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Review

Conservation Agriculture as a System to Enhance Ecosystem Services

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Abstract: Conservation agriculture (CA) is considered a sustainable practice with the potential to maintain or increase crop productivity and improve environmental quality and ecosystem services. It typically improves soil quality and water conservation; however, its effect on crop productivity is highly variable and dependent on local conditions/management. Crop residue retention plays a crucial role in CA and can help to improve overall soil health and ultimately crop productivity and sustainability. However, weed control, herbicide resistance, and weed shift under residue retained fields is a major challenge. Moreover, CA can increase water infiltration and reduce soil loss and runoff. This reduces the surface transport of nitrate and phosphorus from agricultural fields and the eutrophication of water bodies, although leaching of nitrate to groundwater can potentially increase. In addition, CA has been proposed as one of the components in climate-smart agriculture, owing to its reduced period to seed/plant next crop, reduced soil disturbance and low consumption of fossil fuels. Therefore, compared to the conventional intensive tillage, CA has a greater potential for soil C sequestration, favors higher soil biodiversity, lowers greenhouse gas emission, and can assist in mitigating climate change. However, not all experiments report a positive impact. The understanding and decoding the site-specific complexities of CA system is important and requires a multidisciplinary approach.

Keywords: conservation agriculture; no-till farming; ecosystem services; climate change; soil health; biodiversity; water; greenhouse gas; carbon sequestration

Citation: Jayaraman, S.; Dang, Y.P.; Naorem, A.; Page, K.L.; Dalal, R.C. Conservation Agriculture as a System to Enhance Ecosystem Services. *Agriculture* **2021**, *11*, 718. https://doi.org/10.3390/agriculture11080718

Academic Editor: Paolo Ruisi

Received: 25 June 2021
Accepted: 27 July 2021
Published: 29 July 2021

1. Introduction

Globally, conservation agriculture (CA)/no-till (NT) farming has been widely adopted and practiced (about 180 M ha of cropland, ~12.5% of total global cropland area in 2015/16 and an increase of 69% globally since 2008/09) [1] as it provides various benefits to agricultural production driven by soil and water conservation and improvement in soil health [1,2]. CA is often advocated as a sustainable farming practice that can not only maintain or increase crop productivity, but also improve carbon storage, environmental quality, and ecosystem services (ES) [2–6]. However, despite the proven benefits of CA, its adoption has been mainly limited to developed countries [1,7,8]. With the exception of South America, uptake in developing countries is often very low due to various socio-economic and logistical barriers to its implementation (e.g., insufficient access to finance and appropriate machinery, poor extension services, and poor crop yield due to problems with weed/residue/soil fertility management) [9,10]. Other issues such as weed shift, herbicide resistance, nutrient stratification [11], residue borne pest and diseases also hinder the adoption of CA in both developed and developing regions. However, in regions where CA practises are successfully implemented, they are often considered to be more sustainable and improve ES [6,12].

Ecosystems services can be defined as the direct as well as indirect benefits human beings obtain from ecosystems and can include provisioning (e.g., provision of food and fiber), regulating (e.g., regulation of air quality, flood control, and crop pollination), supporting (e.g., providing plants and animals with living space and supporting biodiversity), and cultural services (e.g., non-material benefits from ecosystems such as cultural identity and spiritual well-being) [13]. Over the past 50 years, anthropogenic activities have had an extensive impact on ecosystems and natural resources, owing to the high demand for food, fuel, energy, fiber, and mineral resources [13]. Human beings have largely benefited from this transformation at the cost of environmental degradation and loss of biodiversity [14]. However, an increasing awareness of the need to protect nature/natural resources has led to an improved understanding of the importance of ES and the need to more thoroughly study and account for their protection [6,15–17].

