading ability [37], crop height, tillering capacity [38,39], rapid leaf area and canopy establishment, large leaf area development and duration [38,40], long stem, high biomass upright growth [15,41,42], which are also related to early light interception [43] and allelopathy [40,44,45] affect the interactions between the main crop and the weeds. These features are leveraged by CCs to reduce weed infestation in the main crops. The effectiveness of CCs in this area often depends on the CC species, the composition of weed population, the area covered, persistence of crop residues, physical impedance, reduction in light transmittance to the soil, and decreased

daily soil temperature fluctuations [7,19,46–50] as well as management practices, e.g., cutting or mulching [20,51,52]. However, the effectiveness of weed control by legume CCs depends both on their morphological, phenological and physiological characteristics [19,35,41] (Table 1), as well as on the growing conditions [53,54].

Table 1. Effect of different species of legume CCs on the reduction of weed infestation.

Cover Crops	Crop	Dominant Weed Species	Weed Control	References
Medicago lupulina L.	*Triticum aestivum* L.	-	reduced weed DM (50%)	[55]
M. lupulina L.; *Medicago sativa* L.; *Trifolium pratense* L.; *Trifolium repens* L.	*T. aestivum* L.	-	reduced weed density (40%−57%); reduced aerial DM of *M. lupulina* (about 35 kg DM ha^{-1}) and *M. sativa* (about 16 kg DM ha^{-1})	[13]
M. sativa L.; *T. pratense* L.	*T. aestivum* L. × *Triticosecale* Wittmack	-	reduced weed DM (68%—*M. sativa*; 38%—*T. pratense*); reduced of weed density (65%)	[54]
M. sativa L.; *Lupinus albus* L.	*T. aestivum* L. × *Secale cereale* L.	*Chenopodium album* L., *Poa annua* L., *Stellaria media* (L.) Vill.	reduced weed biomass (54%—*M. sativa*; 42%—*L. albus*)	[43]
M. sativa L.; *T. pratense* L.; *Pisum sativum* L.	*T. aestivum* L.	*Descurainia sophia* (L.) Webb. ex Prantl; *Sonchus oleraceus* L.; *Kochia scoparia* (L.) Schrad.	reduced weed DM (45%—*M. sativa*; 63%—*P. sativum*); increased of weed DM (11%—*T. pratense*)	[53]
Medicago polymorpha L.; *Medicago truncatula* Gaertn.; *Trifolium alexandrinum* L.; *T. pratense* L.	*T. aestivum* L. and *Zea mays* L. rotation system	*Capsella bursa- pastoris* (L.) Medik.; *S. media* (L.) Vill.; *Thlaspi arvense* L.; *T. aestivum* L. (volunteer wheat)	reduced density (41–78%) and dry weight (26%–80%) of winter annual weeds; reduced dry weights of summer annual (70%–*Medicago* spp.) and perenial weeds (35%–75% *Medicago* spp., *T. alexandrinum*)	[56]
M. lupulina L. (United Kingdom); *T. repens* L. (Norway, Germany, Sweden); *Trifolium subterraneum* L. (Germany, Switzerland); mixture of *T. repens* and *Lolium perenne* L. (Sweden); mixture of *M. lupulina*, *Sinapis alba* L., *Brassica napus* L. and *Raphanus sativus* L. (United Kingdom)	*T. aestivum* L. (first year); *Hordeum vulgare* L. in United Kingdom and Norway, and *Z. mays* L. at the other sites (second year)	*S. media* (L.) Vill.; *C. album* L.; *Rumex* spp.; *Tripleurospermum inodorum* (L.) Sch.Bip.; *Elymus repens* (L.) Gould	reduced weed cover throughout the intercrop period (55% to 1% depending on site); no reduced weed biomass or density	[57]
M. lupulina L.; *T. pratense* L.; *T. repens* L.; *T. incarnatum* L.; *Trifolium resupinatum* L.; *M. alba* Medik.; *V. sativa* L.; mixture of *M. lupulina* L. and *L. multiflorum* Lam.	*H. vulgare* L.; *T. aestivum* L.	*Galeopsis* L. spp.; *Myosotis arvensis* (L.) Hill; *S. media* (L.) Vill.; *Viola arvensis* Murr.; *Taraxacum officinale* Weber in Wiggers; *T. inodorum* (L.) Sch.Bip.; *Cirsium arvense* (L.) Scop.); *P. annua* L.	reduced weed density and biomass in *T. aestivum* above 50% (in *H. vulgare*—no effect)	[58]
Medicago scutellata Mill.; *Vicia villosa* Roth.; *T. subterraneum* L.	*Solanum tuberosum* L.	*Lolium temulentum* L.; *S. media* (L.) Vill.	reduced weed biomass (22%–57%)	[59]

Table 1. *Cont.*

Cover Crops	Crop	Dominant Weed Species	Weed Control	References
M. lupulina L.; mixture of *M. lupulina* L. + *Lolium multiflorum* Lam. var. *westerwoldicum* Mansh.	*Beta vulgaris* L.	*Agropyron repens* (L.) P. Beauv.; *C. album* L.; *Echinochloa crus-galli* (L.) Beauv.; *Galium aparine* L.; *V. arvensis* Murr.; *Amaranthus retroflexus* L.; *Solanum nigrum* L.; *S. media* (L.) Vill.	reduced weed number (25%–38%—*M. lupulina*; 44%–55%—mixture of CCs) and air-dry weight of weeds (21%–44%—*M. lupulina*; 45%–51%—mixture of CCs)	[60]
M. lupulina L.; *V. villosa* Roth.; *T. subterraneum* L.; *T. pratense* L.; *T. repens* L.; *Trifolium incarnatum* L.	-	*Chamomilla suaveolens* (Pursh) Rydb.; *Matricaria perforata* Merat; *P. annua* L.	reduced weed dry weight (*V. villosa* reduced 95% compared to *T. repens*)	[61]
monoculture or mixture of *Trifolium hybridum* L., *Lotus corniculatus* L., *M. lupulina* L., *T. incarnatum* L.; *Lolium multiflorum* Lam.; *Lotus pedunculatus* Cav.; *M. sativa* L., *Festuca pratensis* Huds.; *Lathyrus pratensis* L.; *L. perenne* L.; *T. pratense* L.; *Onobrychis viciifolia* Scop.; *Phleum pratense* L.; *T. repens* L.; *Melilotus alba* Medik.; *V. sativa* L.	-	*S. media* (L.) Vill.; *Sonchus arvensis* L.; *Veronica persica* Poiret; *Persicaria maculosa* L.; *Ranunculus repens* L.; *V. arvensis* Murray	reduced weed aboveground biomass (44%–92%—legumes, 72%–90%—*T. pratense*)	[62]
monoculture or mixture of *Trifolium hybridum* L. (AC) and *M. lupulina* L. (BM); AC:BM ratios (100:0, 67:33, 50:50, 33:67, 0:100)	-	-	reduced weed aboveground biomass (39%–96%, depending on the harvest date)	[20]
T. pratense L.	*T. aestivum* L. × *Triticosecale* Wittmack	-	reduced weed density (38%)	[63]
T. pratense L.	*T. aestivum* L.	*Ambrosia artemisiifolia* L.	reduced weed biomass (28%–43%)	[64]
T. pratense L.; *T. repens* L.; mixture of *T. pratense* L. and *Phleum pratense* L.; mixture of *T. pratense* L. and *Lolium* L.	*T. aestivum* L.; *Avena sativa* L.	*Spergula arvensis* L.; *S. media* (L.) Vill.; *V. arvensis* Murray; *C. album* L.; *Erodium cicutarium* (L.) L'Herit; *C. arvense* (L.) Scop.	reduced weed biomass (74%)—mixture of *T. pratense* and *Lolium*; increased seed bank and density of emerged weed (4.5 and 10 times in cloves)	[65]
T. incarnatum L.; *T. subterraneum* L.	*Z. mays* L.	*S. nigrum* L.; *C. album* L.; *A. retroflexus* L.; *Ammi majus* L.; *Cynodon dactylon* (L.) Pers.; *Geranium dissectum* L.; *Polygonum aviculare* L.; *V. persica* Poiret; *Xanthium strumarium* L.; *E. crus-galli* (L.) Beauv.	reduced weed biomass (22%–46%—*T. incarnatum*; 21%–67%—*T. subterraneum*)	[7]
T. pratense L.; *V. villosa* Roth.	*Z. mays* L.	*A. retroflexeus* L.; *Convolvulus arvensis* L.; *Acroptilon repens* (L.) DC.; *Cuscuta* sp.	reduced weed biomass (77%—*V. villosa*)	[66]
T. pratense L.; *V. sativa* L.	-	*Lamium aplexicaule* L.; *Papaver rhoeas* L.; *Sinapis arvensis* L.; *Chamomilla recutita* L.; *Phalaris minor* Retz.	reduced weed number (34%–68%—*V. sativa*; 19%–48%—*T. pratense*) and dry weight (58%–78%—*V. sativa*; 29%–44%—*T. pratense*)	[35]

Table 1. *Cont.*

Cover Crops	Crop	Dominant Weed Species	Weed Control	References
T. repens L.; *T. pratense* L.; *V. villosa* Roth; *Vicia benghalensis* L.; *Trifolium resupinatum* L.	-	*A. retroflexus* L.; *C. album* L.; *Portulaca oleracea* L.; *Persicaria longiseta* (De Bruyn) Kitag.; *S. nigrum* L.	reduced weed dry weight (29%–53%—*V. villosa*)	[19]
T. hybridum L.; *Trifolium michelianum* Savi var. *balansae* (Boiss.) Azn.; *T. alexandrinum* L.; *T. incarnatum* L.; *Trifolium resupinatum* L.; *T. pratense* L.; *T. repens* L.	-	*Brassica juncea* (L.)	reduced mustard biomass (29%–57%—without mowing)	[41]
mixture of *Vicia faba* L. (35%); *Vicia dasycarpa* Ten. (15%); *V. benghalensis* L. (15%); *P. sativum* L. (25%); *A. sativa* L. (10%)	-	*Malva parviflora* L.; *C. bursa-pastoris* L.; *S. media* L.; *Lamium amplexicaule* L.; *Urtica urens* L.; *Sonchus* spp.; *P. annua* L.	reduced weed DM linearly with increasing seeding rate (82%–100%)	[67]
V. dasycarpa Ten.; *V. faba* L.; *Lupinus angustifolius* L.	-	*Bromus cartharticus* Vahl; *C. bursa-pastoris* (L.) Medik.; *C. album* L.; *M. parviflora* L.; *S. media* L.	reduced weed density (23%–80%) and dry weight (30%–80%)	[68]
P. sativum L. and *V. sativa* L.—LSL; *T. incarnatum* L. and *Trifolium squarrosum* L.—SSL; *A. sativa* L. and *H. vulgare* L.—POA; *R. sativus* L. and *Brassica nigra* L.—BRS; mixtures of SSL, LSL + POA, SSL + BRS, LSL + POA + BRS, SSL + POA + BRS, LSL + SSL + POA + BRS	-	*Senecio vulgaris* L.; *Helmintotheca echioides* L.; *Alopecurus myosuroides* L.; *R. repens* L.; *Juncus tenageja* Ehrh.; *Lolium multiflorum* Lam.	reduced weed biomass (93%—mixture of LSL + POA compared to monoculture of *P. sativum*; 54%—mixture of SSL + POA compared to monoculture of *T. incarnatum*)	[69]
V. villosa Rotch.	*Apium graveolens* L.	*S. media* (L.) Vill.; *Amaranthus blitoides* S. Wats; *Cyperus esculentus* L.; *C. bursa-pastoris* (L.) Medik.; *P. oleracea* L.	reduced weed biomass (70%)	[70]
V. villosa Rotch.	*Solanum lycopersicum* L.	*A. retroflexus* L.; *Digitaria sanguinalis* (L.) Scop.; *P. oleracea* L.	reduced weed density (72%–79%) and aboveground biomass (40%)	[71]
V. sativa L.	*Z. mays* L.	*Ipomoea grandifolia* (Dammer) O'Donell; *Euphorbia heterophylla* L.; *D. sanguinalis* (L.) Scop.; *Cyperus rotundus* L.	reduced weed DM (76%) and numer (58%)	[14]
V. villosa Roth.; mixture of *V. villosa* and *S. cereale* L.	*Z. mays* L.	*L. amplexicaule* L.; *S. media* (L.) Vill.; *P. annua* L.	decreased weed biomass (92%—*V. villosa*; 97%—mixture of cover crops)	[72]
V. villosa Roth.	*Glycine max* (L.) Merr.	*Amaranthus rudis* Sauer; *Setaria faberi* Herrm.	decreased weed biomass (26%, in rolled system compared to the burndown system)	[51]

Table 1. *Cont.*

Cover Crops	Crop	Dominant Weed Species	Weed Control	References
mixture of *V. villosa* Roth. and *S. cereale* L.	*G. max* (L.) Merr.	*A. retroflexus* L.; *A. artemisiifolia* L.; *C. album* L.; *Polygonum convolvulus* L.; *Panicum dichotomiflorum* Michx.; *Setaria faberi* Herrm.; *Setaria glauca* L.; *C. esculentus* L.; *T. officinale* Weber in Wiggers	reduced weed density (67%–85%—*C. album A. retroflexus*, *Setaria* spp.), without *C. esculentus* L.	[73]
V. villosa Roth.; *P. sativum* L.	*Brassica oleracea* L. var. *acephala*	*E. cruss galli* (L.) P.B.; *C. dactylon* (L.) Pers.; *C. arvensis* L.; *C. album* L.; *P. oleracea* L.; *A. retroflexus* L.; *C. arvense* (L.) Scop.	reduced weed dry biomass (81%—*V. villosa*, 48%—*P. sativum*) and density (66%—*V. villosa*, 15%—*P. sativum*)	[42]
mixture of *V. villosa* Rotch. and *S. cereale* L.	*Brassica oleracea* var. *capitata* f. rubra	*T. arvense* L.; *C. bursa-pastoris* (L.) Medik.; *Galinsoga parviflora* Cav.; *L. amplexicaule* L.	reduced weed number (25%) and fresh biomass (50%)	[74]
mixture of *V. villosa* Rotch. and *S. cereale* L.	*Capsicum annuum* L.; *B. oleracea* var. *capitata* f. rubra	*C. album* L.; *C. bursa-pastoris* L.; *S. vulgaris* L.; *Matricaria inodora* L.; *L. amplexicaule* L.; *G. parviflora* Cav.; *E. crus-galli* (L.) Beauv.; *U. urens* L.; *Fallopia convolvulus* (L.) Á. Löve; *Polygonum persicaria* L.; *A. retroflexus* L.; *T. arvense* L.; *S. media* (L.) Vill.; *E. cicutarium* (L.) L'Herit	reduced weed number and biomass (39%–58%—cover crops mulching, 10%–45%—cover crops incorporated into soil)	[75]
V. villosa Rotch.; mixture of *V. villosa* Rotch. and *S. cereale* L.	*Solanum lycopersicum* L.; *Cucurbita pepo* L.; *C. annuum* L.	*C. bursa-pastoris* (L.) Medik.; *Setaria* spp.; *C. album* L.; *A. retroflexus* L.	reduced weed density (96%—mixture of cover crops, 80%—*V. villosa*)	[76]
Crotalaria juncea L.	*S. lycopersicum* L.	*Digitaria horizontalis* Willd.; *Gnaphalium spicatum* Lam.; *Cyperus* sp.; *G. parviflora* Cav.; *Amaranthus* sp.	reduced weed DM (97%)	[77]

CCs can be introduced before the main crop, i.e., after crushing, treating with a herbicide, plowing, or left on the surface of the soil as dead mulch (the successive crop is directly drilled through the mulch) or grown together with the main crop as living mulch [20]. In both cultivation systems, CCs, and especially legume CCs, can be successfully used in limiting weed infestations by using two mechanisms: direct and indirect [17,18,20]. Adapting the phenology of legume CCs to the cultivation of the main crop uses its niche pre-emption, which can be a direct, successful competition for weeds in terms of habitat and resources, e.g., light, soil, water, and nutrients [43,78–82]. An indirect effect of CCs legume on weeds is also observable, manifested by physical [83,84] or chemical suppression [52,85–87]. The weed suppression mechanism based on the competing abilities of legume CCs is visible when used as a smother crop or the living mulch.

Bilalis et al. [35] demonstrated that *V. sativa* caused a reduction in the light available for weeds, which led to an observable reduction in the number of weeds and their dry weight. The competitive abilities of common vetch were related to its morphological features, including high overall leaf area, greater height and length of stems, number of shoots per plant, biomass and upright growth. A clear reduction in the emergence of weeds was also observed in the cultivation of *V. villosa* [42,61]. Additionally, in the case of *M. lupulina,* both the morphological features and the rapid growth rate of the plant determined its ability to suppress weeds. In the case of legume CCs characterized by a slower growth rate (*T. hybridum*), their allelopathic properties were decisive for the effectiveness of weed control at an early stage [20]. In turn, Ross et al. [41] stated that the competitiveness of *Trifolium* sp. is determined not only by its morphological features, but also by the method of cultivation. A higher level of weed suppression has been reported on the low-productivity site than on the high-productivity site. Greater competitiveness of *T. alexandrinum* was determined by the following features: upright growth habit, long stems, high biomass production, and late flowering, and of *T. hybridum*: upright growth and long stems. However, in the case of *T. squarrosum*, its high and long-term stability of the weed suppression capacity was decided by its mat-like prostrate growth during early developmental stages [69].

Numerous reports confirmed that annual weeds were suppressed to a greater extent by legume CCs residues, with the end result being more pronounced for small-seeded summer annual weeds than for large-seeded annuals [46,84,88]. Brandsæter and Netland [61] have shown that *T. incarnatum* limited weed infestation to a greater extent than *T. subterraneum*. This proves that the lower weed suppression effectiveness of *T. incarnatum* occurs when perennial and monocotyledonous weeds dominate the flora. Leaving the remains of legume CCs has a lower suppression effect on perennial weeds [73]. Other authors have also reported a lower impact of legume CCs on the reduction of perennial weed infestation (especially winter-seeded species kept only for a single growing season) [56,89–91]. Sjursen et al. [65] also found the lack of the suppressive effect of undersowing clover (*T. pratense, T. repens*) on annual weeds with regard to both short-term (weed emergence) and long-term (seed bank) effects, possibly due to the successive fertilization effect with legume CCs.

CCs, including legume CCs, can suppress not only weeds that are already resistant to herbicides, but also a significant number and biomass of herbicide-susceptible weeds, thus reducing the intensity of their selection in terms of future resistance [92,93]. Reducing weed abundance, biomass or seed production in legume CCs, and suppressing seedling emergence from the weed seed bank reduces the selection pressure at the end of cover crop [92,94], particularly in no-till systems, where herbicides are used to terminate cover crop.

Legume CCs can also compete for resources necessary for growth and development, also with the main crops [95]. It follows that legume CCs not only compete with weeds by inhibiting their emergence and growth, but can also suppress the main crops [78]. Therefore, when selecting CCs species, attention should be paid to their faster growth and shorter vegetation period compared to the main plants, in order to minimize competition, e.g., for the light. It is also necessary to provide the soil with water in order to minimize competition between the crop and CCs [12,96]. The competition of CCs for water, especially in early spring, may be visible in the cultivation of the main crop in

arid and semi-arid regions, where soil moisture is a factor limiting plant production [97]. On the other hand, it was found that legume CCs compete to a lesser extent for N from soil with the main crops [5]. In addition, chemical and physical factors that affect weeds can also affect crops and the CCs themselves. For example, the main crops may be inhibited by allelochemicals released by some legume CCs. Moreover, in the absence of rotation in the cultivation of CCs, accumulation of allelochemicals and even pest (weeds, pests, pathogens) populations may occur. This will negatively affect not only the main crops, but also the CCs themselves [98].

Legumes CCs (*Mucuna deeringiana* (Bort) Merr., *Canavalia ensiformis* (L.) DC., *Leucaena leucocephala* (Lam.) de Wit, *Lysiloma latisiliquum* (L.) Benth.) used as both living CCs and dead mulches (incorporated on soil surface) have reduced the weed biomass. The greatest reduction in weed biomass (68%) was reported for *M. deeringiana* as living CC in corn cultivation. The inhibitory effect of these legumes on the growth and development of weeds is related to their allelopathic properties. The aqueous leachates of all four legumes showed strong phytotoxic effect on the rooth growth of *E. crus-galli* and *Amaranthus hypochondriacus* (L.) [52]. Additionally, aqueous leachates from fresh leaves and volatiles of *Tephrosia vogelii* Hook. inhibit the seed germination and seedling growth of *Festuca arundinacea* Schreb., *Cynodon dactylon* (L.) Pers. and *Digitaria sanguinalis* (L.) Scop. Additionally, mulching with this legume CC resulted in reduction of the weed biomass (15.8%) in corn cultivation [99]. The allelopathic effect in legumes is varietal dependent and might have a genetic basis. The inhibitory effect of *M. sativa* cultivars on weeds was proportional to the number and quantity of growth inhibitors (phenolic compounds), which showed strong allelopathic activity. As a result, the weed suppression of legume CC might be proportional to its allelopathic magnitude [100]. When *M. sativa* was incorporated into soil (as mulch) for weed-control purposes, phenolic acids detected in the soil reached maximum concentrations after 10 to 15 days and were efficacious until 20 to 25 days. Chemicals released from allelopathic plants incorporated into soil are toxic and cause inhibition of certain species and could be applied as a biological tool for weed management [101].

However, depending on the desired purpose of the main plant cultivation, the cultivation of legume CCs can be regulated in terms of sowing time, growth rhythm, retention of N or the biological N-fixing potential. Therefore, they are less competitive with the main crop than the weeds [78].

It has been demonstrated that a higher density of legume CCs also increases competitive interactions and resource consumption between the main crop species. This in turn provides an effective weed reduction [20,102]. With greater coverage of the soil surface with CCs at an early stage of their growth a more effective suppression of weeds was observed, especially at a high sowing density of species characterized by high seed weight. Increasing the coverage with the CC from the early growth stage, even if the plant is low, it can inhibit weed biomass production. Moreover, the cultivation of low CCs as a mixed cropping or intercropping system is beneficial for the main crop, especially for the higher species, as there is little competition for light between the main crop and the cover crop [19]. Bilalis et al. [35] found that *V. sativa* was more effective in reducing weed infestation than *T. pratense*, which was characterized by higher competitiveness in relation to weeds due to a higher number of developed shoots and greater dry matter. This is confirmed by Uchino et al. [19], in whose research *V. villosa* proved more effective in supressing the weed biomass, as compared to *T. repens*, *T. pratense*, *T. resupinatum*, and *V. benghalensis*. Additionally, *M. sativa* is more competitive with weeds than *T. pratense* under semi-arid conditions [53,103,104]. Although some studies have confirmed the positive correlation between CCs biomass and weed suppression [42,105–107], Elsalahy et al. [20] showed that in the case of legumes, this relationship may be weak and inconsistent. The mechanisms that determine the impact of legume CCs biomass on weed biomass are the contrasting characteristics of legume species in the mix (growth rate, response to environmental conditions), which allow the legume CCs to mutually complement throughout the cultivation period [20,69], as well as their allelopathic properties. Under conditions where higher biomass production is limited by environmental conditions, the allelopathic abilities of legume CCs may play an important role in reducing weed infestation [20]. The chemical weed suppression is seen in alfalfa (*M. sativa*), which gives off allelochemicals (phenolic

compounds) harmful to weeds, e.g., *Doparium junceum* Hamilt., *Lindernia pyxidaria* L., *Elatine trianda* Schk. var. *pedicellata* Krylov, *Eleocharis acicularis* (L.) Roem. et Schult., *C. album* L., *E. crus galli* (L.) Beauv. [67,108–111]. *V. villosa* [112–114], *T. pratense* [115,116], *T. incarnatum* [112], and *T. hybridum* [111] also show allelopathic effect against weeds. Kruidhof et al. [43] demonstrated that the suppression of spring weed emergence by plant residues CCs (*M. lupulina*—54% on average) may be related to the release of allelochemicals (saponins, flavonoids and phenolic acids) into the soil. Therefore, in terms of weed control, successive crop cultivation should take into account the physical properties of plants introduced into the soil, determined by the pre-treatment of the residues and the nature of the CCs [20,117].

The indirect effect of legume CCs on weeds is creating a physical barrier (as incorporated or soil surface-placed cover crop residues), which can prevent the newly formed seeds from reaching the soil surface and contribute to depletion of the weed seed bank in the soil, and as a result, inhibit or delay germination and emergence of weeds [115]. In this case, a more effective weed suppression is seen in CCs legume producing more biomass, especially at the beginning of the growing season. Osipitan et al. [118] found that early weed control with CCs is even compared to chemical and mechanical weed control methods in crop systems. In addition, an earlier sowing date, higher seeding density, and a delayed termination date of CCs favors more biomass, and is therefore more effective in suppressing weed infestation, especially for annual summer weeds [35,73,119]. In addition, cultivation practices such as delaying planting and termination dates of CCs may selectively affect weed populations by changing their structure into less competitive species [73]. It is one of the potential mechanisms contributing to the change in the crops' tolerance of weed biomass [120].

Legume CCs can also initiate the germination of weed seeds, leading to faster depletion of the soil weed seed bank, especially in long-term cultivation [91]. Moonen and Bàrberi [91] found a 22% reduction in the soil weed seed bank, even seven years after introducing CC legumes (*T. subterraneum*) into the no-till corn cultivation system. In turn, Sjursen et al. [65] observed that the annual seeding of clovers (*T. pratense* and *T. repens*) favored the increase of weed biomass and the size of the seed bank. This is most likely due to the ability of legumes to fix atmospheric nitrogen, which also becomes available to weeds.

Legume CCs (e.g., *M. sativa*) can also increase the activity of *V. arvensis*, *A. myosuroides* seed predators (both vertebrates and invertebrates) by changing the quality of their habitats [121]. Seed losses reaching 25 to 50% caused by seed predators are sufficient to significantly slow down the growth of the weed population [122]. Youngerman et al. [123] showed that seeds of the main plants can also be damaged by invertebrate seed predators. However, they less prefer CCs seeds with hard seed coats, for example *V. villosa*. Blubaugh et al. [124] found that CCs increased the frequency of weed seed consumption by omnivorous predators by 73%. As a result the cover crops improve biocontrol, not only by promoting increased activity of omnivores, but also by facilitating their function as seed predators on an individual-level.

The presence of dominant weed species in plant crops can be explained by their divergent characteristics, which have allowed them to react differently to environmental fluctuations and management practices, in accordance with a process called "the storage effect". According to the theory of the storage effect, for the species in the weed community to survive, there must be species-specific responses to changing environmental conditions. The responses should then lead to differentiated competition (covariance between the environment and competition), and the durability of the seed bank should buffer the growth of weed populations in years with unfavorable environmental conditions [125]. However, CCs can sometimes have a positive effect on the germination or growth of weeds [117]. Legume CCs play a part in the fixing of atmospheric nitrogen and therefore they can indirectly create more favorable conditions for weed growth than the other CCs [59].

Any undesirable plant in the main crop cultivation, despite its ecosystem advantages, is considered a weed. Therefore, the self-seeding of legume CCs in succeeding crops can be a problem, especially in the case of species that are highly competitive with those of main crops. Their control may be difficult,

especially in the case of perennial species characterized by a rapid growth rate, producing a large number of diasporas and that are resistant to abiotic stress conditions.

3. Effect of Legume CCs Cultivation Systems on Weed Control

As mentioned before, CCs can be introduced into plant production systems as living mulch by sowing into the main crop, or as dead mulch, i.e., sowing the CCs after the main crop harvest and terminating their growth before cultivation of the secondary main crop, by plowing under, crushing or treating with glyphosate. In this case the successive plant is sown directly into the mulch [57]. The use of CCs for weed control is particularly important in no-till systems [119].

Living mulches based on CCs have a positive effect on reducing weed infestation as well as on the health of the crop by reducing pest infection or infestation [126–129]. However, some authors report that when using mulch, excess moisture in the soil may be unfavorable for the soil, increasing the infestation of pathogens and in some cases, pests (snails, rodents) [130,131].

It has been shown that legumes used as live mulch are able to effectively control weeds, but at high density [20]. The effectiveness of legume CCs in suppressing weeds is mainly the result of their higher competitive abilities (e.g., for light and habitat) compared to weeds [20,102,132]. Teasdale and Mohler [47] demonstrated that weed suppression was more effective in the case of *V. villosa* mulch, in early growing season, during the spring biomass accumulation. However, as the season progressed and the mulch degraded, this effect wore down. A notable reduction in weed biomass was observed after cutting legume CCs due to the reduction of weed growth and direct mortality, especially when the cutting height is less than 7 cm. In addition, dead mulch from legume CCs may promote capturing seeds of some wind-dispersed weed species [127]. The competitive equilibrium between legume CCs and weeds is changed also due to the different regrowth of cut weeds, especially annual weeds [20]. However, emergence of weeds can be stimulated by introducing cut mulch into the soil [53,133]. This is confirmed by the reports of Golian et al. [74] who incorporated *S. cereale* and *V. villosa* mixes into the soil. This not only did not reduce weed infestation, but even increased the amount of weeds by 15%.

Legume CCs sown in late summer, for example in cereal crops, provide a winter cover and are terminated before sowing the main crops [51]. Terminating the growth of CCs before the main crop is essential for their usefulness, as regrowing CCs can interfere with the growth and development of the main crop, which causes a decline in the yield [134]. Moreover, the method of CC termination may influence their weed suppression potential in successive crops [50]. In no-till cropping systems, a herbicide may be used to complete the cultivation of CCs, including legume CCs, but physical methods are also available [135,136]. Mowing is one of the physical methods of terminating the cultivation of CCs without disturbing the soil, but in this method regrowth of CCs and an aggregated spatial distribution of crop residues occur [135]. The cover-crop roller-crimper [137] can also be used to terminate the growth of CCs.

It has been found that plant residue management can regulate the diversity and composition of the weed population by introducing qualitative and quantitative changes [138,139]. Residual CCs in the form of dead mulch change soil properties, which can impact weed control by affecting the survival, dormancy, predation, and long-term viability of weed seeds [140,141]. As dead mulch, legume CCs shade the surface of the soil and thus capture solar radiation. This reduces not only light permeability, but also the daily amplitude of soil temperature. Undoubtedly, this inhibits weed seed germination, because the dormancy of seeds of many species of annuals is controlled by light and temperature [47,73,142]. This is confirmed by studies in which the remains of legume CCs (*V. villosa*) inhibit the emergence of weeds due to the reduced access of light to the soil surface [47,143]. Additionally, in the case of mulch produced from a mix of CCs (*O. viciifolia* and *H. vulgare*) these mechanisms contributed to the inhibition of weed infestation [87]. It follows that dead mulch suppresses weeds by creating a physical and chemical barrier [140,144].

The effectiveness of CCs as dead mulch is determined by the ability of CCs to suppress weeds during its active growth and the residual effect of CC mulch after senescence [7]. In addition,

the effectiveness of weed control is also influenced by the even distribution of residual CCs and the way they are placed in the main crop. Residues of CCs on the soil surface decompose more slowly and gradually release agrochemicals, as compared to the residues mixed with the soil [117,145]. Along with an increase in the amount of mulch there was also a decrease in the occurrence of small-seeded annual weeds [46,84]. Teasdale and Mohler [84] reported that weed suppression was impacted to a greater degree by the amount of residual CCs than by their type, however, in the case of perennial weeds, increasing the amount of residue CCs had no damping effect.

Decaying residue of CCs may create a more favorable environment for weed germination and development [144]. Leaving residue on the soil surface may result in better availability of water, which supports weed development [47,146]. It was also shown that a small amount of plant residue of *V. villosa* promotes light transmission and triggers a phytochrome reaction, occasionally stimulating the emergence of weeds, especially *Amaranthus hybridus* [147]. This is also confirmed by the studies by Mischler et al. [90], who demonstrated that *V. villosa* stimulates the germination and growth of weeds—especially in conditions of increased temperature and soil moisture [15]. This is due to the relatively rapid decomposition of *V. villosa* biomass, even during its growth. CCs plant residue may also interfere with sowing or mechanical weed control, which in turn may have a negative effect on successive tillage [148].

CCs used as intercrops can potentially reduce weed infestation, which positively impacts the crop yield. Intercrops maintain high competition with weeds, irrespective of the species and productivity of the weeds, the biomass of the main crop or the availability of nitrogen in the soil [149]. Weed infestation is inhibited by reducing the space available for weeds in the habitat, and by reducing their resources, e.g., water, light, and nutrients. Nitrogen and light play an important role in reducing weed infestation due to the complementary abilities of intercrop species, their use of nitrogen (mineral nitrogen in soil and atmospheric nitrogen N_2), as well as light capture and soil surface coverage [149,150]. These mechanisms are often interrelated and depend on the temporal and spatial growth dynamics of the above-ground and underground parts of the plant [151]. Therefore, this may explain the increase in intercrop yields and the inhibition of weed infestation [152,153]. Intercrop species with different characteristics in terms of growth rate and response to environmental conditions favor the inhibition of weed infestation. For example, species with varying growth rates can cause a temporary asynchronicity in species growth dynamics; a fast-growing species competes with weeds early in the growing season and a slow-growing species competes with later-emerging weeds. This enables effective weed management throughout the growing season, while also reducing direct competition for resources between species in the intercrop [20]. High and constant inhibition of weed infestation in the legume/cereal intercrop was demonstrated even with a low share of the cereal plant in the intercrop biomass, while for a sole legume crop, a decrease and high variability in weed suppression were noted [149,154]. For example, in the sole crop, *P. sativum* is a weak competitor in relation to weeds [155], therefore, with greater pressure from weeds, this species reacts with a limited use of N and a decrease in the seed yield [156,157], which is also confirmed by studies on other legume species [158,159].

Numerous studies have also confirmed the effectiveness of the relay intercropping of a forage legume (RIL) in controlling the main crop weeds [18,53–55,63,64,160]. In RIL, CCs are left in the field until the crop is harvested, which enables weed control before undersowing [65]. This allows avoiding the bare soil period, which favors the emergence of weeds between the cash crop harvest and the full establishment of a CC, when it is sown between two cash crops [18]. To achieve a significant reduction of weed biomass, it is necessary to maintain the CCs legume until late autumn [18,53]. According to Blaser et al. [54,63] and Amossé et al. [18] the presence of legume CCs effectively reduced weed density even during the harvest of the crop. Legume CCs were found effective in reducing the number of weeds emerging in spring, as well as in increasing the mortality of weed seedlings. These mechanisms are also associated with limited resources (e.g., light, water), which negatively affects the growth and development of weed seedlings [43]. Leaving CCs until autumn effectively suppresses the emergence of weeds, which leads to reducing the weed seed bank in the soil [161]. Amossé et al. [18] concluded

that both legume CCs and cereal crops are necessary to reduce weed abundance and biomass during RIL. The reduction of weed infestation in RIL is thus managed by the cumulative effect of the crop and the legume CCs. The combination of winter crops and RIL decreases weed infestation in spring, reducing the number of annuals. Therefore, in crop rotations with a high proportion of spring crops and with weed populations adapted to this crop cycle, the use of RIL is very effective in reducing the number of spring weeds [18].