Research into ES can highlight the links between the natural and social systems that can help in developing a more sustainable ecosystem [18] (Figure 1a,b). In this regard, technologies applied in agriculture are studied for their contribution to ES. CA is widely advocated as a sustainable agricultural practice that can not only maintain or increase crop productivity, but also improves environmental quality [10] (Figure 1a,b). The FAO (2014) recommended CA as a "*sustainable approach that could manage the agroecosystems to maintain sustainable crop production while protecting the natural resources and the environment*" (Figure 1a,b). There are three main principles involved in CA, namely minimum or zero soil disturbances, crop rotation or intercropping, and permanent soil cover, with at least 30% of the soil covered through organic residue/mulch between the planting and harvesting [7,19] (Figure 2a,b). In addition to these principles, a fourth component of integrated pest and nutrient management has been proposed, especially for resource-poor farmers [20]. Relative to conventional agricultural systems, these practices can affect a number of important provisioning, regulating and supporting ecosystem services, as described below. The impact of CA on cultural services is considered outside the scope of this paper and will not be discussed.

In general, CA is designed in such a way that cultivation is minimized to avoid land degradation, while still maintaining the sustainability of agricultural production (Figure 2). Conservation agriculture changes soil properties and processes compared to conventional tillage-based agriculture. These changes can affect a number of ES (Table 1 and Figures 1 and 3), including:

Provisioning services—CA can have influence on yield and productivity and, thus, the provision of food and fiber. In addition, it can have a significant influence on soil water storage.

Regulating services—CA has numerous important impacts on erosion, soil fertility, greenhouse gas emission, air and water quality, and the moderation of extreme events (floods/drought).

Supporting services—CA can impact soil biological community structure and diversity.

The ESs provided by CA follow a chain-like process. For example, improvement in soil aggregation in CA plots increases water infiltration and moisture retention, thus decreasing soil erosion and surface runoff, which also reduces the loss of nutrients from the topsoil and improves crop yield. Although CA can often provide improved ES relative to conventional intensive agriculture, for some producers, particularly smallholders, the adoption of CA can be slow due to the costs (e.g., new equipment and some initial loss of yield) and difficulties in its implementation [21]. However, as farmers play a crucial role in moderating ES through their land management practices, it is important to understand each of the ES delivered through CA in order to better promote it as a sustainable agricultural practice. This paper will deliver comprehensive information on the links between CA components and ES through a narrative review of peer-reviewed research papers.