Elsalahy et al. [20] reported higher capability of some small-seeded legume mixes to suppress weeds compared to the capabilities of monocultures of these species. These authors believe that this is most likely due to complementary growth features of the plants over time, i.e., a faster growing species (*M. lupulin*) suppresses weeds at the beginning of cultivation, and a slower growing species (*T. hybridum*) inhibits the later growth of weeds [20]. A better reduction of weed infestation was also found in mixes of leguminous plants with other species, as compared to the monocultures of these species [62,69,86,162]. These mixes allow obtaining a higher biomass of CCs, as well as retarding the decomposition of plant residues, e.g., legumes. This, in turn, affects their greater ability to reduce weed infestation [86]. The effectiveness of the mixes in reducing weed infestation is determined not only by the produced biomass, but also by other plant properties, such as allelopathic activity or canopy architecture, and the related soil shading surface [86,87]. Ranaldo et al. [69] confirmed that biodiversity in CC mixes has a more beneficial effect on the suppression of weeds, e.g., by producing more CC biomass, also under difficult field conditions. The mechanism explaining the effect of species diversity in CC mixes on weed control is the complementarity of resource use. Smith et al. [163] formulated the Resource Pool Diversity Hypothesis according to which, with a more diverse pool of soil resources, a lower abundance of weeds is expected. The increase in the ability to suppress weeds is influenced by the differentiation of the functional traits of the CCs (e.g., the growth form, root system, nutrient use strategy), i.e., the synergy between complementary species traits in the CC mix [69]. This will ensure a more complementary and consistent production of CC biomass throughout the growing season, even under changing environmental conditions [105,106,164]. However, Elsalahy et al. [20] confirmed that the ability to suppress weeds was influenced to a greater extent by the species identity in legume mix, than by the species diversity. In addition, the changing proportion of species in the legume mix has no significant impact on the suppression of weeds. However, a mix of legumes with a single dominant species had better effects in suppressing weeds compared to a mix comprising a balanced share of individual species [20]. In turn, Suter et al. [165] confirmed that mixes of species help control weeds, especially when individual species are functionally diverse. Due to the functional complementarity of the individual species, a higher sowing rate can be applied in multi-species mixes, as compared to the sowing standard for species grown in a monoculture. Moreover, obtaining a higher plant density thanks to the use of many species in the mix is more effective in controlling weeds [62,166]; this is a practice used in organic farming conditions. However, Smith et al. [27] argue that CCs mixes do not suppress weeds any more than the top CCs with the highest weed suppression capacity, grown as a monoculture. Moreover, according to the authors, a more diverse mix of CCs (14 species) does not outperform a less diverse mix. Research by Panasiewicz et al. [167] with narrow-leaved lupine in crop rotations with 75% cereal composition also indicate that the method of tillage has a significant influence on weed infestation and consequently, the seed yield. Dry weigt of weeds under conventional tillage was significantly lower than in reduced tillage and no-tillage. There was also a significant difference between dry weight of weeds in reduced tillage and no-tillage. The weight of weeds in no-tillage was approximately two times greater than in reduced tillage.

In the organic system undoubted benefits can be generated by introduction of legume CCs. In chisel-plow based organic system (OR) with CCs (crimson clover before corn, rye before soybean) and manure applied for nutrients and postplanting cultivation, higher soil combustible C and N concentrations at all depth intervals to 30 cm compared to other cultivation systems were reported for weed control. In addition, corn grown under organic system had more N available compared to conventional no-tillage. Systems that incorporate high amounts of organic inputs from manure and

CCs can improve soil more than conventional no-tillage systems despite reliance on a minimum level of tillage. Authors suggest that if adequate weed control could be achieved in reduced tillage organic systems, higher soil quality could be achieved with yield-enhancing benefits compared to conventional no-tillage systems [89]. Additionally cover crop-based, organic rotational no-till crop production (mechanical termination of CCs with a roller-crimper and no-till planting crop into CC mulches) becomes a viable strategy for reduction of tillage in organic annual grain systems. Authors suggest that N-release synchrony with corn demand and improvement of weed suppression can be improved with grass-legume mixture. Integration of high-residue inter-row cultivation improves weed control consistency and may reduce reliance on optimization of CC biomass accumulation for weed suppression. However, breeding efforts are required to improve CC germplasm and develop regionally-adapted varieties [15].

Other ecosystem functions are also supported by legume CC, as conservative biological control with legume and non-legume CCs is an interesting alternative to the chemical control of many insects [168,169]. It was reported that cover crops regulate the tetranychidae mite populations in citrus orchards [168,170] as well as reduce thrips infestation in cotton cultivation [169]. However, legume cover crops may not affect the population of the root weevil in citrus groves or its feeding damage [171].

Cover crops provide a constant and abundant supply of food sources for natural enemies (predators and parasitoids) during the flowering period, allowing natural enemies to build up in the system, thereby keeping pest populations at acceptable levels. [172]. Altieri et al. [173] confirmed that correct agroecosystem diversification strategies such as CCs usually regulate pests by restoring the natural control of insect pests. Legume CCs (such as *Neonotonia wightii*) act as a reservoir for phytoseiid mites, thus contributing to the biological control of phytophagous mites in citrus orchards [174]. However, increase of the floral diversity in sown CCs could constitute a complementary method in management programs, by providing a greater amount of alternative food resources and alternative hosts to enhance the conservation and biological control of natural enemy populations [175]. Different CC species, with different blooming phenologies, provide habitat and resources for potential wild pollinators, particularly native bees. As a result, flowering CCs can be used for pollinator conservation purposes [176,177].

4. Effect of Legume CCs on the Soil Environment

4.1. Effect of Legume CCs on the Content of Organic Matter and Nitrogen in Soil

The main factors causing the degradation of agricultural soils are: intensive agrotechnical treatments, excessive chemical treatment, cultivation in a monoculture and inappropriate melioration. In consequence, soil organic matter is reduced, which in turn is associated with the deterioration of the physicochemical properties, sorption capacity, and biological activity of the soil. The high content of organic matter stabilizes the soil structure as well as reducing its susceptibility o compaction and erosion. It is also an indicator of soil fertility [178]. An important component of soil are microorganisms, which play a key role in the process of biomass decomposition and humus formation, nutrient circulation and increasing soil resistance to harmful factors [23,179]. Diversity of soil microorganisms is a prerequisite for maintaining soil fertility and has a positive effect on plant health. It conditions their proper growth and development, and, consequently, yielding [180].

One of the most important factors influencing the maintenance of soil fertility and productivity is a rich crop rotation, which should include CCs [22,181]. It increases the productivity of crops at a reduced workload, and at the same time cuts down the negative impact on the environment. In addition to enriching the crop rotation by increasing biodiversity, crop rotation brings additional benefits such as: increasing the content of organic matter in the soil, reducing weed pressure, reducing the spread of pathogens, and protecting the soil in periods between main crops [182,183]. Keeping CCs during the autumn and winter period is especially important as it limits nutrient losses and erosion, especially in

light soils. The lack of plant cover in this period causes disturbances in the soil structure, reduces the infiltration of water into the substrate, and at the same time increases the leaching or blowing away of the arable layer [184].

Fabaceae are excellent ground cover crops; growing them brings a number of benefits for improving soil quality. Due to the biological ability to fix atmospheric nitrogen, their biomass is used entirely as green fertilizer or crop residues, which enrich the soil with nutrients, including organic carbon and nitrogen. This is beneficial from the point of view of the successive crop (Table 2) [185–187].

Table 2. Effect of legume CCs on the content of organic carbon and nitrogen in soil.

Legume Cover Crops	Crop/Tillage	Soil Texture	Potentially Mineralizable Carbon (kg·ha⁻¹)	Permanganate Oxidizable Carbon (kg·ha⁻¹)	Potentially Mineralizable Nitrogen (mg·kg⁻¹)	Soil Inorganic N	Soil Organic C	References
no legume CCs *P. sativum* L. mixture of *P. sativum* L. and *A. sativa* L. mixture of *P. sativum* L. and *B. napus* L. mixture of *P. sativum* L., *A. sativa* L. and *B. napus* L. mixture of *P. sativum* L., *A. sativa* L., *B. napus* L., *V. villosa* Rotch, *R. sativus* L. and *H. vulgare* L.	*T. aestivum* L./no-till	clay loam	133 202 192 210 158 190	795 769 831 776 810 850				[188]
no legume CCs mixture of *S. cereale* L. and *V. villosa* Roth. mixture of *S. cereale* L. and *T. incarnatum* L. mixture of *S. cereale* L., *A. sativa* L., *R. sativus* var. niger J. Kern., *Brassica campestris* L. and *T. incarnatum* L.	*Z. mays* L. *G. max* (L.) Merr./no-till	silt loam			28.4 34.7 32.6 35.8	**(mg·kg⁻¹)** 15.5 18.5 20.6 19.4		[189]
no legume CCs *M. sativa* L. *T. pratense* L. *P. sativum* L.	*T. aestivum* L./ conventional tillage, fall planted	sandy clay loam				**(kg·ha⁻¹)** 19.6 43.8 34.6 30.0		[53]
no legume CCs *M. sativa* L. *T. pratense* L. *P. sativum* L.	*T. aestivum* L./conventional tillage, spring planted	sandy clay loam				**(kg·ha⁻¹)** 20.8 27.1 18.5 24.2		[53]
no legume CCs *P. sativum* L. *V. villosa* Rotch/	*Z. mays* L./conventional tillage	silt loam				**(g·kg⁻¹)** 1.22 1.26 1.28	**(g·kg⁻¹)** 15.7 16.0 15.8	[190]
no legume CCs *T. incarnatum* L. *V. villosa* Rotch.	*Sorghum bicolor* (L.) Moench/ conventional tillage	sandy clay loam				**(g·kg⁻¹)** 1.0–1.3 1.3–1.5 1.3–1.5	**(g·kg⁻¹)** 8.5–10.1 10.6–12.8 10.2–11.8	[191]
no legume CCs mixture of *S. cereale* L., *P, sativum* L. and *T. incarnatum* L.	*Z. mays* L. *G. max* (L.) Merr./conventional tillage	silt loam			5.78 7.62	**(weight %)** 0.11 0.10		[192]

Table 2. *Cont.*

Legume Cover Crops	Crop/Tillage	Soil Texture	Potentially Mineralizable Carbon (kg·ha^{-1})	Permanganate Oxidizable Carbon (kg·ha^{-1})	Potentially Mineralizable Nitrogen (mg·kg^{-1})	Soil Inorganic N	Soil Organic C	References
no legume CCs *S. cereale* L. (in *Z. mays*) and *V. villosa* Rotch. (in *G. max*) *S. cereale* L. (in *Z. mays*) and mixture of *S. cereale* L. and *V. villosa* Rotch. (in *G. max*)	*Z. mays* L. *Glycine max* (L.) Merr./no-till	silt loam				**(mg·kg^{-1})** 0.26 0.29 0.21		[193]
no legume CCs *Mucuna pruriens* (L.) DC. no legume CCs *M. pruriens* (L.) DC.	*Z. mays* L./ no-till	sandy loam					**(Mg·ha^{-1})** 6.76/0–5 9.42/0–5 19.2/0–20 25.1/0–20	[194]

The amount of organic carbon and nitrogen introduced into the soil depends on many factors such as: quantity, quality, and management of biomass or crop residues, as well as frequency of cultivation and climatic conditions [195]. Amossé et al. [18] showed that legume ground cover plants such as *M. lupulina*, *M. sativa*, *T. pratense* and *T. repens* significantly enriched the soil with symbiotic nitrogen, increasing the yield of Z. mays as a successor plant by 31%. However, they did not significantly affect the yield of *T. aestivum* (winter wheat) into which they were sown. Nitrogen content in biomass of ground cover plants, analyzed in late autumn, after *T. aesivum* harvest, showed that from 71% to 96% of N came from symbiotically fixed nitrogen, which enriched the soil by 38 to 67 kg N·ha^{-1}. Legume CCs also usually have a C:N ratio of under 20:1, which promotes faster nitrogen mineralization. This reduces the amount of nitrogen available to the main crop [21]. This is especially important in management systems where there are nitrogen deficiencies in the soil, such as organic cereal cultivation, where the use of nitrogen in mineral fertilizers is unacceptable [149,196–200].

In addition, in cereal/legume intercrops grown in arid, semi-arid, tropical, and temperate climates the intercropping may be advantageous when nitrogen availability corresponding to soil nitrogen plus N-fertilizer is below a determined threshold (12 g N m^{-2}) due to a high degree of complementary nitrogen use between the two species for low N levels [201–203].

According to Abdalla et al. [166], CCs which included legumes increased the yield of the successive crop by an average of 13%, in contrast to CCs with no legumes, which reduced the yield of the main crop by an average of 4%. According to the authors of the presented meta-analysis of 106 studies in 372 locations, including different countries and climatic zones, the advantages of CCs (legumes or legume mixes), justify their widespread adoption as good agricultural practice in sustainable management. However, the authors believe that in order to increase the efficiency of CCs, field management technology should be optimized to local climatic conditions, water abundance, soil type, and the cultivation system.

Biomass and post-harvest residues of CCs positively affect the quality of physical and chemical parameters of the soil, e.g., by increasing the content of organic matter, the amount of stable soil aggregates, and the content of available nitrogen [22,24]. The beneficial effects of legumes increase when the crop rotation is more diversified. Studies have shown that the use of three or more plant species and, additionally, a legume plant as intercrop allows for a greater accumulation of soil organic matter than in the case of two plants in a crop rotation, along with a legume intercrop [22]. On the other hand, García-González et al. [204] showed that the use of a mix of *H. vulgare* with *V. sativa* as a CC for several years increased the soil organic matter and field water capacity, as well as reduced leaching of nitrogen compounds from the soil. Greater stabilization of the soil structure, the formation of a lumpy structure and an increase in the amount of waterproof soil aggregates were also observed.

The literature on the subject reports that non-legume CCs significantly reduce the leaching of nitrates to the groundwater by incorporating nitrogen into the biomass [205,206], while opinions regarding legumes vary. According to Abdalla et al. [181], all analyzed cover plants (legumes, non-legumes, and legume mixes) significantly reduced nitrogen leaching. Justes et al. [207] reported that the efficiency of *Fabaceae* as CCs in reducing nitrates was half that of *Poaceae* and *Brassicaceae*. In turn, Valkama et al. [208] demonstrated that legumes were not effective at capturing nitrogen, contrary to *Poaceae*. More efficient soil nitrogen capturing by *Poaceae* and *Brassicaceae* than *Fabaceae* species is most likely influenced by their more developed root system and greater resistance to lower temperatures, which favors the extension of their growing season [59,133].

Apart from reduction of N leaching to ground water, CCs contribute to increase SOC sequestration (soil carbon sequestration) without having significant effects on direct N$_2$O emissions [181]. Lal [209] suggest that the SOC can be enriched by use of apposite crop rotations. Crop rotation can improve biomass production and thereafter the soil C sequestration, principally the rotations of legumes with non-legumes. The legume-based rotations are more efficient in converting biomass C into SOC in compression to the grass-based rotation. Hajduk et al. [210] suggest that the inclusion of legumes in rotation has the potential to guarantee the in-situ availability of N, which in turn played a vital

role in generating higher biomass C. It also promotes the release of C via root exudation in to the rhizospheric zone. N fixed by the root nodules of legumes also accelerates the C sequestration potential of succeeding crop in the rotation, by improved microbial functionaries and biomass production by successive crop. When provided with the legumes, they enhance the nitrogen use efficiency and produce more root biomass and thus C inputs in soil [211]. In legumes based rotation endorsed the accumulation of liable C pool in soil ecosystem, which is beneficial for successive plants [209]. Legume and non-legume CCs in mixtures also have a better effect on the main crops, preventing a reduction in yield or even increasing it (by 13%) without significantly affecting N in grain. CCs can also mitigate the net greenhouse gas balance (NGHBG), contributing to the resilience of farming systems to environmental changes, such as climate change, through increased fertility, productivity and better water quality, which undoubtedly affects succeeding crops [181].

4.2. Effect of Legume CCs on Soil Fauna and Microflora

Due to the large amount of post-harvest residues and root secretions, *Fabaceae* CCs increase the amount of carbon and nitrogen compounds introduced into the soil, which is the main source of energy for soil microorganisms [179]. Peralta et al. [180] showed a significant increase in the functional groups of microorganisms responsible for the suppressive properties of the soil with a diversified crop rotation including *Z. mays—G. max—T. aesivum* plus two CCs—*T. pratense* and *S. cereale*, as compared to a *Z. mays* monoculture. In soils where rotation was applied, the pool of the gene responsible for the production of the bacterial antibiotic pyrrolithrin was increased compared to the soil under *Z. mays* monoculture cultivation. This proves an intensive development of microorganisms and plant protection properties. A more simplified crop rotation, which included only two plant species, such as: *T. aesivum* and *B. napus*, or *Z. mays* and *G. max* had no significant effect on soil microbial activity [180]. Using *T. repens* as a CC increased the microbial biomass and the population of earthworms (*Lumbricidae*) in the cultivation of *T. aesivum* [212], while in *Z. mays* cultivation, populations of all soil microorganisms, i.e., bacteria, fungi, nematodes, and mites, were increased [213]. According to Bardgett and van der Putten [214], increasing the diversity and number of species of cultivated plants has a positive effect on soil fertility, due to diversification of the available food sources for microorganisms and, consequently, for plants. The biomass of microorganisms also increases, and the structure of the soil microbiome is exposed to change, which has a huge impact on their functionality as well as soil fertility. Crop rotation also significantly impacts the increasing biodiversity in the soil environment [182]. In turn, Somenahally et al. [23] observed an increase in the biomass of mycorrhizal fungi in *T. aesivum* cultivation with the use of legumes as CCs.

4.3. Effect of Legume CCs on the Physical Properties of Soil

The physical properties of soil are related to the size and distribution of soil particles, as well as the movement of liquids and gases in the soil, which affect the appearance and structure of the soil. The main physical properties of soil are texture, structure, density, porosity, soil water, soil temperature, and color. The infiltration properties of soil are determined by its physical properties, such as bulk density, porosity, sorption, and aggregation. CCs may change the physical and structural properties of soil, both directly through the influence of roots on the formation of pores and aggregates, and indirectly, by introducing plant residues into the soil, and their decomposition [215].

It has been shown that leaving the CCs biomass as a dead mulch on the soil surface, with no tillage, potentially contributes to the reduction of soil bulk density, increasing soil porosity, sorption and aggregation, and thus increases its infiltration properties. Reduced bulk density, as well as increased porosity and macro-aggregation of the soil also reduce the potential for runoff, erosion and evaporation by increasing the potential for faster water capture and greater water availability to plants. However, the positive effect of dead mulch on the physical properties of the soil, in particular on increasing infiltration and reducing evaporation, depends on the climatic conditions. In the case of prolonged drought, no differences were found to bare soil [216].

4.3.1. Effect of Legume CCs on Soil Structure and Aggregation

The structure of the soil is the shape, size, and arrangement of primary and secondary particles in a specific structural pattern. Residues of CC plants, including legume CCs, improve soil structure by influencing soil strength, porosity and hydraulic properties. They also increase the diffusion capacity of soil air, as well as the formation of soil aggregates (basic units of soil structure) [217–219] (Table 3).

Table 3. Effect of legume CCs on the physical properties of soil.