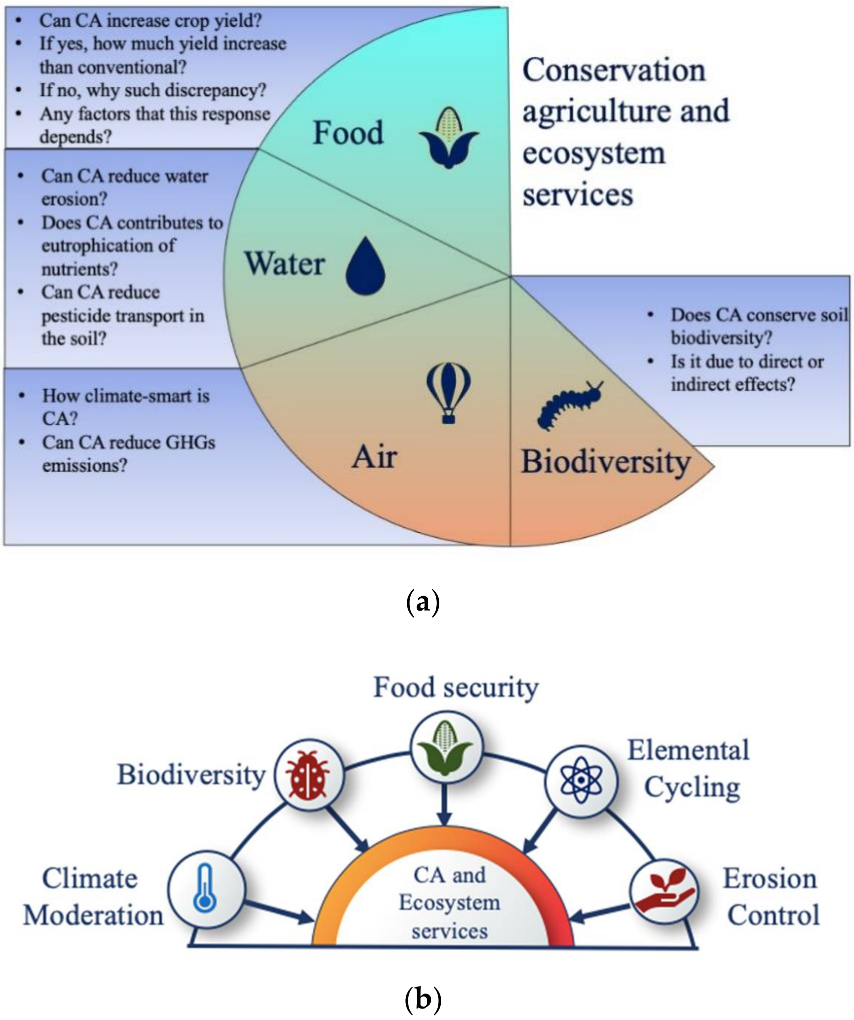

Figure 1. (**a**) Ecosystem services offered through conservation agriculture (top); and (**b**) a schematic diagram depicting the main ecosystem services delivered through conservation agriculture (Source: Modified from [12]).

Figure 2. Crop raised under conservation agriculture: (**a**) Chickpea (*Cicer arietinum*) (**left**), (**b**) wheat (*Triticum aestivum*) (**right**).

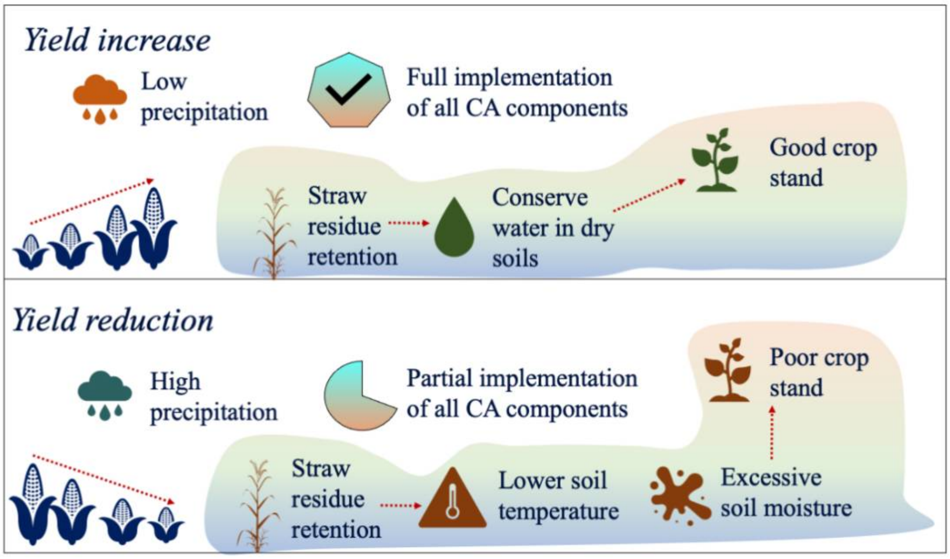

Figure 3. Probable reasons for yield fluctuations in conservation agriculture.

Table 1. Comparison of ecosystem services typically provided by conservation agriculture (CA/NT) versus conventional farming practices (CT).

Ecosystem Services	Conservation Agriculture (CA/NT)	Conventional Farming Practices (CT)
Provisioning Services		
Crop yields	↘ → ↑	↑ ↘ →
System productivity	→ ↗ ↑	↑ ↘ →
Water storage	↑	↓
Regulating Services		
Erosion	↑ ↓	↑
Soil fertility/health	↗ ↓ ↔	↘ ↓
Greenhouse gas emission	↑ ↓ ↔	↑
Clean air	no residue burning ↑	large scale residue burning ↓
Clean water	↑	↓
Moderation of extreme events (droughts/floods)	↑	↓
Supporting Services		
Soil Biodiversity	↑	↓

↑ Indicates higher; ↓ indicates lower; ↔ No effect Arrows on an angle indicate more gradual change over time (Source: [10,22,23]).

2. Conservation Agriculture and Crop Productivity: The Rise and Fall of Yield

2.1. Water Storage

One of the most well-established benefits of CA systems is their ability to improve soil water storage. Reduced soil disturbance coupled with increased residue retention typically leads to increases in SOC at the soil surface in CA systems [24]. This increases aggregate stability, helps preserve macropores capable of rapidly transmitting water into the soil profile, and can improve rates of water infiltration and thus the capture of rainfall for crop use [25–28]. In addition, the retention of crop residues on the soil surface decreases rates of soil water evaporation [29], also contributing to increases in soil water storage. In drier rainfed regions, where water availability is one of the main factors limiting plant production, this increase in water storage can have a major positive impact on crop productivity and potentially help agricultural systems adapt to the increasing incidence of drought under climate change. In irrigated regions, it can reduce the amount of water required for crop production and help conserve water resources. However, in cold regions or where soils are prone to waterlogging, these improvements can lead to no, or reduced, yield benefit, as discussed below.

2.2. Yield and Productivity

Although CA has been delivering positive results on improving soil water conservation, the effects of CA on crop productivity are less clear cut [9,30] (Table 1). CA systems have been observed to increase [31–33], decrease [34] and lead to no change in yield [35,36]. The increase or decrease in crop yield following the adoption of CA largely depends on whether CA has been partially or fully implemented, regional climatic conditions, and the type of cropping systems and management practices followed [7,34,37,38] (Figure 3). For example:

- Climatic conditions: In cooler regions, crop residue retention can lower soil temperatures, delay plant maturity and negatively affect yield [20,35,39]. Similarly, in higher rainfall regions with poorly drained soils, the increased infiltration, and lower evaporation in CA systems can lead to waterlogging and yield loss [35,39–42], although in suitably drained soils, CA can also bring yield advantages in wet climates [43,44]. In contrast, when CA is implemented in warmer and drier regions, higher yield is often observed due to a lowering of soil temperatures and increases in soil water storage [22,45,46].
- Management practices: In conventional systems, cultivation is used to control many weeds, pests and diseases. If CA is implemented without suitable modifications to tillage/weed/pest/disease management systems, it can lead to increases in infestations and losses in yield [47–49]. Similarly, the high carbon (C):nitrogen (N) ratio of crop residue retained in CA systems can immobilize N and lead to N deficiency. If fertilizers or crop rotations incorporating legumes are not used to maintain available N, yield decreases can also occur [22]. However, when weeds/pests/diseases and nutrient availability are successfully managed, the improvements in soil physico-chemical properties often observed with CA (e.g., improved soil aggregation, soil structural stability, SOC, water storage, and nutrient supply) can lead to yield increases, particularly in CA systems that have been operating for a number of years and the physico-chemical benefits have increased over time [20,30].
- Full versus partial implementation. Where the components of CA are only partially implemented, yield increases may be reduced. For example, no-till with crop residue retention can generate a higher yield than no-till (without residue) alone, owing to the improved soil qualities in crop residue mulching [45]. Similarly, when appropriate crop rotations are not implemented to help control weeds/pests/diseases and maintain soil fertility, yield loss can occur [50]. These variations in response highlight the need for an integrated approach and to apply caution when interpreting the results of research into CA. There is a need to standardize research methodologies (definitions/different components and techniques of CA) to avoid conflicting results due to incorrect classification of systems as CA [51].

A meta-analysis conducted by Pittelkow et al. [9] observed that globally there was an average yield reduction of −2.5% under CA practices (NT+ residue retention + crop diversification), which increased to ~9.9% when there was only partial implementation of CA components (NT alone). However, CA implementation in dry, rainfed areas lead to a 7.3% increase in crop yield, likely due to improvements in soil water storage. These results highlight the importance of implementing all components of the CA system to achieve maximum yield benefits and the need to implement it in a location-specific manner and appropriately adapt management practices to avoid yield loss. It may also take a number of years for yield improvements to be realized as until the soil quality is improved through these CA components, the yield gain under CA can be minimal [10].

3. Conservation Agriculture and Water: From Erosion to Eutrophication

To feed the growing human population (~7.9 billion), natural ecosystems are being increasingly converted to cultivated areas. This agricultural expansion leads to more soil disturbance and soil erosion, which degrades soil quality, leads to the pollution of waterways, and damages infrastructure [52,53]. For example, in South Asian countries, water erosion affects 21% of the total land area and is one of the main forms of land degradation [52,54], while worldwide, approximately 75 billion tonnes of soil is eroded from arable land each year [53].