Legume Cover Crops	Crop/Tillage	Soil Texture	Bulk Density (g cm^{-3})	Water–Stable Agregates (%)	Mean Weight Diameter (mm)	Total Aggregate-Associated Carbon (dag kg^{-1})	Soil Particle Size Fractions (>0.002 mm)	Soil Total Porosity (%)	Soil Capillary Porosity (%)	Soil Penetration Resistance (MPa)	References
no legume CCs V. villosa Rotch.	Z. mays L./no-till	fine sandy loam	1.44 1.47								[220]
no legume CCs T. incarnatum L. V. villosa Rotch.	Z. mays L./no-till	clay loam		56.3 55.0 58.2							[191]
no legume CCs T. incarnatum L. V. villosa Rotch.	S. bicolor (L.) Moench/ conventional tillage	sandy clay loam		28.9 37.9 36.7							[191]
no legume CCs V. villosa Rotch. mixture of S. cereale L. and V. villosa Rotch.	Z. mays L. G. max (L.) Merr./no-till	silt loam	1.32 1.23 1.23	38.0 43.0 44.0							[24]
no legume CCs G. max (L.) Merr	T. aestivum L. S. bicolor (L.) Moench /no-till	silt loam	1.21 1.24		0.42 0.76						[221]
mixture of Phaseolus vulgaris L. and Pennisetum glaucum L. mixture of P. vulgaris L. and P. glaucum L. mixture of P. vulgaris L. and P. glaucum L.	Z. mays L./no-till minimum tillage conventional tillage	Typic Hapludult	1.58/0–10 1.71/10–20 1.47/0–10 1.48/10–20 1.64/0–10 1.77/10–20		1.79/0–5 1.47/5–10 1.05/10–20 1.79/0–5 1.16/5–10 1.05/10–20 1.53/0–5 1.26/5–10 1.42/10–20	0.96/0–5 0.57/5–10 0.36/10–20 1.08/0–5 0.66/5–10 0.54/10–20 0.51/0–5 0.39/5–10 0.54/10–20				1.94/0–10 4.07/10–20 1.64, 0–10 6.55/10–20 2.06/0–10 5.13/10–20	[217]
no legume CCs mixture of V. faba L. and V. villosa Rotch no legume CCs mixture of V. faba L. and V. villosa Rotch	T. aestivum L./plough or conservation tillage	silt loam	1.56/5–10 1.50/5–10 1.62/15–20 1.53/15–20				8 10 (plough tillage) 5 7 (conservation tillage)	38.5/5–10 40.7/5–10 36.4/15–20 39.1/15–20	34.4/5–10 35.0/5–10 32.4/15–20 33.0/15–20		[218]

Table 3. *Cont.*

Legume Cover Crops	Crop/Tillage	Soil Texture	Bulk Density (g cm^{-3})	Water–Stable Agregates (%)	Mean Weight Diameter (mm)	Total Aggregate-Associated Carbon (dag kg^{-1})	Soil Particle Size Fractions (>0.002 mm)	Soil Total Porosity (%)	Soil Capillary Porosity (%)	Soil Penetration Resistance (MPa)	References
no legume CCs *S. cereale* L. (in *Z. mays*) and *V. villosa* Rotch. (in *G. max*) *S. cereale* L. (in *Z. mays*) and mixture of *S. cereale* L. and *V. villosa* Rotch. (in *G. max*)	*Z. mays* L. *G. max* (L.) Merr./no-till	silt loam	1.41 1.37 1.37	38.6 42.1 44.1						1.41 1.49 1.46	[193]
no legume CCs *T. incarnatum* L. *V. villosa* Rotch	*Solanum lycopersicum* L. *Solanum melongena* L./ conventional tillage	sandy loam			1.70 1.66 1.71						[222]
no legume CCs mixture of *S. cereale* L., *P. sativum* L., and *T. incarnatum* L.			1.61 1.65								[192]

It has been shown that supplying plant residues, e.g., CCs, improves soil structure [219]. It depends not only on the total organic C content, but is a function of many factors, including the chemical composition of the organic matter and the applied management system [223].

An important physical property of soil is aggregation. It affects the soil's bulk density, porosity, followed by water infiltration, water consumption efficiency, wind and water erosion and, consequently, the yield. Many factors affect soil aggregation, especially organic matter content and soil texture. The mechanism of binding soil particles into stable aggregates varies depending on factors related to soil parent material, climate, vegetation, and management practices [224]. It was observed that earlier removal of crop residues and the reduction of organic matter content in the soil results in a decrease in the stability of aggregates [225]. The tillage system also affects aggregation. It was found that in conventional soil cultivation, the stability of aggregates and decomposition of plant residues decreased. This, in turn, led to the degradation of the soil structure. It was found that no-till soil not only increases the stability of the aggregates, but also improves the content of organic matter within the aggregates. It follows that post-harvest CC residues increase soil aggregation and its structural stability [191,226–228]. The use of CCs in cultivation increased the stability of aggregates in the soil (expressed as mean weight diameter) and the content of diluted acid-extractable polysaccharides. The diluted acid-extractable polysaccharides fraction has been shown to represent active binding agents under short-term cover crops [228]. Application *V. villosa* as a CC also contributed to the improvement of water-aggregate stability by 9% to 17% compared to cultivation without CCs [24]. Other authors also confirmed the beneficial effects of legume CCs (*T. incarnatum*, *V. villosa*) to increase water-stable aggregates, even by 1.2 to 2 times compared to cultivation without CCs [25,191]. Improving the stability of soil aggregates by introducing CCs into the cultivation also affects other physical properties of the soil, leading to improved water storage, soil macroporosity, as well as increased content of organic carbon and nutrients. As a result, this supports the growth of the plant root system, reduces soil erosion (protecting it against raindrops) and improves microbial activity [12]. The beneficial effect of roots on soil structure is seen in reduced soil volume density in the topsoil or in changed pore size distribution, but without increasing the total porosity [229,230]. This is confirmed by Carof et al. [231], who observed larger functional pores and an increased number of tubules in the soil under a no-till legume CC system, attributing these changes to the activity of the roots. The impact of CCs on increasing soil porosity and reducing the amount of occluded pores was also reported by Villamil et al. [24].

Numerous reports have confirmed that the stability of soil aggregates is associated with an increased concentration of organic carbon [232–234]. However, the improvement in water-stable aggregates may depend on the soil texture class, as legume CCs (*T. incarnatum*, *V. villosa*) improved this feature in sandy clay loam, but not in clay loam [191]. In addition, the use of a legume CC (*V. villosa*) also decreased penetration resistance and bulk density of the soil due to plant residues and increased soil organic matter compared to cultivation without CCs [24].

4.3.2. Effect of Legume CCs on Soil Water Management

By increasing soil aggregation, CCs improve its hydraulic properties, i.e., water infiltration, water retention capacity and saturated hydraulic conductivity (Table 4). It was found that the long-term effects of legume CCs, e.g., *V. villosa* and *T. incarnatum*, contributed to increasing soil porosity, saturated hydraulic conductivity, and water retention capacity [235], thus protecting its top layer. In turn, increasing water infiltration improves the ability to capture precipitation and store water [12].

Table 4. Effect of legume CCs on soil water management.

Legume Cover Crops	Crop/Tillage	Soil Texture	Water Infiltration (cm)	Soil Water Content /Depth (cm)	Soil Moisture	Water Stability Index (%)	References
V. villosa Rotch.	*Z. mays* L./no-till	silt loam	0.52				[236]
no legume CCs *G. max* (L.) Merr	*T. aestivum* L. *S. bicolor* (L.) Moench /no-till	silt loam	5.7 11.4				[221]
no legume CCs mixture of *A. sativa* L. and *V. villosa* Rotch.	*S. lycopersicum* L./ conventional tillage	loam	19.0 20.3				[237]
no legume CCs *Trifolium fragiferum* L.	orchard/conventional tillage	sandy loam	3.3 6.3				[237]
no legume CCs *V. dasycarpa* L. *L. angustifolius* L. no legume CCs mixture of *A. sativa* L.(90%) and *V. dasycarpa* L. (10%) mixture of *A. sativa* L.(70%) and *V. dasycarpa* L. (30%) mixture of *A. sativa* L.(50%) and *V. dasycarpa* L. (50%)	-	sandy loam	cumulative (mm) 40 41 43 28 41 44 57	($m^3 \cdot m^{-3}$) 0.56 0.72 0.68 0.74 0.77 0.77 0.80			[238]
no legume CCs *M. sativa* L. *T. pratense* L. *P. sativum* L.	*T. aestivum* L./ conventional tillage, fall planted	sandy clay loam		($g \cdot kg^{-1}$) 192/90 171/90 190/90 188/90			[52]
no legume CCs *M. sativa* L. *T. pratense* L. *P. sativum* L.	*T. aestivum* L./ conventional tillage, spring planted	sandy clay loam		($g \cdot kg^{-1}$) 188/90 189/90 189/90 185/90			[52]
no legume CCs *P. sativum* L. mixture of *P. sativum* L. and *A. sativa* L. mixture of *P. sativum* L. and *B. napus* L. mixture of *P. sativum* L., *A. sativa* L. and *B. napus* L. mixture of *P. sativum* L., *A. sativa* L., *B. napus* L., *V. villosa* Rotch, *R. sativus* L. and *H. vulgare* L.	*T. aestivum* L./no-till	clay loam		(%) 15.0 11.5 11.0 11.5 10.7 11.0			[188]

Table 4. *Cont.*

Legume Cover Crops	Crop/Tillage	Soil Texture	Water Infiltration (cm)	Soil Water Content /Depth (cm)	Soil Moisture	Water Stability Index (%)	References
no legume CCs *T. pratense* L. no legume CCs *T. pratense* L.	*T. aestivum* L. *Z. mays* L. *G. max* (L.) Merr./no-till	clay loam		(%) 27.1/0–10 27.0/0–10 31.2/0–30 30.8/0–30			[239]
no legume CCs *T. pratense* L. no legume CCs *T. pratense* L.	*T. aestivum* L. *Z. mays* L. *G. max* (L.) Merr./conventional tillage	clay loam		(%) 24.1/0–10 23.4/0–10 27.9/0–30 29.7/0–30			[239]
no legume CCs mixture of *S. cereale* L. and *V. villosa* Roth. mixture of *S. cereale* L. and *T. incarnatum* L. mixture of *S. cereale* L., *A. sativa* L., *Raphanus sativus* var. *niger* J. Kern., *B. campestris* L. and *T. incarnatum* L.	*Z. mays* L. *G. max* (L.) Merr./no-till	silt loam			(mm) 17 20 19 21		[189]
no legume CCs mixture of *V. faba* L. and *V. villosa* Rotch no legume CCs mixture of *V. faba* L. and *V. villosa* Rotch	*T. aestivum* L.	silt loam			(%) 16.7/5–10 17.6/5–10 (%) 16.9/15–20 18.2/15–20	40.4 70.2	[218]
mixture of *P.vulgaris* L. and *P. glaucum* L. mixture of *P. vulgaris* L. and *P. glaucum* L. mixture of *P. vulgaris* L. and *P. glaucum* L.	*Z. mays* L./no-till minimum tillage conventional tillage	Typic Hapludult			(g g⁻¹) 0.06/0–10 0.03/10–20 0.05/0–10 0.03/10–20 0.10/0–10 0.06/10–20		[217]
no legume CCs mixture of *P. sativum* L. ssp. *arvense* and *S. cereale* L. mixture of *V. villosa* Rotch and *S. cereale* L.	*Z. mays* L./no-till	loamy sand clay loam S		(%) volumetric 0.182/10 0.178/10 0.198/10			[86]
no legume CCs mixture of *P. sativum* L. ssp. *arvense* and *S. cereale* L. mixture of *V. villosa* Rotch and *S. cereale* L.	*Z. mays* L./no-till	clay loam S		(%) volumetric 0.251/10 0.257/10 0.261/10			[86]

The use of legume CCs as dead mulch contributes to reducing water loss by evapotranspiration. This improves water infiltration and moisture retention, inhibiting surface runoff, reducing soil degradation, slow nutrient release and delivering them to the rhizosphere of the plant, which ultimately improves resource efficiency [218,238,240–243]. Many authors have reported the beneficial effect of legume CCs on increasing soil moisture [195,244,245]. This effect is likely to result from improving the soil's structural features, which increase the infiltration rate and reduce soil water evaporation [246,247]. Singh et al. [216] confirmed that infiltration and water permeability is greater under no-tillage than under plow tillage because of the greater number of macrospores and increased microbial activity.

Increasing soil moisture is more favorably influenced by a greater variation of CCs in the mix [187,189]. CCs characterized by a deep root system (e.g., *L. angustifolius*), can also be particularly effective in increasing the effective root depth and subsoil water storage capacity [21,248]. However, Ghimire et al. [188] found that legume CCs can reduce soil water content by 2% to 3% compared to leaving the soil fallow (at the end of CC cultivation). However, leaving residual CCs between main crops increased the water content as well by 2% to 4% compared to fallow soil. Thorsted et al. [148] confirmed that in supporting the cultivation of the main crop with a legume intercrop, the water consumption in the soil increases due to the increased canopy transpiration from these plant species. Some authors found that a CC intercrop stimulated higher soil moisture only in the top layer (0–10 cm), while their effect on moisture in deeper layers turned out to be insignificant [249,250]. On the other hand, Harasim et al. [218] proved an increase in soil moisture at a depth of 15 to 20 cm with legume CCs cultivated as intercrops. RIL directly affects the availability of water for cultivated plants during the growing season, especially at a depth of 90 cm [251]. However, a lower legume CC used as intercrop has a lesser impact on the limited water availability than the main crop. Amossé et al. [251] found that the availability of water for the main crop is primarily determined by the development and size of the legume CCs root system, which the authors prove on the example of *M. sativa*. The legume is characterized by a strongly developed root system and, despite the lower above-ground part, it had a greater impact on reducing soil moisture than *T. pratense*.

It was found that in RIL cultivation, the time interval between sowing the main crop and the legume CCs allowed for sufficient development of the root system of the crop (before sowing the legume CCs) so that the plant could take up water from deeper soil layers. On the other hand, competition for soil water between the main crop and the legume CCs could have led to its roots growing to a greater depth. Therefore, despite the drying out of the top layer of soil, which is additionally increased by the sown legumes, the legume may not disturb the water uptake of the main crop if its root system is well developed and would not be limited by excessive soil compaction [251].

The negative influence of legume CCs as living mulch in the cultivation of the main crops is reported by Thorsted et al. [148] and Martens et al. [252] according to whom the competition between the legume CCs (*T. repens*, *T. pratense*) and a crop (*T. aestivum*) is decisive in terms of water availability in soil, apart from environmental conditions. Nielsen et al. [245] demonstrated that in a semi-arid environment, CCs use limited water reserves in the soil, which may also affect the availability of water for the successive crop cultivation and, consequently, its yield. Under these environmental conditions, the cultivation of mixed-species CCs is also unjustified as they use a similar amount of water as single-species CC cultivations.

On the other hand, in semi-arid Texas, cover crop as mulch (incorporated on soil surface) increased available soil water by 73% and more than doubled grain sorghum yields [253]. The availability of soil water at CC planting and depletion during growth are always a concern in semi-arid and arid regions. Therefore the potential benefits must be balanced against possible negative effects on the cash crop. Additionally, conservation tillage increases storage of precipitation in the soil through increased infiltration and reduced evaporation. This additional water supplements growing season precipitation and irrigation to meet crop water needs on the semi-arid regions [254].

4.3.3. Effect of Legume CCs on Soil Temperature and Light Availability

CCs help to mitigate soil temperature fluctuations by capturing solar radiation and isolating the soil, which prevents it from overheating. Numerous authors have confirmed that legume CCs used as mulch increases light reflection due to the lighter color of the soil surface. This in turn lowers the soil temperature and ultimately improves resource efficiency [218,240–243]. It was shown that residues of legume CCs reduce daily fluctuations in soil temperature in no-till systems, lowering its maximum and increasing the minimum, compared to conventional tillage systems. However, the effectiveness of CCs on soil temperature is determined by both the size of the CCs canopy cover and the amount of plant residues [21]. Cultivating CCs as living mulch allowed decreasing the maximum temperature by approximately 5 °C at 5 cm soil depth, compared to dead mulch left on the soil surface [255]. This is also confirmed by the studies of other authors, who additionally found an increase in the minimum soil temperature by 1 °C after application of legume CCs [46,221]. In turn, leaving the legume CC (*T. alexandrium*) after harvesting the main plant contributed to a delayed and shallower (by 0.2 m) soil freezing in late autumn, and earlier thawing and heating of the soil in spring (by approximately 3 °C) compared to the soil not covered with CCs [256]. Harvest residues of legume CCs regulate soil temperature, contributing to warming in winter and cooling in spring and summer [216]. Decreasing the maximum soil temperature during the summer period reduces evaporation from the soil surface and also increases water retention in the soil. On the other hand, the impact of CCs on the soil temperature in spring depends on the climatic conditions: in warm climates, slowing down the heating of the soil is beneficial for plants, while in cooler climates it may delay the germination and emergence of seeds, which adversely affects sowing [12]. Drury et al. [239] confirmed that decreasing the daily maximum temperature by using legume CCs as mulch can be particularly harmful in cool regions. In the case of plants grown in warmer regions, the use of legume CCs as mulch decreased the maximum soil temperature, favoring the growth and development of plants [257]. On the other hand, the darker color of the *V. villosa* mulch only slightly increased the soil temperature at a depth of 5 cm (by 0.5 °C) compared to the lighter mulch of *T. aestivum* [258].

However, according to Dabney et al. [21] soil temperature is more impacted by CCs used as living mulch or mulch left on the soil surface than CC harvest residues. Moreover, the effectiveness of soil temperature regulation by residual CCs is determined by the rate of their decomposition, and legume CCs tend to decompose as residue CCs faster than other CCs [46]. Hence, it is commonly believed that legume CCs have a lower soil temperature regulating effect than cereal crops. Moreover, according to Martens et al. [252], legume CCs also reduce temperature fluctuations at 5 cm above the soil surface.

Carof et al. [79] have shown that legume CCs, especially in the early stages of crop growth, can shade and compete with them for light. Therefore, when selecting legume Ccs, the species that should be taken into account are those with active growth and a relatively short growing season, so that they compete as little as possible with the crop for light. In the RIL system, the shading effect of the main crop (*T. aestivum*) occurred before its harvest, but only in the highest species of legumes (*M. sativa*) [251]. However, legume CCs can also compete for light with weeds whose seeds require light to germinate (e.g., small-seeded annual weeds), limiting their growth and development [136]. Plant residues of CCs can act as a physical barrier to emerging weeds by blocking their access to light, or by creating conditions similar to those in deeper soil layers (no light, lower daily temperature amplitude) [78]. However, living CCs legumes have a greater suppressive effect on weeds at all stages of their development than their crop residues. This is due to the fact that live CC legumes absorb red light to a greater extent and reduce the far-red ratio sufficient to inhibit phytochrome-mediated seed germination of weeds. In contrast, harvest residues of legume CCs have little effect on this ratio [126].