Soil erosion under conventional agriculture is mainly attributed to greater soil disturbance and non-adoption of site-specific soil and water conservation measures. The inclusion of crop residue retention under CA can increase surface roughness and reduce runoff and soil losses [10,55]. Improvement in soil aggregate stability and water storage under CA also directly or indirectly affects runoff and soil losses [25,56,57]. The effectiveness of CA in reducing soil water erosion varies according to the climate, cropping system and experimental duration [6], although in comparison to conventional systems, and particularly those incorporating extended periods of bare fallow, CA can reduce annual soil loss by over 90% (Table 2).

Nitrogen and phosphorus (P) loss from agricultural fields into waterways can lead to eutrophication and N and P are recognized as major water pollutants worldwide [58]. As CA offers several advantages over conventional tillage in various aspects of soil and water conservation, it is also expected to affect N and P export [59]. CA can reduce soil loss and runoff due to less soil disturbance, greater surface stability and increased rates of water infiltration [20,60] (Figure 4 and Table 2). Where this is the case, the surface transport of N and P from agricultural fields into surface water bodies is expected to be reduced. However, in some instances, CA has been observed to increase rates of runoff (Table 3), particularly in the early stages of adoption when surface sealing can be a problem and tillage can increase rates of infiltration. Greater snow capture by standing stubble can also increase runoff in CA systems [61]. Under these circumstances, CA can increase the potential for the transport of soluble forms of N to surface water. Table 3 depicts some examples of the changes in surface runoff (mm) that have been observed under conventional and CA practices.

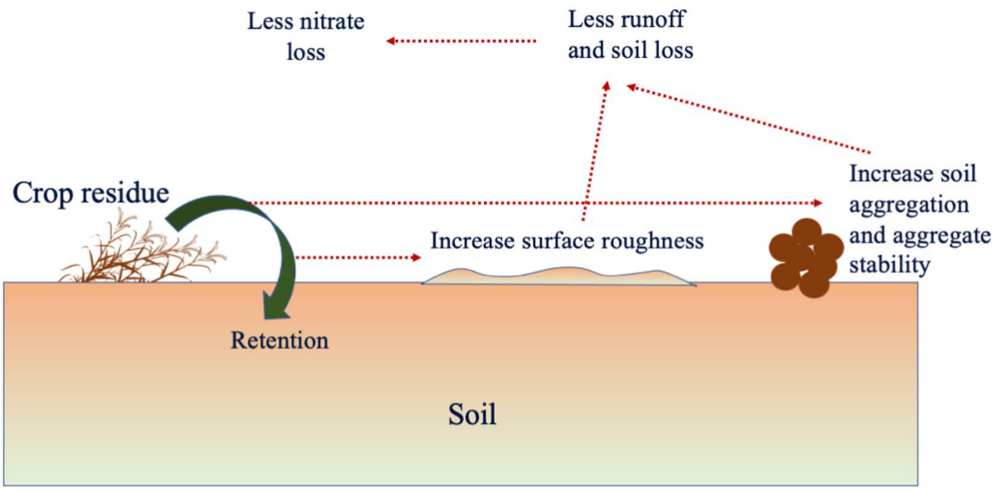

Figure 4. Effect of conservation agriculture on water erosion.

In addition, the increased infiltration of water into the soil profile under CA can also increase rates of profile leaching [62] and potentially increase the transport of nitrate into groundwater. Some studies have found increased rates of nitrate leaching from NT profiles [62,63], although others have also found that NT had no effect on nitrate loss [64] or could reduce nitrate concentration in groundwater [65]. The variability in these results is due to complex interaction and contribution of several factors, such as soil physical characteristics, rainfall patterns and soil management practices that directly or indirectly affect the nitrate mobility and export from the fields to another location [66]. In order to achieve the full potential of CA to reduce nitrate loss, cover crops and balanced fertilizer management needs to be incorporated into the CA system to improve soil nitrogen retention and water quality [67].