Low light levels hinder not only growth but also fixing N_2 in legumes, which need light to maintain symbiosis with *Rhizobium* and assimilation of N. This is more pronounced in the species *T. repens* than in *T. pratense* sown in the main crop [160].

4.4. Effect of Legume CCs on Wind and Water Soil Erosion

One of the benefits of growing CCs is to prevent soil degradation as a result of wind and water erosion. Water erosion affects both soil and water quality, as floodwater flows through various water bodies (including irrigation ditches, water reservoirs, drinking water). On the other hand, wind erosion mainly affects soil quality as it reduces its fertility [259].

Legume CCs effectively reduce the decline of the topsoil due to water erosion, as shown in the example *V. villosa*, or *V. villosa/T. aestivum* mix. In cultivation of *Gossypium hirsutum* L., the latter caused an 82% lower soil loss (conventional till) or 73% (no-till), compared to cultivation without CCs [260]. In turn, a decrease in soil loss by 39%, 68%, and 92%, respectively, was found in *Lens culinaris* Medik. (winter lentil) and *P. sativum* (spring pea) as CCs (*T. aestivum* as the main crop) [95] and a mix of *S. cereale* and *V. villosa* as CCs (with *Z. mays* as the main crop) [261]. On the other hand, runoff reduction was decreased by 13% (with a mix of *S. cereale* and *V. villosa* as CCs, *Z. mays* as the main crop) [261], 42% (with *L. culinaris* as CC, *T. aestivum* as the main crop), and up to 73% (with *P. sativum* as CCs, *T. aestivum* as the main crop) [96].

CCs are an effective technique to protect soil from erosion, especially when grown between primary crops, when they extend the period of soil coverage with plants [215]. However, at the beginning of winter, when CCs freeze, their aboveground biomass is less effective at protecting soil from water erosion, although their root system may still play an important role in improving soil resistance. Thick root cover plants are less effective in preventing soil loss by concentrated flow erosion than the finely branched root cover plants [262].

The influence of cover crops on erosive processes depends on how much they reduce the soil detachment and transporting forces. CCs reduce inter-row erosion, primarily by increasing the amount of soil covering with live plants or their remains, and its duration. Inter-row erosion is caused by the detachment of soil particles by the impacting raindrops. In contrast, live CCs or their debris intercept raindrops and dissipate the impact energy, contributing to the reduction of inter-row erosion [215].

CCs also reduce the loss of sediment and the dissolved nutrients (total P and NO_3—N), thus influencing the improvement of water quality, soil fertility, and plant yield [215]. CCs protect soil by absorbing the energy of raindrops, reducing detachment of aggregates and promoting formation of stable aggregates in the soil, increasing topsoil roughness, delaying the onset of runoff and intercepting it, reducing runoff speed, and increasing water infiltration [221]. However, the effectiveness of CCs in reducing soil water erosion is determined by the speed of plant growth and the production of biomass. Moreover, mixes of legume CCs with other species (e.g., grasses) are more effective in increasing the uniform surface cover than the monoculture cultivation, which ultimately helps to reduce soil erosion to a greater extent [263].

CCs also help to reduce wind erosion, which adversely affects the quality of the soil, especially in a semi-arid environment in the period when strong winds occur in the absence of plant cover (late winter and early spring). The use of winter or spring CCs that grow well in these conditions helps to reduce wind erosion. Blanco-Canqui et al. [78] observed a reduction in susceptibility to soil wind erosion by growing CCs (e.g., legumes and grasses) during fallow in wheat crop rotation. This reduced the fraction of soil susceptible to erosion (<0.84 mm in diameter) by 80% and increased the size of dry aggregates by 60%. Among the legume CCs, spring lentil contributed most to the increase in soil aggregate size distribution and the 1.6-fold reduction of the soil fraction susceptible to wind erosion. However, due to the faster decomposition of plant residues and the lower plant residue height, legume CCs are less effective at reducing wind erosion compared to grasses. Reducing the risk of wind erosion by CC cultivation is possible due to the improvement of the physical properties of the soil by improving its structure, as well as by increasing the organic C content of the soil and the physical retention of soil aggregates by the CCs' root system. Moreover, increasing the content of organic C in soil has an anti-erosion effect. It increases the stability of aggregates and reduces the fraction of soil susceptible to wind erosion, as organic C can physically, chemically and biologically fix soil particles to form stable macro-aggregates [264].

5. Conclusions

Legume CCs seem to be a useful agronomic solution in crops, especially when the aim is to protect natural resources, apart from improving or maintaining agricultural production at a high level. However, it is difficult to propose technical cultivation strategies that are applicable to all conditions. The reason for this is that legume CCs species have different agrotechnical requirements as well as morphological, phenological, and physiological characteristics that can affect the productivity of the main crop. Therefore, some authors argue that using multi-species CCs mixes that include legumes may be a good solution as the characteristics of individual species would complement each other or work synergistically.

In addition, legume CCs are seen as a systemic approach to weed control. Apart from reducing weed infestation, they provide many other agro-system benefits, including soil improvement. Living legume CCs inhibit the development of weed populations through niche pre-emption, while their crop residues inhibit or delay weed emergence and growth by creating a physical and chemical barrier (allelopathic effect). The multi-purpose character of legume CCs is visible in reducing compaction and erosion of the soil, improving its structural and hydraulic properties, increasing the content of organic matter and activity of soil microorganisms, or increasing its nitrogen content due to symbiotic N_2 fixing. This review shows that a wider use of legume CCs is needed in crops, especially in those with limited use of pesticides and mineral fertilizers (organic). It is also necessary to determine the benefits of legume CCs for successive crops under these growing conditions, both in terms of inhibiting weed population and improving soil fertility and its properties. Further research is also needed to determine the potential impact of legume CCs on the improvement of the quality of degraded soils, or those with less favorable physicochemical properties.

Author Contributions: Conceptualization, A.K., M.S., K.P. and H.L.; writing—original draft preparation, A.K., M.S., M.T., R.K., J.C., K.P., H.L.; writing—review and editing, A.K., M.S., K.P., H.L.; supervision, A.K. All authors have read and agreed to the published version of the manuscript.

References

1. Meena, M.S.; Singh, K.M. Conservation Agriculture: Innovations, Constraints and Strategies for Adoption. *Munich Pers. RePEc Arch.* **2013**, 49380. Available online: https://mpra.ub.uni-muenchen.de/49380/ (accessed on 31 July 2020). [CrossRef]

2. Oliveira, M.C.; Butts, L.; Werle, R. Assessment of Cover Crop Management Strategies in Nebraska, US. *Agriculture* **2019**, *9*, 124. [CrossRef]

3. Melander, B.; Rasmussen, I.A.; Bàrberi, P. Integrating physical and cultural methods of weed control-examples from European research. *Weed Sci.* **2005**, *53*, 369–381. [CrossRef]

4. Hartwig, N.L.; Ammon, H.U. Cover crops and living mulches. *Weed Sci.* **2002**, *50*, 688–699. [CrossRef]

5. Sarrantonio, M.; Gallandt, E. The role of cover crops in North American cropping systems. *J. Crop Prod.* **2003**, *8*, 53–74. [CrossRef]

6. Blackshaw, R.E.; Moyer, J.R.; Huang, H.C. Beneficial effects of cover crops on soil health and crop management. *Rec. Res. Dev. Soil Sci.* **2005**, *1*, 15–35.

7. Bàrberi, P.; Mazzoncini, M. Changes in weed community composition as influenced by cover crop and management system in continuous corn. *Weed Sci.* **2001**, *49*, 491–499. [CrossRef]

8. Shennan, C. Cover crops, nitrogen cycling and soil properties in semi-irrigated vegetable production systems. *HortScience* **1992**, *27*, 749–754. [CrossRef]

9. Wyland, L.J.; Jackson, L.E.; Chaney, W.E.; Klonsky, K.; Koike, S.T.; Kimple, B. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management. *Agric. Ecosyst. Environ.* **1996**, *59*, 1–17. [CrossRef]

10. Ritter, W.F.; Scarborough, R.W.; Chirnside, A.E.M. Winter cover crops as a best management practice for reducing nitrogen leaching. *J. Contam. Hydrol.* **1998**, *34*, 1–15. [CrossRef]

11. Shrestha, A.; Knezevic, S.Z.; Roy, R.C.; Ball-Coelho, B.R.; Swanton, C.J. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *Weed Res.* **2002**, *42*, 76–87. [CrossRef]

12. Blanco-Canqui, H.; Shaver, T.M.; Lindquist, J.L.; Shapiro, C.A.; Elmore, R.W.; Francis, C.A.; Hergert, G.W. Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils. *Agron. J.* **2015**, *107*, 2449–2474. [CrossRef]

13. Jabran, K.; Tursum, N.; Isik, D.; Demir, Z. Use of Living, Mowed, and Soil-Incorporated Cover Crops for Weed Control in Apricot Orchards. *Agronomy* **2018**, *8*, 150. [CrossRef]

14. Cutti, L.; Lamego, F.P.; de Aguiar, A.D.M.; Kaspary, T.E.; Gonsiorkiewicz-Rigon, C.A. Winter cover crops on weed infestation and maize yield. *Rev. Caatinga* **2016**, *29*, 885–891. [CrossRef]

15. Wallace, J.M.; Williams, A.; Liebert, J.A.; Ackroyd, V.J.; Vann, R.A.; Curran, W.S.; Keene, C.L.; VanGessel, M.J.; Ryan, M.R.; Mirsky, S.B. Cover Crop-Based, Organic Rotational No-Till Corn and Soybean Production Systems in the Mid-Atlantic United States. *Agriculture* **2017**, *7*, 34. [CrossRef]

16. Rizzardi, M.A.; Silva, L.F. Influence of Black Oats and Rape as Cover Crops on Chemical Weed Control Timing in No-till Corn. *Planta Daninha* **2006**, *24*, 669–675. [CrossRef]

17. Lemessa, F.; Wakjira, M. Cover Crops as a Means of Ecological Weed Management in Agroecosystems. *J. Crop Sci. Biotechnol.* **2015**, *18*, 133–145. [CrossRef]

18. Amossé, C.; Jeuffroyb, M.H.; Celettea, F.; Davida, C. Relay-intercropped forage legumes help to control weeds in organic grain production. *Eur. J. Agron.* **2013**, *49*, 158–167. [CrossRef]

19. Uchino, H.; Iwama, K.; Jitsuyama, Y.; Ichiyama, K.; Sugiura, E.; Yudate, T. Stable characteristics of cover crops for weed suppression in organic farming systems. *Plant Prod. Sci.* **2011**, *14*, 75–85. [CrossRef]

20. Elsalahy, H.; Döring, T.; Bellingrath-Kimura, S.; Arends, D. Weed Suppression in Only-Legume Cover Crop Mixtures. *Agronomy* **2019**, *9*, 648. [CrossRef]

21. Dabney, S.M.; Delgado, J.A.; Reeves, D.W. Using winter cover crops to improve soil and water quality. *Commun. Soil Sci. Plan.* **2001**, *32*, 1221–1250. [CrossRef]

22. Tiemann, L.K.; Grandy, A.S.; Atkinson, E.E.; Marin-Spiotta, E.; McDaniel, M.D. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecol. Lett.* **2015**, *18*, 761–771. [CrossRef] [PubMed]

23. Somenahally, A.; DuPont, J.I.; Brady, J.; McLawrence, J.; Northup, B.; Gowda, P. Microbial communities in soil profile are more responsive to legacy effects ofwheat-cover crop rotations than tillage systems. *Soil Biol. Biochem.* **2018**, *123*, 126–135. [CrossRef]

24. Villamil, M.B.; Bollero, G.A.; Darmody, R.G.; Simmons, F.W.; Bullock, D.G. No-till corn/soybean systems including winter cover crops: Effects on soil properties. *Soil Sci. Soc. Am. J.* **2006**, *70*, 1936–1944. [CrossRef]

25. Hubbard, R.K.; Strickland, T.C.; Phatak, S. Effects of cover crop systems on soil physical properties and carbon/nitrogen relationships in the Coastal Plain of southeastern USA. *Soil Tillage Res.* **2013**, *126*, 276–283. [CrossRef]

26. Gupta, Y.P. Anti-nutritional and toxic factors in food legumes: A review. *Plant Food Hum. Nutr.* **1987**, *37*, 201–228. [CrossRef] [PubMed]

27. Balbinot, A.A., Jr.; Fleck, N.G. Weed management in the corn crop through plant spatial arrangement and characteristics of genotypes. *Cienc. Rural* **2005**, *35*, 245–252. [CrossRef]

28. Smith, R.G.; Warren, N.D.; Cordeau, S. Are cover crop mixtures better at suppressing weeds than cover crop monocultures? *Weed Sci.* **2020**, *68*, 186–194. [CrossRef]

29. Wiggins, M.; McClure, M.; Hayes, R.; Steckel, L. Integrating Cover Crops and POST Herbicides for Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) Control in Corn. *Weed Technol.* **2015**, *29*, 412–418. [CrossRef]

30. Oerke, E.C. Crop losses to pests. *J. Agric. Sci.* **2006**, *144*, 31–43. [CrossRef]

31. den Hollander, N.G. Growth Characteristics of Several Clover Species and Their Suitability for Weed Suppression in a Mixed Cropping Design. Ph.D Thesis, Wageningen University, Wageningen, The Netherlands, 2012.

32. Tollenaar, M.; Dibo, A.A.; Aqilera, A.; Weise, S.F.; Swanton, C.J. Effect of crop density on weed interference in maize. *Agron. J.* **1994**, *86*, 591–595. [CrossRef]

33. Phatak, S.C. An integrated sustainable vegetable production system. *HortScience* **1992**, *27*, 738–741. [CrossRef]

34. Bastiaans, L.; Paolini, R.; Baumann, D.T. Integrated Crop Management: Opportunities and Limitations for Prevention of Weed Problems. In Proceedings of the 12th EWRS (European Weed Research Society) Symposium 2002, Wageningen, The Netherlands, 24–27 June 2002; pp. 8–9.

35. Bilalis, D.; Karkanis, A.; Efthimiadou, A. Effects of two legume crops, for organic green manure, on weed flora, under Mediterranean conditions: Competitive ability of five winter season weed species. *Afr. J. Agric. Res.* **2009**, *4*, 1431–1441.

36. Efthimiadou, A.P.; Karkanis, A.C.; Bilalis, D.J.; Efthimiadis, P. Review: The phenomenon of crop-weed competition; a problem or a key for sustainable weed management. *J. Food Agric. Environ.* **2009**, *7*, 861–868.

37. Lemerle, D.; Verbeek, B.; Orchard, B. Ranking the ability of wheat varieties to compete with *Lolium rigidum*. *Weed Res.* **2001**, *41*, 197–209. [CrossRef]

38. Pester, T.A.; Burnside, O.C.; Orf, J.H. Increasing crop competitiveness to weeds through crop breeding. *J. Crop Prod.* **2011**, *2*, 59–76. [CrossRef]

39. Korres, N.E.; Froud-Williams, R.J. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. *Weed Res.* **2002**, *42*, 417–428. [CrossRef]

40. Seavers, G.P.; Wright, K.J. Crop canopy development and structure influence weed suppression. *Weed Res.* **2002**, *39*, 319–328. [CrossRef]

41. Ross, S.M.; King, J.R.; Izaurralde, R.C.; O'Donovan, J.T. Weed suppression by seven clover species. *Agron. J.* **2001**, *93*, 820–827. [CrossRef]

42. Mennan, H.; Ngouajio, M.; Kaya, E.; Isık, D. Weed Management in Organically Grown Kale Using Alternative Cover Cropping Systems. *Weed Technol.* **2009**, *23*, 81–88. [CrossRef]

43. Kruidhof, H.M.; Bastiaans, L.; Kropff, M.J. Ecological weed management by cover cropping: Effects on weed growth in autumn and weed establishment in spring. *Weed Res.* **2008**, *48*, 492–502. [CrossRef]

44. Khanh, T.D.; Chung, M.I.; Xuan, T.D.; Tawata, S. The exploitation of crop allelopathy in sustainable Agricultural production. *J. Agron. Crop Sci.* **2005**, *191*, 172–184. [CrossRef]

45. Weston, L.A. Utilization of allelopathy for weed management in agroecosystems. *Agron. J.* **1996**, *88*, 860–866. [CrossRef]

46. Mohler, C.L.; Teasdale, J.R. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. *Weed Res.* **1993**, *33*, 487–499. [CrossRef]

47. Teasdale, J.R.; Mohler, C.L. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. *Agron. J.* **1993**, *85*, 673–680. [CrossRef]

48. Teasdale, J.R. Contribution of cover crops to weed management in sustainable agricultural systems. *J. Prod. Agric.* **1996**, *9*, 475–479. [CrossRef]

49. Blanco-Canqui, H. Crop residue removal for bioenergy reducessoil carbon pools: How can we offset carbon losses? *Bioenergy Res.* **2013**, *6*, 358–371. [CrossRef]

50. Campiglia, E.; Radicetti, E.; Brunetti, P.; Mancinelli, R. Do cover crop species and residue management play a leading role in pepper productivity? *Sci. Hortic.* **2014**, *166*, 97–104. [CrossRef]

51. Davis, A.S. Cover-Crop Roller—Crimper Contributes to Weed Management in No-Till Soybean. *Weed Sci.* **2010**, *58*, 300–309. [CrossRef]

52. Caamal-Maldonado, J.A.; Jiménez-Osornio, J.J.; Torres-Barragán, A.; Anaya, A.L. The use of allelopathic legume cover and mulch species for weed control in cropping systems. *Agron. J.* **2001**, *93*, 27–36. [CrossRef]

53. Blackshaw, R.E.; Molnar, L.J.; Moyer, J.R. Suitability of legume cover crop winter wheat intercrops on the semi-arid Canadian prairies. *Can. J. Plant Sci.* **2010**, *90*, 479–488. [CrossRef]

54. Blaser, B.C.; Singer, J.W.; Gibson, L.R. Winter cereal canopy effect on cereal and interseeded legume productivity. *Agron. J.* **2011**, *103*, 1180–1185. [CrossRef]

55. Hartl, W. Influence of undersown clovers on weeds and on the yield of winter wheat in organic farming. *Agric. Ecosyst. Environ.* **1989**, *27*, 389–396. [CrossRef]

56. Fisk, J.W.; Hesterman, O.B.; Shrestha, A.; Kells, J.J.; Harwood, R.R.; Squire, J.M.; Sheaffer, C.C. Weed Suppression by Annual Legume Cover Crops in No-Tillage Corn. *Agron. J.* **2001**, *93*, 319–325. [CrossRef]

57. Reimer, M.; Ringselle, B.; Bergkvist, G.; Westaway, S.; Wittwer, R.; Baresel, J.P.; van der Heijden, M.G.A.; Mangerud, K.; Finckh, M.R.; Brandsæter, L.O. Interactive Effects of Subsidiary Crops and Weed Pressure in the Transition Period to Non-Inversion Tillage, A Case Study of Six Sites Across Northernand Central Europe. *Agronomy* **2019**, *9*, 495. [CrossRef]

58. Salonen, J.; Ketoja, E. Undersown cover crops have limited weed suppression potential when reducing tillage intensity in organically grown cereals. *Org. Agric.* **2019**. [CrossRef]

59. Campiglia, E.R.; Paolini, G.C.; Mancunelli, R. The effects of cover cropping on yield and weed control of potato in a transitional system. *Field Crop. Res.* **2009**, *112*, 16–23. [CrossRef]

60. Buraczyńska, D.; Ceglarek, C. The role of green manures, in form of undersown cover crops, and straw in sugar beet cultivation Part I. Sugar beet plantations infestation with weeds. *Biul. IHAR* **2004**, *234*, 171–180.

61. Brandsæter, L.O.; Netland, J. Winter Annual Legumes for Use as Cover Crops in Row Crops in Northern Regions: I. Field Experiments. *Crop Sci.* **1999**, *39*, 1369–1379. [CrossRef]

62. Döring, T.F.; Storkey, J.; Baddeley, J.A.; Collins, R.P.; Crowley, O.; Howlett, S.A.; Jones, H.E.; McCalman, H.; Measures, M.; Pearce, H.; et al. Weeds in organic fertility-building leys: Aspects of species richness and weed management. *Org. Farming* **2017**, *3*, 51–65. [CrossRef]

63. Blaser, B.C.; Gibson, L.R.; Singer, J.W.; Jannink, J.L. Optimizing seeding rates for winter cereal grains and frost-seeded red clover intercrops. *Agron. J.* **2006**, *98*, 1041–1049. [CrossRef]

64. Mutch, D.R.; Martin, T.E.; Kosola, K.R. Red clover (*Trifolium pratense*) suppression of common ragweed (*Ambrosia artemisiifolia*) in winter wheat (*Triticum aestivum*). *Weed Technol.* **2003**, *17*, 181–185. [CrossRef]

65. Sjursen, H.; Brandsæter, L.O.; Netland, J. Effects of repeated clover undersowing, green manure ley and weed harrowing on weeds and yields in organic cereals. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2012**, *62*, 138–150. [CrossRef]

66. Yeganehpoor, F.; Salmasi, S.Z.; Abedi, G.; Samadiyan, F.; Beyginiya, V. Effects of cover crops and weed management on corn yield. *J. Saudi Soc. Agric. Sci.* **2015**, *14*, 178–181. [CrossRef]

67. Brennan, E.B.; Boyd, N.S.; Smith, R.F.; Foster, P. Seeding Rate and Planting Arrangement Effects on Growth and Weed Suppression of a Legume-Oat Cover Crop for Organic Vegetable Systems. *Agron. J.* **2009**, *101*, 979–988. [CrossRef]

68. Murungu, F.S.; Chiduza, C.; Muchaonyerwa, P. Biomass accumulation, weed dynamics and nitrogen uptake by winter cover crops in a warm-temperate region of South Africa. *Afr. J. Agric. Res.* **2010**, *5*, 1632–1642.

69. Ranaldo, M.; Carlesi, S.; Costanzo, A.; Barberi, P. Functional diversity of cover crop mixtures enhances biomass yield and weed suppression in a Mediterranean agroecosystem. *Weed Res.* **2019**, *60*, 96–108. [CrossRef]

70. Charles, K.S.; Ngouajio, M.; Warncke, D.D.; Poff, K.L.; Hausbeck, M.K. Integration of cover crops and fertilizer rates for weed management in celery. *Weed Sci.* **2006**, *54*, 326–334. [CrossRef]

71. Campiglia, E.; Caporali, F.; Radicetti, E.; Mancinelli, R. Hairy vetch (*Vicia villosa* Roth.) cover crop residue management for improving weed control and yield in no-tillage tomato (*Lycopersicon esculentum* Mill.) production. *Eur. J. Agron.* **2010**, *33*, 94–102. [CrossRef]

72. Seman-Varner, R.; Varco, J.J.; O'Rourke, M.E. Winter Cover Crop and Fall-Applied Poultry Litter Effects on Winter Cover and Soil Nitrogen. *Agron. J.* **2019**, *111*, 3301–3309. [CrossRef]

73. Mirsky, S.B.; Curran, W.S.; Mortensen, D.M.; Ryan, M.R.; Shumway, D.L. Timing of Cover-Crop Management Effects on Weed Suppression in No-Till Planted Soybean using a Roller-Crimper. *Weed Sci.* **2011**, *59*, 380–389. [CrossRef]

74. Golian, J.; Anyszka, Z.; Kosson, R.; Grzegorzewska, M. Effectiveness of selected methods of weed management and their effect on nutrition value and storage ability of red head cabbage. *J. Res. Appl. Agric. Eng.* **2016**, *61*, 144–150.

75. Kohut, M.; Anyszka, Z.; Golian, J. Changes in infestation and yielding of selected vegetable species depending on weed management method. *J. Res. Appl. Agric. Eng.* **2013**, *58*, 255–260.

76. Leavitt, M.J.; Sheaffer, C.C.; Wyse, D.L.; Allan, D.L. Rolled Winter Rye and Hairy Vetch Cover Crops Lower Weed Density but Reduce Vegetable Yields in No-tillage Organic Production. *HortScience* **2011**, *46*, 387–395. [CrossRef]

77. Da Silva, A.C.; Hirata, E.K.; Monquero, P.A. Straw yield and cover crop weed suppression in a no tillage system for processing tomato. *Pesq. Agropec. Bras.* **2009**, *44*, 22–28.

78. Teasdale, J.R.; Brandsæter, L.O.; Calegari, A.; Skora Neto, F. Cover Crops and Weed Management. In *Non-Chemical Weed Management: Principles, Concepts and Technology*; Upadhyaya, M.K., Blackshaw, R.E., Eds.; CABI: Wallingford, UK, 2007; pp. 49–64.

79. Carof, M.; de Tourdonnet, S.; Saulas, P.; le Floch, D.; Roger-Estrade, J. Undersowing wheat with different living mulches in a no-till system. II. Competition for light and nitrogen. *Agron. Sustain. Dev.* **2007**, *27*, 357–365. [CrossRef]

80. Fradgley, N.S.; Creissen, H.E.; Pearce, H.; Howlett, S.A.; Pearce, B.D.; Döring, T.F.; Girling, R.D. Weed Suppression and Tolerance in Winter Oats. *Weed Technol.* **2017**, *31*, 740–751. [CrossRef]

81. Weidlich, E.W.A.; von Gillhaussen, P.; Delory, B.M.; Blossfeld, S.; Poorter, H.; Temperton, V.M. The Importance of Being First: Exploring Priority and Diversity Effects in a Grassland Field Experiment. *Front. Plant Sci.* **2017**, *7*, 1–12. [CrossRef]

82. Mediene, S.; Valantin-Morison, M.; Sarthou, J.P.; Tourdonnet, S.; Gosme, M.; Bertrand, M.; Roger-Estrade, J.; Aubertot, J.N.; Rusch, A.; Motisi, N.; et al. Agroecosystem management and biotic interactions: A review. *Agron. Sustain. Dev.* **2011**, *31*, 491–514. [CrossRef]

83. Teasdale, J.R.; Beste, C.E.; Potts, W.E. Response of weeds to tillage and cover crop residue. *Weed Sci.* **1991**, *39*, 195–199. [CrossRef]

84. Teasdale, J.R.; Mohler, C.L. The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci.* **2000**, *48*, 385–392. [CrossRef]

85. Weston, L.A.; Duke, S.O. Weed and crop allelopathy. *Crit. Rev. Plant Sci.* **2003**, *22*, 367–389. [CrossRef]

86. Wells, M.S.; Reberg-Horton, S.C.; Mirsky, S.B. Planting Date Impacts on Soil Water Management, Plant Growth, and Weeds in Cover-Crop-Based No-Till Corn Production. *Agron. J.* **2016**, *108*, 162–170. [CrossRef]

87. Diyanat, M. Weed Management in Organic Horticulture by Cover Crop in Iran. *Int. J. Adv. Biol. Biom. Res.* **2015**, *3*, 153–162.

88. Bhowmik, P.C. Challenges and opportunities in implementing allelopathy for natural weed management. *Crop Prot.* **2003**, *22*, 661–671. [CrossRef]

89. Teasdale, J.R.; Coffman, C.B.; Mangum, R.W. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. *Agron. J.* **2007**, *99*, 1297–1305. [CrossRef]

90. Mischler, R.; Duiker, S.; Curran, W.S.; Wilson, D. Hairy Vetch Management for No-Till Organic Corn Production. *Agron. J.* **2010**, *120*, 355–362. [CrossRef]

91. Moonen, A.C.; Bàrberi, P. Size and composition of the weed seedbank after 7 years of different cover crop-maize management systems. *Weed Res.* **2004**, *44*, 163–177. [CrossRef]

92. Wallace, J.M.; Curran, W.S.; Mortensen, D.A. Cover crop effects on horseweed (*Erigeron canadensis*) density and size inequality at the time of herbicide exposure. *Weed Sci.* **2019**, *67*, 327–338. [CrossRef]

93. Wiggins, M.S.; Hayes, R.M.; Steckel, L.E. Evaluating cover crops and herbicides for glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) control in cotton. *Weed Technol.* **2016**, *30*, 415–422. [CrossRef]

94. Brainard, D.C.; Bellinder, R.R.; Kumar, V. Grass-legume mixtures and soil fertility affect cover crop performance and weed seed production. *Weed Technol.* **2011**, *35*, 473–479. [CrossRef]

95. Lu, Y.; Watkins, K.; Teasdale, J.R.; Abdul-Baki, A. Cover crops in sustainable food production. *Food Rev. Int.* **2000**, *16*, 121–157. [CrossRef]

96. Blanco-Canqui, H.; Holman, J.D.; Schlegel, A.J.; Tatarko, J.; Shaver, T. Replacing fallow with cover crops in a semiarid soil: Effects on soil properties. *Soil Sci. Soc. Am. J.* **2013**, *77*, 1026–1034. [CrossRef]

97. Teasdale, J.R. Principles and Practices for Using Cover Crops in Weed Management Systems. In *Weed Management for Developing Countries*; Add. 1, FAO Paper 120; Labrada, R., Ed.; Fao: Rome, Italy, 2003.

98. Kalinova, J. Allelopathy and Organic Farming. In *Sociology, Organic Farming, Climate Change and Soil Science, Sustainable Agriculture Reviews*; Lichtfouse, E., Ed.; Springer Science+Business Media BV.: Dordrecht, The Netherlands, 2010; Volume 3, pp. 379–418.

99. Wang, R.; Yang, X.; Song, Y.; Zhang, M.; Hu, L.; Su, Y.; Zeng, R. Allelopathic potential of *Tephrosia vogelii* Hook. f.: Laboratory and field evaluation. *Allelopathy J.* **2011**, *28*, 53–62.

100. Xuan, T.D.; Shinkichi, T.; Khanh, T.D.; Min, C.I. Biological control of weeds and plant pathogens in paddy rice by exploiting plant allelopathy: An overview. *Crop Prot.* **2005**, *24*, 197–206. [CrossRef]

101. Xuan, T.D.; Tawata, S.; Khanh, T.D.; Chung, I.M. Decomposition of allelopathic plants in soil. *J. Agron. Crop Sci.* **2005**, *191*, 162–171. [CrossRef]

102. Hauggaard-Nielsen, H.; Andersen, M.K.; Jørnsgaard, B.; Jensen, E.S. Density and relative frequency effects on competitive interactions and resource use in pea-barley intercrops. *Field Crop. Res.* **2006**, *95*, 256–267. [CrossRef]

103. Exner, D.N.; Cruse, R.M. Interseeded forage legume potential as winter ground cover, nitrogen source, and competitor. *J. Prod. Agric.* **1993**, *6*, 226–231. [CrossRef]

104. Schlegel, A.J.; Havlin, J.L. Green fallow for the central great plains. *Agron. J.* **1997**, *89*, 762–767. [CrossRef]

105. Finney, D.M.; White, C.M.; Kaye, J.P. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. *Agron. J.* **2016**, *108*, 39–52. [CrossRef]

106. Bybee-Finley, K.; Mirsky, S.B.; Ryan, M.R. Crop Biomass Not Species Richness Drives Weed Suppression in Warm-Season Annual Grass–Legume Intercrops in the Northeast. *Weed Sci.* **2017**, *65*, 669–680. [CrossRef]

107. Hiltbrunner, J.; Liedgens, M.; Bloch, L.; Stamp, P.; Streit, B. Legume cover crops as living mulches for winter wheat: Components of biomass and the control of weeds. *Eur. J. Agron.* **2007**, *26*, 21–29. [CrossRef]

108. Weston, L.; Inderjit, S. Allelopathy: A Potential Tool in the Development of Strategies for Biorational Weed Management. In *Non-Chemical Weed Management: Principles, Concepts and Technology*; Upadhyaya, M.K., Blackshaw, R.E., Eds.; CABI: Wallingford, UK, 2007; pp. 65–76.

109. Xuan, T.D.; Tsuzuki, E.; Uematsu, H.; Terao, H. Weed control with alfalfa pellets in transplanting rice. *Weed Biol. Manag.* **2001**, *1*, 231–235. [CrossRef]

110. Xuan, T.D.; Tsuzuki, E.; Terao, H.; Matsuo, M.; Khanh, T.D. Correlation between growth inhibitory exhibition and suspected allelochemicals (phenolic compounds) in the extract of alfalfa (*Medicago sativa* L.). *Plant Prod. Sci.* **2003**, *6*, 165–171. [CrossRef]

111. Elsalahy, H.; Bellingrath-Kimura, S.; Döring, T. Allelopathic effects in species mixtures of legumes. In *Improving Sown Grasslands through Breeding and Management, Proceedings of the Joint 20th Symposium of the European Grassland Federation and the 33rd Meeting of the EUCARPIA, Zurich, Switzerland, 24–27 June 2019*; Huguenin-Elie, O., Studer, B., Kölliker, R., Reheul, D., Probo, M., Barre, P., Feuerstein, U., Roldán-Ruiz, I., Mariotte, P., Hopkins, A., Eds.; Organising Committee: Zurich, Switzerland, 2019; p. 128.

112. White, R.H.; Worsham, A.D.; Blum, U. Allelopathic potential of legume debris and aqueous extracts. *Weed Sci.* **1989**, *37*, 674–679. [CrossRef]

113. Kamo, T.; Hiradate, S.; Fujii, Y. First isolation of natural cyanamide as a possible allelochemical from hairy vetch *Vicia Villosa*. *J. Chem. Ecol.* **2003**, *29*, 275–283. [CrossRef]

114. Bradow, J.M.; Connick, W.J., Jr. Volatile Seed Germination Inhibitors from Plant Residues. *J. Chem. Ecol.* **1990**, *16*, 645–666. [CrossRef]

115. Ohno, T.; Doolan, K.; Zibilske, L.M.; Liebman, M.; Gallandt, E.R.; Berube, C. Phytotoxic effects of red clover amended soils on wild mustard seedling growth. *Agric. Ecosyst. Environ.* **2000**, *78*, 187–192. [CrossRef]

116. Ohno, T.; Doolan, K.L. Effects of red clover decomposition on phytotoxicity to wild mustard seedling growth. *Appl. Soil Ecol.* **2001**, *16*, 187–192. [CrossRef]

117. Kruidhof, H.M.; Bastiaans, L.; Kropff, M.J. Cover crop residue management for optimizing weed control. *Plant Soil* **2009**, *318*, 169–184. [CrossRef]

118. Osipitan, O.A.; Dille, J.A.; Assefa, Y.; Knezevic, S.Z. Cover Crop for Early Season Weed Suppression in Crops: Systematic Review and Meta-Analysis. *Agron. J.* **2018**, *110*, 2211–2221. [CrossRef]

119. Mennan, H.; Jabran, K.; Zandstra, B.H.; Pala, F. Non-Chemical Weed Management in Vegetables by Using Cover Crops: A Review. *Agronomy* **2020**, *10*, 257. [CrossRef]

120. Ryan, M.R.; Mortensen, D.A.; Bastiaans, L.; Teasdale, J.R.; Mirsky, S.B.; Curran, W.S.; Seidel, R.; Wilson, D.O.; Hepperly, P.R. Elucidating the apparent maize tolerance to weed competition in long-term organically managed systems. *Weed Res.* **2010**, *50*, 25–36. [CrossRef]

121. Meiss, H.; le Lagadec, L.; Munier-Jolain, N.; Waldhardt, R.; Petit, S. Weed seed predation increases with vegetation cover in perennial forage crops. *Agric. Ecosyst. Environ.* **2010**, *138*, 10–16. [CrossRef]

122. Medd, R.W.; Ridings, H.I. Relevance of Seed Kill for the Control of Annual Grass Weeds in Crops. In Proceedings of the VII International Symposium on the Biological Control of Weeds, Rome, Italy, 6–11 March 1989; pp. 645–650.