Conservation agriculture can also affect the transportation of pesticides to waterbodies. Crop residues can intercept pesticides, especially apolar pesticides or those with low polarity [68]. Therefore, retention of crop residues on the soil surface under CA can affect the efficiency of pesticide interception. When more than 30% of the soil surface is covered with crop residues, 40–70% of the applied pesticide can be intercepted [69]. Moreover, these crop residues have 10 to 60 times more sorption capacity than soil [70]. CA can also modify the concentration and transport of pesticides in the soil, although as pesticide behavior in soil is highly variable, the effect of CA on pesticide transport is also often inconsistent [58]. Conservation agriculture can enhance the soil organic matter content, especially in the top surface layers [2,25], which can increase the retention of pesticides and limit their susceptibility to microbial degradation. However, Alletto et al. [71] highlighted that the conservation tillage system has lesser effects than initial soil condition on pesticide transport. Overall, a recent review concluded that pesticide transport from CA systems in runoff can be greater, reduced and no different from conventional systems depending on the chemical in question, but that CA is more effective in reducing the transport of pesticides sorbed onto soil surfaces due to its ability to decrease erosion rates [72].

Table 2. Comparison of conservation agriculture (CA) and conventional tillage (CT) on soil loss (t/ha).

Cropping System	Location	Year	Type of Soil	Soil Loss (t/ha)		Change of CA over CT (%)	References
				CT	CA		
Wheat-Teff (NT on raised beds)	North Ethiopia	2005–2007	Calcic Vertisol	24	5	↓79	[73]
Fallow land-winter wheat	Zurich, Switzerland	2014–2017	Loamy cambisols	2.66 **	0.49 **	↓81	[74]
Wheat-soybean-maize	Northeast Italy	2017–2018	Silty loam	3.37	0.41	↓88	[75]
Wheat	Queensland Australia	1978–1988	Fine textured soil	64	4	↓94	[76]
Corn and soybean	North Carolina	July 1997 June 2000 July 1997	Sandy clay loam and clay loam (fine mixed, active, thermic, Ultic Hapludalfs)	241.8 92.9 62.6	2.5 2.3 1.1	↓99 ↓98 ↓98	[77]
Maize Cowpea	Nigeria	1984–1987	Oxic Paleustalf	6.90 4.90	0.46 0.72	↓93 ↓85	[78]
Winter wheat-fallow-winter chickpea	North eastern Oregon, USA	2001–2004	Typic Haploxerolls	11 *	0.21 *	↓98	[79]
Maize Soybean Winter wheat	Daruvar, CentralCrotia	1995 1996 1996/97	Stagnic Luvisols	146.3 110.1 86.7	22.8 13.6 0.21	↓84 ↓88 ↓99	[80]
Maize	Ohio, USA	1970–1973	Silt Loam	23.9	0.26	↓99	[81]

↓ arrow indicates reduction compared to conventional tillage; * mean data t/ha/yr ** mean data of four years in t/ha/h.

Table 3. Comparison of conservation agriculture (CA) and conventional tillage (CT) on surface runoff (mm).

Cropping System	Location	Year	Type of Soil	Runoff (mm)		Change of CA over CT (%)	References
				CT	CA		
Green gram-mustard and pearl millet + pigeon pea	Vasad, India	1990–1993	Coarse loamy soil	241.9	160.7	↓34	[82]
Cowpea-mustard and cowpea-castor		1995–2001		234.8	230.4	↓2	
Wheat	Queensland, Australia	1978–1988	Fine textured soil	98	81	↓17	[76]
Wheat-Teff (NT on raised beds)	North Ethiopia	2005–2007	Calcic Vertisol	98.1	46.3	↓53	[73]
Wheat-soybean-maize	Northeast Italy	2017–2018	Sandy clay loam	60.9	27.5	↓58	[75]
Wheat (1 t residue/ha/year)	Humid Highlands, Ethoipia	2009–2011	Eutric Nitisols	214.6	273.3	↑27	[83]
Wheat (2 t residue/ha/year)				198.2	256.5	↑29	
Wheat-fallow	Saskatchewan, Canada	1995–2000	Brown Chernozm	27.1	52.6	↑48	[61]
Winter wheat-fallow-winter chickpea	North eastern Oregon, USA	2001–2004	Typic Haploxerolls	79 *	23 *	↓71	[79]
Maize	Daruvar, Central Crotia	1995	Stagnic Luvisols	186.3	77.8	↓58	[80]
Soybean		1996		210.6	48.7	↓77	
Winter wheat		1996/97		118.2	55.5	↓53	

↓/↑ arrows indicate reduction/increase compared to conventional tillage; * average values for the study period in mm/yr.

4. Large Scale Crop Residue Burning in Conventional Farming: A Significant Threat to Air Quality

The large scale burning of crop residues has numerous adverse effects including air pollution, due to the increase in particulate matter (also known as 'black carbon') and carbon emissions, which contributes to regional and global climate change. In areas where burning is widespread, such as the Indo-Gangetic plains (IGP), it can be responsible for significant health (toxic smog) and environmental impacts [84,85]. For example, Kaskaoutis et al. [86] used AERONET imaging data from the Kanpur Research Station for identifying hot-spots of residue burning. They reported that large scale atmospheric emissions, pollution, and accumulation of aerosols have increased over the IGP during the past decade, especially from October to February [87,88]. Carbon monoxide (CO) and nitrogen dioxide (NO_2) are among the main components of smog. The smoke plumes from crop residue burning are mostly concentrated between the ground and about 800–900 m in altitude captured by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) instrument. Where the uptake of CA in a region is widespread, the elimination of residue burning in favor of residue retention can thus lead to significant reductions in air pollution.

5. Conservation Agriculture and Greenhouse Gas Emissions: Decoding the Complexities

Crop and soil management practices affect the release as well as capture of greenhouse gases (GHGs) from the soil to the atmosphere and vice-versa [89]. Consequently, agriculture has been identified as one of the four important sectors that could contribute to reducing global GHGs emissions [90]. The reduction in fuel usage associated with the smaller number of tillage operations under CA is well established to reduce GHGs emissions. For example, fossil fuel emissions from agricultural operations under conventional tillage (moldboard plough) were estimated to be 0.05 Mg ha^{-1} yr^{-1} compared to 0.03 Mg ha^{-1} yr^{-1} under no-till conditions [91]. In addition, the conversion from conventional to CA has been reported to lead to soil C sequestration, although the amount sequestered is often highly variable and dependent on climate, soil type and management practices. Estimates of C sequestration can be negative (i.e., net C loss) in cool moist regions where tillage buries residues in regions of the profile with lower decomposition rates and/or lowers yield [92], but positive in regions where soil and climate are favorable for biomass production, CA has a positive impact on yield, and the reduced soil disturbance helps protect organic matter from microbial decomposition [93,94]. Many worldwide estimates of average sequestration are around ~0.3–0.5 Mg ha^{-1} yr^{-1} [94–97], although in individual regions, higher rates may be observed (e.g., 0.85 Mg ha^{-1} yr^{-1} in Spain when NT has been in place for <10 years [98]). However, estimates are often highly uncertain due to the methodological challenges of measuring C change [24,99]. It should be noted that rates of sequestration will also decrease over time as sites approach their equilibrium C content.

In addition to C change, CA can also affect the flux of other GHGs, particularly methane (CH_4) and nitrous oxide (N_2O). Similar to C storage, CA has been observed to both increase and decrease N_2O emissions (Table 4), depending on the influence it has on soil moisture and microbial activities and, thus, nitrification and denitrification. For example, where CA increases soil moisture, microbial biomass, and labile carbon, there is potential for greater rates of nitrification and denitrification and thus N_2O emission [6]. However, when CA lowers soil temperatures, and improves soil structure and drainage, denitrification and N_2O emissions can decrease [6,100]. Less information is available regarding the impact of CA on CH_4 emissions; however, these are commonly observed to either remain unchanged or decrease due to improvements in aggregate stability/porosity and the subsequent uptake of CH_4 by methanotrophic bacteria [95,101].