123. Youngerman, C.Z.; di Tommaso, A.; Losey, J.E.; Ryan, M.R. Cover crop seed preference of four common weed seed predators. *Renew. Agric. Food Syst.* **2019**, 1–11. [CrossRef]

124. Blubaugh, C.K.; Hagler, J.R.; Machtley, S.A.; Kaplan, I. Cover crops increase foraging activity of omnivorous predators in seed patches and facilitate weed biological control. *Agric. Ecosyst. Environ.* **2016**, *231*, 264–270. [CrossRef]

125. Teasdale, J.R.; Mirsky, S.B.; Cavigelli, M.A. Weed species and traits associated with organic grain crop rotations in the mid-Atlantic region. *Weed Sci.* **2019**, *67*, 595–604. [CrossRef]

126. Teasdale, J.R.; Daughtry, C.S.T. Weed Suppression by Live and Dessicated Hairy Vetch. *Weed Sci.* **1993**, *41*, 207–212. [CrossRef]

127. Masiunas, J.B.; Eastburn, D.M.; Mwaja, V.N.; Estman, C.E. The Impact of Living and Cover Crop Mulch System on Pests and Yield of Snap Beans and Cabbage. *J. Sustain. Agric.* **1997**, *9*, 61–89. [CrossRef]

128. Teasdale, J.R.; Mangum, R.W.; Radhakrishnan, J.; Cavigelli, M.A. Weed seedbank dynamics in three organic farming crop rotations. *Agron. J.* **2004**, *96*, 1429–1435. [CrossRef]

129. Hoffman, M.L.; Regnier, E.E. Contributions to Weed Suppression from Cover Crops. In *Sustainable Weed Management*; Singh, P., Batish, D.R., Kohli, R.K., Eds.; Food Products Press: New York, NY, USA, 2006; pp. 51–75.

130. Blackshaw, R.E.; Semach, G.; Li, X.; O'donovan, J.T.; Neil Harker, K. An integrated weed management approach to managing foxtail barley (*Hordeum jubatum*) in conservation tillage systems. *Weed Technol.* **1999**, *13*, 347–353. [CrossRef]

131. Streit, B.; Rieger, S.B.; Stamp, P.; Richner, W. The effect of tillage intensity and time of herbicide application on weed communities and populations in maize in Central Europe. *Agric. Ecosyst. Environ.* **2002**, *92*, 211–224. [CrossRef]

132. Sanderson, M.A.; Brink, G.; Stout, R.; Ruth, L. Grass-Legume proportions in forage seed mixtures and effects on herbage yield and weed abundance. *Agron. J.* **2013**, *105*, 1289–1297. [CrossRef]

133. Blum, U.; King, L.D.; Gerig, T.M.; Lehman, M.E.; Worsham, A.D. Effects of clover and small grain cover crops and tillage techniques on seedling emergence of some dicotyledonous weed species. *Am. J. Altern. Agric.* **1997**, *4*, 146–161. [CrossRef]

134. Singer, J.W.; Kohler, K.A.; McDonald, P.B. Self-seeding winter cereal cover crops in soybean. *Agron. J.* **2007**, *99*, 73–79. [CrossRef]

135. Creamer, N.G.; Dabney, S.M. Killing cover crops mechanically: Review of recent literature and assessment of new research results. *Am. J. Alt. Agric.* **2002**, *17*, 32–40. [CrossRef]

136. Teasdale, J.R.; Rosecrance, R.C. Mechanical versus herbicidal strategies for killing a hairy vetch cover crop and controlling weeds in minimum-tillage corn production. *Am. J. Altern. Agric.* **2003**, *18*, 95–102. [CrossRef]

137. Ashford, D.L.; Reeves, D.W. Use of a mechanical roller–crimper as an alternative kill method for cover crops. *Am. J. Altern. Agric.* **2003**, *18*, 37–45. [CrossRef]

138. Judice, W.E.; Griffin, J.L.; Etheredge, L.M.; Jones, C.A. Effects of Crop Residue Management and Tillage on Weed Control and Sugarcane Production. *Weed Technol.* **2007**, *21*, 606–611. [CrossRef]

139. Mahmood, A.; Ihsan, M.Z.; Khaliq, A.; Hussain, S.; Cheema, Z.A.; Naeem, M.; Daur, I.; Hussain, H.A.; Alghabari, F. Crop Residues Mulch as Organic Weed Management Strategy in Maize. *Clean Soil Air Water* **2015**, *43*, 1–8. [CrossRef]

140. Khaliq, A.; Matloob, A.; Hussain, A.; Hussain, S.; Aslam, F.; Zamir, S.I.; Chattha, M.U. Wheat Residue Management Options Affect Productivity, Weed Growth and Soil Properties in Direct-Seeded Fine Aromatic Rice. *Clean Soil Air Water* **2015**, *43*, 1259–1265. [CrossRef]

141. Gallandt, E.R.; Molloy, T.; Lynch, R.P.; Drummond, F.A. Effect of cover-cropping systems on invertebrate seed predation. *Weed Sci.* **2005**, *53*, 69–76. [CrossRef]

142. Fahad, S.; Hussain, S.; Chauhan, B.S.; Saud, S.; Wu, C.; Hassan, S.; Tanveer, M.; Jan, A.; Huang, J. Weed Growth and Crop Yield Loss in Wheat as Influenced by Row Spacing and Weed Emergence Times. *Crop Prot.* **2015**, *71*, 101–108. [CrossRef]

143. Ranaivoson, L.; Naudin, K.; Ripoche, A.; Affholder, F.; Rabeharisoa, L.; Corbeels, M. Agro-Ecological functions of crop residues under conservation agriculture. A review. *Agron. Sustain. Dev.* **2017**, *37*, 1–17. [CrossRef]

144. Reddy, K.N. Effect of Cereal and Legume Cover Crop Residues on Weeds, Yield and Net Return in Soybean (*Glycine max* L.). *Weed Technol.* **2001**, *15*, 660–668. [CrossRef]

145. Sims, B.; Corsi, S.; Gbehounou, G.; Kienzle, J.; Taguchi, M.; Friedrich, T. Sustainable Weed Management for Conservation Agriculture: Options for Smallholder Farmers. *Agriculture* **2018**, *8*, 118. [CrossRef]

146. Liebl, R.; Simmons, F.W.; Wax, L.M.; Stoller, E.W. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (*Glycine max*). *Weed Technol.* **1992**, *6*, 838–846. [CrossRef]

147. Teasdale, J.R.; Pillai, P. Contribution of ammonium to stimulation of smooth pigweed (*Amaranthus hybridus* L.) germination by extracts of hairy vetch (*Vicia villosa* Roth) residue. *Weed Biol. Manag.* **2005**, *5*, 19–25. [CrossRef]

148. Thorsted, M.D.; Weiner, J.; Olesen, J.E. Above- and below-ground competition between intercropped winter wheat *Triticum aestivum* and white clover *Trifolium repens*. *J. Appl. Ecol.* **2006**, *43*, 237–245. [CrossRef]

149. Bedoussac, L.; Journet, E.P.; Hauggaard-Nielsen, H.; Naudin, C.; Corre-Hellou, G.; Jensen, E.S.; Prieur, L.; Justes, E. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agron. Sustain. Dev.* **2015**, *35*, 911–935. [CrossRef]

150. Bedoussac, L.; Justes, E. Dynamic analysis of competition and complementarity for light and N use to understand the yield and the protein concentration of a durum wheat-winter pea intercrop. *Plant Soil* **2010**, *330*, 37–54. [CrossRef]

151. Dreccer, M.; Schapendonk, A.; Slafer, G.; Rabbinge, R. Comparative response of wheat and oilseed rape to nitrogen supply: Absorption and utilisation efficiency of radiation and nitrogen during the reproductive stages determining yield. *Plant Soil* **2000**, *220*, 189–205. [CrossRef]

152. Poggio, S.L. Structure of weed communities occurring in monoculture and intercropping of field pea and barley. *Agric. Ecosyst. Environ.* **2005**, *109*, 48–58. [CrossRef]

153. Banik, P.; Midya, A.; Sarkar, B.K.; Ghose, S.S. Wheat and chickpea intercropping systems in an additive experiment. Advantages and weed smothering. *Eur. J. Agron.* **2006**, *24*, 325–332. [CrossRef]

154. Corre-Hellou, G.; Dibet, A.; Hauggaard-Nielsen, H.; Crozat, Y.; Gooding, M.; Ambus, P.; Dahlmann, C.; von Fragstein, P.; Pristeri, A.; Monti, M.; et al. The competitive ability of pea-barley intercrops against weeds and the interactions with crop productivity and soil N availability. *Field Crop. Res.* **2011**, *122*, 264–272. [CrossRef]

155. McDonald, G.K. Competitiveness against grass weeds in field pea genotypes. *Weed Res.* **2003**, *43*, 48–58. [CrossRef]

156. Corre-Hellou, G.; Crozat, Y. N2 fixation and N supply in organic pea (*Pisum sativum* L.) cropping systems as affected by weeds and peaweevil (*Sitona lineatus* L.). *Eur. J. Agron.* **2005**, *22*, 449–458. [CrossRef]

157. Bojarszczuk, J.; Księżak, J.; Staniak, M. Evaluation of weed infestation of triticale and pea mixtures grown for fodder seeds. *J. Res. Appl. Agric. Eng.* **2017**, *62*, 42–48.

158. Staniak, M.; Bojarszczuk, J.; Księżak, J. Undersown serradella (*Ornithopus sativus* L.) as an element of weed control in triticale crops. *J. Res. Appl. Agric. Eng.* **2017**, *62*, 144–148.

159. Księżak, J.; Staniak, M.; Bojarszczuk, J. Evaluation of mixtures of yellow lupine (*Lupinus luteus* L.) with spring cereals grown for seeds. *Appl. Ecol. Environ. Res.* **2018**, *16*, 1683–1696. [CrossRef]

160. Bergkvist, G.; Stenberg, M.; Wetterlind, J.; Båth, B.; Elfstrand, S. Clover cover crops under-sown in winter wheat increase yield of subsequent spring barley—Effect of N dose and companion grass. *Field Crop. Res.* **2011**, *120*, 292–298. [CrossRef]

161. Mirsky, S.B.; Gallandt, E.R.; Mortensen, D.A.; Curran, W.S.; Shumway, D.L. Reducing the germinable weed seedbank with soil disturbance and cover crops. *Weed Res.* **2010**, *50*, 341–352. [CrossRef]

162. Saucke, H.; Ackermann, K. Weed suppression in mixed cropped grain peas and false flax (*Camelina sativa*). *Weed Res.* **2006**, *46*, 453–461. [CrossRef]

163. Smith, R.G.; Mortensen, D.A.; Ryan, M.R. A new hypothesis for the functional role of diversity in mediating resource pools and weed-crop competition in agroecosystems. *Weed Res.* **2010**, *50*, 37–48. [CrossRef]

164. Döring, T.F.; Baddeley, J.A.; Brown, R.; Collins, R.; Crowley, O.; Cuttle, S.; Howlett, S.A.; Jones, H.E.; Mccalman, H.; Measures, M.; et al. *Using Legume-Based Mixtures to Enhance the Nitrogen Use Efficiency and Economic Viability of Cropping Systems: Final Report (LK09106/HGCA3447)*; Project Report 513; HGCA/Agriculture and Horticulture Development Board: Kenilworth, UK, 2013. Available online: https://orgprints.org/24662/1/PR513.pdf (accessed on 2 August 2020).

165. Suter, M.; Hofer, D.; Luscher, A. Weed suppression enhanced by increasing functional trait dispersion and resource capture in forage ley mixtures. *Agric. Ecosyst. Environ.* **2017**, *240*, 329–339. [CrossRef]

166. Weiner, J.; Andersen, S.B.; Wille, W.K.M.; Griepentrog, H.W.; Olsen, J.M. Evolutionary Agroecology: The potential for cooperative, high density, weed-suppressing cereals. *Evol. Appl.* **2010**, *3*, 473–479. [CrossRef] [PubMed]

167. Panasiewicz, K.; Faligowska, A.; Szymańska, G.; Szukała, J.; Ratajczak, K.; Sulewska, H. The Effect of Various Tillage Systems on Productivity of Narrow-Leaved Lupin-Winter Wheat-Winter Triticale-Winter Barley Rotation. *Agronomy* **2020**, *10*, 304. [CrossRef]

168. Aguilar-Fenollosa, E.; Ibáñez-Gual, M.V.; Pascual-Ruiz, S.; Hurtado, M.; Jacas, J.A. Effect of ground-cover management on spider mites and their phytoseiid natural enemies in clementine mandarin orchards (I): Bottom-up regulation. *Biol. Control* **2011**, *59*, 158–170. [CrossRef]

169. Bowers, C.; Toews, M.; Liu, Y.; Schmidt, J.M. Cover crops improve early season natural enemy recruitment and pest management in cotton production. *Biol. Control* **2020**, *141*, 104–149. [CrossRef]

170. Aguilar-Fenollosa, E.; Pascual-Ruiz, S.; Hurtado, M.A.; Jacas, J.A. Efficacy and economics of ground cover management as a conservation biological control strategy against *Tetranychus urticae* in clementine mandarin orchards. *Crop Prot.* **2011**, *30*, 1328–1333. [CrossRef]

171. Lapointe, S.L. Leguminous cover crops and their interactions with citrus and *Diaprepes abbreviatus* (Coleoptera: Curculionidae). *Fla. Entomol.* **2003**, *86*, 80–85. [CrossRef]

172. Altieri, M.A.; Nicholls, C.I.; Ponti, L. Crop Diversification Strategies for Pest Regulation in IPM Systems. In *Integrated Pest Management*; Radcliffe, E.B., Hutchinson, W.D., Cancelado, R.E., Eds.; Cambridge University Press: Cambridge, UK, 2009; pp. 116–130.

173. Altieri, M.A.; Nicholls, C.I. Vegetational Designs to Enhance Biological Control of Insect Pests in Agroecosystems. In *Natural Enemies of Insect Pests in Neotropical Agroecosystems*; Souza, B., Vázquez, L., Marucci, R., Eds.; Springer Nature: Cham, Switzerland, 2019; pp. 3–13. [CrossRef]

174. Mailloux, J.; le Bellec, F.; Kreiter, S.; Tixier, M.S.; Dubois, P. Influence of ground cover management on diversity and density of phytoseiid mites (Acari: Phytoseiidae) in Guadeloupean citrus orchards. *Exp. Appl. Acarol.* **2010**, *52*, 275–290. [CrossRef] [PubMed]

175. Damien, M.; le Lann, C.; Desneux, N.; Alford, L.; al Hassan, D.; Georges, R.; van Baaren, J. Flowering cover crops in winter increase pest control but not trophic link diversity. *Agric. Ecosyst. Environ.* **2017**, *247*, 418–425. [CrossRef]

176. Ellis, K.E.; Barbercheck, M.E. Management of Overwintering Cover Crops Influences Floral Resources and Visitation by Native Bees. *Environ. Entomol.* **2015**, *44*, 999–1010. [CrossRef] [PubMed]

177. Saunders, M.E.; Luck, G.W.; Mayfield, M.M. Almond orchards with living ground cover host more wild insect pollinators. *J. Insect Conserv.* **2013**, *17*, 1011–1025. [CrossRef]

178. Lal, R. Restoring soil quality to mitigate soil degradation. *Sustainability* **2015**, *7*, 5875–5895. [CrossRef]

179. Brookes, P.C.; Cayuela, M.L.; Contin, M.; de Nobili, M.; Kemmitt, S.J.; Mondini, C. The mineralization of fresh and humified soil organic matter by the soil microbial biomass. *Waste Manag.* **2008**, *28*, 716–722. [CrossRef]

180. Peralta, A.L.; Sun, Y.; McDaniel, M.D.; Lennon, J.T. Crop rotational diversity increases disease suppressive capacity of soil microbiomes. *Ecosphere* **2018**, *9*, e02235. [CrossRef]

181. Abdalla, M.; Hastings, A.; Cheng, K.; Yue, Q.; Chadwick, D.; Espenberg, M.; Truu, J.; Rees, R.M.; Smith, P. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. *Glob. Chang. Biol.* **2019**, *25*, 2530–2543. [CrossRef]

182. Venter, Z.S.; Jacobs, C.; Hawkins, H.J. The impact of crop rotation on soil microbial diversity: A meta-analysis. *Pedobiol. J. Soil Ecol.* **2016**, *59*, 215–223. [CrossRef]

183. D'Acunto, L.; Andrade, J.F.; Poggio, S.L.; Semmartin, M. Diversifying crop rotation increased metabolic soil diversity and activity of the microbial community. *Agric. Ecosyst. Environ.* **2018**, *257*, 159–164. [CrossRef]

184. Battany, M.; Grismer, M.E. Rainfall runoff and erosion in Napa Valley vineyards: Effects of slope, cover and surface roughness. *Hydrol. Process.* **2000**, *14*, 1289–1304. [CrossRef]

185. Lüscher, A.; Mueller-Harvey, I.; Soussana, J.F.; Rees, R.M.; Peyraud, J.L. Potential of legume-based grassland-livestock systems in Europe: A review. *Grass Forage Sci.* **2014**, *69*, 206–228. [CrossRef] [PubMed]

186. Olson, K.; Ebelhar, S.A.; Lang, J.M. Long-term effects of cover crops on crop yields, soil organic carbon stocks and sequestration. *Open J. Soil Sci.* **2014**, *4*, 284–292. [CrossRef]

187. Wortman, S.E.; Francis, C.A.; Bernards, M.L.; Drijber, R.A.; Lindquist, J.L. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. *Agron. J.* **2012**, *104*, 1425–1435. [CrossRef]

188. Ghimire, R.; Ghimire, B.; Mesbah, A.O.; Sainju, U.M.; Idowu, O.J. Soil Health Response of Cover Crops in Winter Wheat—Fallow System. *Agron. J.* **2019**, *111*, 2108–2115. [CrossRef]

189. Chu, M.; Jagadamma, S.; Walker, F.R.; Eash, N.S.; Buschermohle, M.J.; Duncan, L.A. Effect of Multispecies Cover Crop Mixture on Soil Properties and Crop Yield. *Agric. Environ. Lett.* **2017**, *2*, 170030. [CrossRef]

190. Kuo, S.; Jellum, E.J.; Sanju, U. The Effect of Winter Cover Cropping on Soil and Water Quality. In Proceedings of the Western Nutrient Management Conference, Salt Lake City, UT, USA, 9–10 March 1995; pp. 56–64.