Overall, it is the net impact that CA has on CO_2, CH_4 and N_2O flux that determines whether a CA system will act as a net sink or source of GHGs. However, relatively few studies consider the flux of all GHGs from the soil concurrently. One meta-analysis that summarized the results of nine studies conducted globally reported an average difference in global warming potential (GWP) of −2.39 Mg ha^{-1} yr^{-1} in NT compared to conventionally tilled systems when considering both soil GHGs flux and emissions from farm operations [102]. However, a second analysis noted greater GHGs emissions from the soil of NT compared to conventional systems during the first 5 years of practice (GWP of +0.39 and +1.51 Mg ha^{-1} yr^{-1} in humid and dry temperate regions, respectively), but lower or similar emissions after 20 years (GWP −2.07 and −0.36 Mg ha^{-1} yr^{-1} in humid and dry temperate regions, respectively) [103]. The decline in GHG emissions in NT systems over time was largely due to declines in N_2O emissions, which have been found to reduce as soil aggregation and drainage improve in more established NT systems [103].

Table 4. N_2O production in some of the conventional (CT) and conservation agriculture (CA: reduced or no-till) practices.

Crop	Location	Soil Type	N_2O Production (kg ha^{-1})		Change in CA over CT (%)	References
			CT	CA		
Wheat	USA	Loamy (Ustic Torriorthents)	4.09	3.12	−23.71	[104]
Wheat	North China	Loamy	2.14	1.46	−31.74	[105]
Corn	Ohio	Silt loam	8.26	4.42	−46.48	[106]
Corn	Ohio	Silt loam (Aeric Ochraqualf)	1.82	0.94	−48.35	[107]
Wheat (stubble, 90kg N ha^{-1})	Australia	Clay Vertisol	1.94	1.30	−49.23	[108]
Wheat (straw incorporated) Wheat (no straw incorporation)	Southeast China	Sandy loam	1.53 2.24	2.15 3.91	+40.52 +74.55	[109]

6. Can Conservation Agriculture Really Conserve Soil Biodiversity?

As CA promotes the accumulation of soil organic carbon at the surface of the profile, it is expected that the microbial activity and biomass must be higher in CA farms due to the increased availability of organic substrates [110]. The improvements in soil aggregation, aeration and moisture availability also create favorable conditions for increases in both the size and diversity of microbial populations, as can crop diversification through crop rotation or intercropping [111]. Full implementation of CA components has been reported to increase the diversity of both fungal and bacterial populations [112], with NT in particular favoring the increase in fungal diversity due to the absence of tillage [113]. The increase in microbial diversity has several significant implications for crop productivity and soil health. For example, several plant growth-promoting soil microbes proliferate in these favorable conditions and contribute to enhanced plant growth, disease suppression and abiotic stress tolerance [114]. Microbial-induced enzymes associated with nutrient cycling are also found in greater amounts under CA, leading to higher nutrient availability under CA [115].

CA has the potential to not only improve microbial diversity but also to influence such soil macro-fauna as earthworms, ants, termites and beetles [116]. These macro-fauna improve soil health by breaking down plant residues, increasing macroporosity, and improving water infiltration, soil aggregation and nutrient cycling [117]. Intensive tillage practices often kill or disturb the functions of soil macro-fauna, exposing them to the soil surface and other predators. This loss of soil biodiversity severely affects the soil physico-chemical properties and ultimately influences crop productivity. Therefore, biological parameters are often used as indices in characterization of CA soils. The significant effects of CA on soil macro-fauna could be greater in warm temperate zones and soils with higher clay content (>30%) and low soil pH (<5.5) [116].

7. Conclusions

Compared to conventional agriculture, CA improves several aspects of cropping systems that can enhance ES. Conservation agriculture improves soil structure and typically leads to reduced soil erosion and surface runoff. It is particularly advantageous in drier regions, where it helps to increase soil water storage and maintain greater crop yield. Compared to the intensive agriculture, CA also generally enhances soil organic carbon storage, particularly in the topsoil. This can help with climate mitigation through carbon sequestration, reduced emission of greenhouse gases (CO_2, CH_4, N_2O) and water regulation. However, not all experiments report that CA has a positive impact on ES. This can be due to the duration of experiments, as well as cropping system, climate, soil type and land management practices. Therefore, understanding and decoding the complexities involved in soil–climate-management-dependent CA is important and requires a multidisciplinary approach. Whether CA can deliver significant ESs under a climate changing scenario is also an important question that needs to be addressed by studying the differential effects of temperature, warming and changes to rainfall patterns on soil processes and ES in CA-adopted farms/experiments.

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

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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