191. McVay, K.A.; Radcliffe, D.E.; Hargrove, W.L. Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Sci. Soc. Am. J.* **1989**, *53*, 1856–1862. [CrossRef]

192. Sarr, S.; Gebremedhin, M.; Coyne, M.; Topè, A.; Sistani, K.; Lucas, S. Do Conservation Practices Bring Quick Changes to Key Soil Properties for Resource-Limited Farmers? *J. Ky. Acad. Sci.* **2019**, *80*, 6–16. [CrossRef]

193. Villamil, M.B.; Miguez, F.E.; Bollero, G.A. Multivariate Analysis and Visualization of Soil Quality Data for No-Till Systems. *J. Environ. Qual.* **2008**, *37*, 2063–2069. [CrossRef]

194. Amado, T.J.C.; Bayer, C.; Conceiqdo, P.C.; Spagnollo, E.; de Campos, B.H.C.; da Veiga, M. Potential of Carbon Accumulation in No-Till Soils with Intensive Use and Cover Crops in Southern Brazil. *J. Environ. Qual.* **2006**, *35*, 1599–1607. [CrossRef] [PubMed]

195. Smith, P.; Martino, D.; Cai, Z.; Gwary, D.; Janzen, H.; Kumar, P.; McCarl, B.; Ogle, S.; O'Mara, F.; Rice, C.; et al. Greenhouse gas mitigation in agriculture. *Philos. Trans. R. Soc. B Biol. Sci.* **2008**, *363*, 789–813. [CrossRef] [PubMed]

196. Carlsson, G.; Huss-Danell, K. Nitrogen fixation in perennial forage legumes in the field. *Plant Soil* **2003**, *253*, 353–372. [CrossRef]

197. Casagrande, M.; David, C.; Valantin-Morison, M.; Makowski, D.; Jeuffroy, M.H. Factors limiting the grain protein content of organic winter wheat in south-eastern France: A mixed-model approach. *Agro. Sustain. Dev.* **2009**, *29*, 565–574. [CrossRef]

198. Berry, P.M.; Sylvester-Bradley, R.; Philipps, L.; Hatch, D.J.; Cuttle, S.P.; Rayns, F.W.; Gosling, P. Is the productivity of organic farms restricted by the supply of available nitrogen? *Soil Use Manag.* **2002**, *18*, 248–255. [CrossRef]

199. David, C.; Jeuffroy, M.H.; Henning, J.; Meynard, J.M. Yield variation in organic winter wheat: A diagnostic study in the Southeast of France. *Agron. Sustain. Dev.* **2005**, *25*, 213–223. [CrossRef]

200. Mazzoncini, M.; Canali, S.; Giovannetti, M.; Castagnoli, M.; Tittarelli, F.; Antichi, D.; Nannelli, R.; Cristani, C.; Bárberi, P. Comparison of organic and conventional stockless arable systems: A multidisciplinary approach to soil quality evaluation. *Appl. Soil Ecol.* **2010**, *44*, 124–132. [CrossRef]

201. Fujita, K.; Ofosubudu, K.G.; Ogata, S. Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant Soil* **1992**, *141*, 155–175. [CrossRef]

202. Jensen, E.S. Grain yield, symbiotic N2 fixation and interspecific competition for inorganic N in pea-barley intercrops. *Plant Soil* **1996**, *182*, 25–38. [CrossRef]

203. Naudin, C.; Corre-Hellou, G.; Pineau, S.; Crozat, Y.; Jeuffroy, M.H. The effect of various dynamics of N availability on winter pea-wheat intercrops: Crop growth, N partitioning and symbiotic N2 fixation. *Field Crop. Res.* **2010**, *119*, 2–11. [CrossRef]

204. García-González, I.; Hontoria, C.; Gabriel, J.L.; Alonso-Ayuso, M.; Qemada, M. Cover crops to mitigate soil degradation and enhance soil functionality in irrigated land. *Geoderma* **2018**, *322*, 81–88. [CrossRef]

205. Basche, A.D.; Miguez, F.E.; Kaspar, T.C.; Castellano, M.J. Do cover crops increase or decrease nitrous oxide emissions? *A meta-analysis. J. Soil Water Conserv.* **2014**, *69*, 471–482. [CrossRef]

206. Quemada, M.; Baranski, M.; Nobel-de Lange, M.N.J.; Vallejo, A.; Cooper, J.M. Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. *Agric. Ecosys. Environ.* **2013**, *174*, 1–10. [CrossRef]

207. Justes, E.; Beaudoin, N.; Bertuzzi, P.; Charles, R.; Constantin, J.; Dürr, C.; Réchauchère, O. *The Use of Cover Crops in the Reduction of Nitrate Leaching: Impact on the Water and Nitrogen Balance and Other Ecosystem Services*; Summary of the study report; INRA: Paris, France, 2012.

208. Valkama, E.; Lemola, R.; Känkänen, H.; Turtola, E. Meta-analysis of the effects of under-sown catch crops on nitrogen leaching loss and grain yields in the Nordic countries. *Agric. Ecosys. Environ.* **2015**, *203*, 93–101. [CrossRef]

209. Lal, R. Enhancing eco-efficiency in agro-ecosystems through soil C sequestration. *Crop Sci.* **2010**, *50* (Suppl. 1), S-120. [CrossRef]

210. Hajduk, E.; Właśniewski, S.; Szpunar-Krok, E. Influence of legume crops on content of organic C in sandy soil. *Soil Sci. Annu.* **2015**, *66*, 52–56. [CrossRef]

211. Meena, R.S.; Kumar, S.; Yadav, G.S. Soil Carbon Sequestration in Crop Production. In *Nutrient Dynamics for Sustainable Crop Production*; Meena, R.S., Ed.; Springer Nature Singapore Pte Ltd.: Singapore, 2020; pp. 1–39. [CrossRef]

212. Schmidt, O.; Curry, J.P.; Hackett, R.A.; Purvis, G.; Clements, R.O. Earthworm communities in conventional wheat monocropping and lowinput wheat-clover intercropping systems. *Ann. Appl. Biol.* **2001**, *138*, 377–388. [CrossRef]

213. Nakamoto, T.; Tsukamoto, M. Abundance and activity of soil organisms in fields of maize grown with a white clover living mulch. *Agric. Ecosys. Environ.* **2006**, *115*, 34–42. [CrossRef]

214. Bardgett, R.D.; van der Putten, W.H. Belowground biodiversity and ecosystem functioning. *Nature* **2014**, *515*, 505–511. [CrossRef]

215. Kaspar, T.C.; Singer, J.W. The Use of Cover Crops to Manage Soil. *USDAARS UNL Fac.* **2011**, 1382. Available online: https://digitalcommons.unl.edu/usdaarsfacpub/1382 (accessed on 2 August 2020).

216. Singh, R.; Serawat, M.; Singh, A. Effect of Tillage and Crop Residue Management on Soil Physical Properties. *J. Soil Salin. Water Qual.* **2018**, *10*, 200–206.

217. Oliveira, F.C.C.; Ferreira, G.W.D.; Souza, J.L.S.; Vieira, M.E.O.; Pedrotti, A. Soil physical properties and soil organic carbon content in northeast Brazil: Long-term tillage systems effects. *Sci. Agric.* **2020**, *77*, e20180166. [CrossRef]

218. Harasim, E.; Antonkiewicz, J.; Kwiatkowski, C.A. The Effects of Catch Crops and Tillage Systems on Selected Physical Properties and Enzymatic Activity of Loess Soil in a Spring Wheat Monoculture. *Agronomy* **2020**, *10*, 334. [CrossRef]

219. Lynch, J.M.; Bragg, E. Microorganisms and soil aggregate stability. *Adv. Soil Sci.* **1985**, *5*, 133–171. [CrossRef]

220. Wagger, M.G.; Denton, H.P. Influence of cover crop and wheel traffic on soil physical properties in continuous notill corn. *Soil Sci. Soc. Am. J.* **1989**, *53*, 1206–1210. [CrossRef]

221. Blanco-Canqui, H.; Mikha, M.M.; Presley, D.R.; Claassen, M.M. Addition of cover crops enhances no-till potential for improving soil physical properties. *Soil Sci. Soc. Am. J.* **2011**, *75*, 1471–1482. [CrossRef]

222. Sainju, U.M.; Whitehead, W.F.; Singh, B.P. Cover crops and nitrogen fertilization effects on soil aggregation and carbon and nitrogen pools. *Can. J. Soil Sci.* **2003**, *83*, 155–165. [CrossRef]

223. Dormaar, J.F. Chemical properties of soil and waterstable aggregates after sixty-seven years of cropping to spring wheat. *Plant Soil* **1983**, *75*, 51–61. [CrossRef]

224. Kay, B.D. Rates of change of soil structure under different cropping systems. *Adv. Soil Sci.* **1990**, *12*, 1–52. [CrossRef]

225. Blanco-Canqui, H.; Lal, R. Corn stover removal for expanded uses reduces soil fertility and structural stability. *Soil Sci. Soc. Am. J.* **2009**, *73*, 418–426. [CrossRef]

226. Cannell, R.Q.; Hawes, J.D. Trends in tillage practices in relation to sustainable crop production with special reference to temperate climates. *Soil Tillage Res.* **1994**, *30*, 245–282. [CrossRef]

227. Singh, B.; Chanasyk, D.S.; McGill, W.B.; Nyborg, M.P.K. Residue and tillage management effects on soil properties of a typic cryoboroll under continuous barley. *Soil Tillage Res.* **1994**, *32*, 117–133. [CrossRef]

228. Liu, A.G.; Ma, B.L.; Bomke, A.A. Effects of cover crops on soil aggregate stability, total organic carbon, and polysaccharides. *Soil Sci. Soc. Am. J.* **2005**, *69*, 2041–2048. [CrossRef]

229. Henderson, C.W.L. Lupin as a biological plough: Evidence for, and effects on wheat growth and yield. *Aust. J. Exp. Agric.* **1989**, *29*, 99–102. [CrossRef]

230. Rosolem, C.A.; Foloni, J.S.S.; Tiritan, C.S. Root growth and nutrient accumulation in cover crops as affected by soil compaction. *Soil Tillage Res.* **2002**, *65*, 109–115. [CrossRef]

231. Carof, M.; de Tourdonnet, S.; Coquet, Y.; Hallaire, V.; Roger-Estrade, J. Hydraulic conductivity and porosity under conventional and no-tillage and the effect of three species of cover crop in northern France. *Soil Use Manag.* **2007**, *23*, 230–237. [CrossRef]

232. Blanco-Canqui, H.; Shapiro, C.A.; Wortmann, C.S.; Drijber, R.A.; Mamo, M.; Shaver, T.M.; Ferguson, R.B. Soil organic carbon: The value to soil properties. *J. Soil Water Conserv.* **2013**, *68*, 129A–134A. [CrossRef]

233. Chenu, C.; le Bissonnais, Y.; Arrouays, D. Organic matter influence on clay wettability and soil aggregate stability. *Soil Sci. Soc. Am. J.* **2000**, *64*, 1479–1486. [CrossRef]

234. Pagliai, M.; Vignozzi, N.; Pellegrini, S. Soil structure and the effect of management practices. *Soil Tillage Res.* **2004**, *79*, 131–143. [CrossRef]

235. Keisling, T.C.; Scott, H.D.; Waddle, B.A.; Williams, W.; Frans, R.E. Winter cover crops influence on cotton yield and selected soil properties. *Commun. Soil Sci. Plant Anal.* **1994**, *25*, 3087–3100. [CrossRef]

236. Steele, M.K.; Coale, F.J.; Hill, R.L. Winter annual cover crop impacts on no-till soil physical properties and organic matter. *Soil Sci. Soc. Am. J.* **2012**, *76*, 2164–2173. [CrossRef]

237. Folorunso, O.A.; Rolston, D.E.; Prichard, T.; Louie, D.T. Soil surface strength and infiltration rate as affected by winter cover crops. *Soil Technol.* **1992**, *5*, 189–197. [CrossRef]

238. Mupambwa, H.A.; Wakindiki, I.I.C. Winter cover crops effects on soil strength, infiltration and water retention in a sandy loam Oakleaf soil in Eastern Cape, South Africa. *S. Afr. J. Plant Soil* **2012**, *29*, 121–126. [CrossRef]

239. Drury, C.F.; Tan, C.S.; Welacky, T.W.; Oloya, T.O.; Hamill, A.S.; Weaver, S.E. Red clover and tillage influence on soil temperature, water content, and corn emergence. *Agron. J.* **1999**, *91*, 101–108. [CrossRef]

240. Malhi, S.; Lemke, R. Tillage, Crop Residue and N Fertilizer Effects on Crop Yield, Nutrient Uptake, Soil Quality and Nitrous Oxide Gas Emissions in a Second 4-yr Rotation Cycle. *Soil Tillage Res.* **2007**, *96*, 269–283. [CrossRef]

241. Bajgai, Y.; Kristiansen, P.; Hulugalle, N.; McHenry, M. Comparison of Organic and Conventional Managements on Yields, Nutrients and Weeds in a Corn-Cabbage Rotation. *Renew. Agric. Food Syst.* **2015**, *30*, 132–142. [CrossRef]

242. Khaliq, A.; Shakeel, M.; Matloob, A.; Hussain, S.; Tanveer, A.; Murtaza, G. Influence of Tillage and Weed Control Practices on Growth and Yield of Wheat. *Phillips. J. Crop Sci.* **2013**, *38*, 54–62.

243. Mupangwa, W.; Twomlow, S.; Walker, S. Reduced Tillage, Mulching and Rotational Effects on Maize (*Zea mays* L.), Cowpea (*Vigna unguiculata* (Walp) L.) and Sorghum (*Sorghum bicolor* L. (Moench)) Yields under Semi-Arid Conditions. *Field Crop. Res.* **2012**, *132*, 139–148. [CrossRef]

244. Blanco-Canqui, H.; Claassen, M.; Presley, D. Summer cover crops fix nitrogen, increase crop yield, and improve soil–crop relationships. *Agron. J.* **2012**, *104*, 137–147. [CrossRef]

245. Nielsen, D.C.; Lyon, D.J.; Hergert, G.W.; Higgins, R.K.; Calderón, F.J.; Vigil, M.F. Cover Crop Mixtures Do Not Use Water Differently than Single-Species Plantings. *Agron. J.* **2015**, *107*, 1025–1038. [CrossRef]

246. Colla, G.; Mitchell, J.P.; Joyce, B.A.; Huyet, L.M.; Wallender, W.W.; Temple, S.R. Soil physical properties and tomato yield and quality in alternative cropping systems. *Agron. J.* **2000**, *92*, 924–932. [CrossRef]

247. Lotter, D.W.; Seidel, R.; Liebhardt, W. The performance of organic and conventional cropping systems in an extreme climate year. *Am. J. Altern. Agric.* **2003**, *18*, 146–154. [CrossRef]

248. Wang, Z.; Zhao, X.; Wu, P.; Chen, X. Effects of water limitation on yield advantage and water use in wheat (*Triticum aestivum* L.)/maize (*Zea mays* L.) strip intercropping. *Eur. J. Agron.* **2015**, *71*, 149–159. [CrossRef]

249. Irmak, S.; Sharma, V.; Mohammed, A.T.; Djaman, K. Impacts of cover crops on soil physical properties: Field capacity, permanent wilting point, soil-water holding capacity, bulk density, hydraulic conductivity, and infiltration. *Am. Soc. Agric. Biol. Eng.* **2018**, *61*, 1307–1321. [CrossRef]

250. Licht, M.A.; Al-Kaisi, M. Strip-tillage effect on seedbed soil temperature and other soil physical properties. *Soil Tillage Res.* **2005**, *80*, 233–249. [CrossRef]

251. Amossé, C.; Jeuffroy, M.H.; David, C. Relay intercropping of legume cover crops in organic winter wheat: Effects on performance and resource availability. *Field Crop. Res.* **2013**, *145*, 78–87. [CrossRef]

252. Martens, J.R.T.; Hoeppner, J.F.; Entz, M.H. Legume Cover Crops with Winter Cereals in Southern Manitoba: Establishment, Productivity, and Microclimate Effects. *Agron. J.* **2001**, *93*, 1086–1096. [CrossRef]

253. Unger, P.W.; Vigil, M.F. Cover crops effects on soil water relationships. *J. Soil Water Cons.* **1998**, *53*, 241–244.

254. Clark, A. *Managing Cover Crops Profitably*, 3rd ed.; Handbook Series Book 9; Sustainable Agriculture Research & Education (SARE) Program, University of Maryland: College Park, MD, USA, 2012.

255. Zibilskie, L.M.; Makus, D.J. Black oat cover crop management effects on soil temperature and biological properties on a Mollisol in Texas, USA. *Geoderma* **2009**, *149*, 379–385. [CrossRef]

256. Kahimba, F.C.; Sri Ranjan, R.; Froese, J.; Entz, M.; Nason, R. Cover crop effects on infiltration, soil temperature, and soil moisture distribution in the Canadian prairies. *Appl. Eng. Agric.* **2008**, *24*, 321–333. [CrossRef]

257. Thiagalingam, K.; Dalgliesh, N.P.; Gould, N.S.; McCown, R.L.; Cogle, A.L.; Chapman, A.L. Comparison of no-tillage and conventional tillage in the development of sustainable farming systems in the semi-arid tropics. *Aust. J. Exp. Ag.* **1996**, *36*, 995–1002. [CrossRef]

258. Sharratt, B.S.; Flerchinger, G.N. Straw color for altering soil temperature and heat flux in the subarctic. *Agron. J.* **1995**, *87*, 814–819. [CrossRef]

259. Hansen, L.; Ribaudo, M. *Economic Measures of Soil Conservation Benefits: Regional Values for Policy Assessment*; USDA Technical Bulletins 1922; 2008. Available online: https://www.ers.usda.gov/webdocs/publications/47548/11517_tb1922_reportsummary.pdf?v=0 (accessed on 10 June 2020).

260. Langdale, G.W.; Blevins, R.L.; Karlen, D.L.; McCool, D.K.; Nearing, M.A.; Skidmore, E.L.; Thomas, A.W.; Tyler, D.D.; Williams, J.R. Cover Crop Effects on Soil Erosion by Wind and Water. In *Cover Crops for Clean Water, Proceedings of an International Conference, Jackson, TN, USA, 9–11 April 1991*; Hargrove, W.L., Ed.; Soil and Water Conservation Society: Ankeny, IA, USA, 1999; pp. 15–22.

261. Martin, C.K.; Cassel, D.K. Soil loss and silage yield for three tillage management systems. *J. Prod. Agric.* **1992**, *5*, 581–586. [CrossRef]

262. De Baets, S.; Poesen, J.; Meersmans, J.; Serlet, L. Cover Crops and Their Erosion-Reducing Effects during Concentrated Flow Erosion. *Catena* **2011**, *85*, 237–244. [CrossRef]

263. 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]

264. Colazo, J.C.; Buschiazzo, D.E. Soil dry aggregate stability and wind erodible fraction in a semiarid environment of Argentina. *Geoderma* **2010**, *159*, 228–236. [CrossRef]