Abstract: Sustainable food production has long been a priority for mankind and this is being challenged by limited arable land, challenged landscapes, and higher human population growth. China started conservation farming around the 1950’s. However, main Conservation Tillage (CT) research started in 1992. Using a systematic meta-analysis approach, this review aims at examining China’s approach to CT and to characterize the main outcomes of long-term CT research across northern China. Data from organizations in charge of CT research in China showed an improvement in crop yield of at least 4% under double cropping systems and 6% under single cropping systems in dry areas of northern China. Furthermore, long-term CT practices were reported to have improved soil physical properties (soil structure, bulk density, pore size, and aggregate stability), soil nutrient levels, and reduction in greenhouse gas emission. Other benefits include significant increase in income levels and protection of the environment. Limitations to CT practice highlighted in this study include occasional reduction in crop yields during initial years of cropping, significant reduction in total N of soils, increase in N₂O emission, and the need for customized machinery for its implementation. Outcomes of CT practice are ecologically and economically beneficial though its limitations are worth cogitating.

Keywords: conservation tillage; traditional tillage; agriculture; no-till; soil; sustainability; northern China

1. Introduction

Tillage, which has been an essential constituent of crop production systems since the start of agriculture, is defined as an approach to “working” the soil by physical, mechanical, chemical or biological means to create appropriate conditions for germination, establishment, and growth of seedlings [1]. Tillage is an important and fundamental practice particularly in the cultivation of field crops. According to Simmons and Nafziger [2] soil is the most precious and abundant natural resource, and it needs to be tilled in order to be suitable for crop cultivation. Proper soil management is key to sustainable agriculture. They added that in order to manage the soil properly there are six essential practices, which include: type of tillage, maintenance of soil organic matter, proper nutrient supply to the plants, avoidance of soil contamination, maintaining the correct soil acidity, and control of soil erosion.

The process involved in tilling or preparing soil was significantly refined with the development of the first plow by the Chinese as early as the sixth century BC and from then, different kinds of tillage equipment and machinery were developed for seedbed groundwork and cultivation [3]. The emphasis in tillage practice is on soil conservation. However, conserving soil moisture, agro-inputs, energy,
labor, and even equipment delivers additional benefits, which has led to the development of various forms of tillage practices across the world. According to Food and Agricultural Organization (FAO) [1], to be considered conservation tillage, it is important that the system should provide conditions that resist environmental hazards and erosion caused by rain, wind, and running water. Such resistance is attained either by protecting the soil surface with crop residues or growing cover plants, or by preserving sufficient surface roughness or soil permeability to increase water filtration and therefore reduce soil erosion.

In most cases, it seems that each country or region has a different understanding of what represents Conservation Tillage (CT) and therefore the term is frequently adapted to suit the specific purposes of the country or region in question [4]. The basic operating principle underpinning CT practice is to minimize the disturbance of the soil; this includes basic elements including: no burning, little or no soil disturbance, crop rotation, direct drilling, and permanent soil cover, among others.

The use of CT is becoming global and the number of adopters is continually increasing [5]. In 2008 for instance, minimum tillage practice was adopted in about 110 Mha globally [6]. North and South America are the top continents where CT practice is high, with about 40% and 45%, respectively, of arable fields cultivated using CT practices. However, CT practice is less used within Europe but its adoption rate is gradually increasing. CT adoption rate in Africa and Asia is low, but as these regions experience improved economic growth and access to larger and commercial machinery needed for CT practice, the adoption rate is increasing as well. Few countries have yearly statistics and data on the different forms of CT being practiced. Therefore data from most parts of the world is either very rare or non-existent and in most countries, the statistics on CT are based mainly on estimates [7]. CT and Traditional Tillage (TT) also known as conventional tillage, are two common practices within the farming systems of China. CT has been practiced in all provinces of northern China.

There is a continual challenge to global food security, and therefore food production in its current way can only be sustained with a careful and intensified cropping system, more effective use of production resources, and protection of the soil [8]. China is the biggest producer (by volume) of agricultural products and is one of the world’s major dryland farming countries, which is also seriously threatened and affected by desertification. The agricultural sector in China has had a huge impact on the country’s high financial growth in recent years [9].

Although there has been a lot of CT research in China, access to this data has been limited to the scholarly community, and in most cases these datasets or documented information are either unpublished or mainly recorded in native Chinese language. Awareness to the usefulness of agricultural data beyond the original research outcomes is changing speedily and the interest in the reuse of this data is becoming greater than ever [10,11]. The development of systems to aid in data sharing in disciplines such as the biophysical sciences and agriculture is quickly growing within libraries and information centers [12,13].

Awareness is on the rise of the negative effect of traditional or conventional tillage systems on agriculture across the world. It causes reduction in soil fertility due mostly to soil erosion and loss of soil organic matter over time, and this leaves the soil surface bare and unprotected especially in periods of heavy rainfall, wind, and heat [7]. This review seeks to characterize the outcomes and major findings focused on long-term CT research conducted in northern China and its effect on crop productivity and a sustainable environment.

1.1. Theoretical Background to Conservation Tillage

The terminology “Conservation Tillage” (CT) generally embodies a tillage practice that “moderates the volume of soil disturbed” [4]. CT itself is described generally as a “collective umbrella term” which signifies practices that have a conservation aim of some type [4]. CT is generally synonymous to conservation agriculture. However, the latter embodies other conservation or sustainable practices for agricultural production other than just tillage practices. The terminology “conservation tillage” or no-till is commonly used in Chinese. CT, which varies in its practice among regions in China, has been
defined by the Conservation Technology Information Center (CTIC) in China as a tillage system that leaves a crop residue cover of at least 30%. According to the CTIC [14], in China there are four main categories or types of CT practice (no-tillage, mulch tillage, reduced or minimum tillage, and ridge tillage).

The United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) also defines CT as a system that leaves sufficient crop residues on the soil surface after cropping to provide at least 30% soil cover [15]. Another broader definition of CT by Barker et al. [16] added that typically, the retention of 30% surface cover by crop residues consists the base limit to be classified as CT. However, other conservation goals for this practice may include conservation of soil water, earthworms, soil structure, nutrients, and fuel. Therefore residue cover level alone does not sufficiently describe all conservation tillage types. Research has acknowledged 30% cover as the minimum amount of residue needed to avoid any significant soil loss; however higher residue amounts are ideal. The use of cover crops is critical to producing and meeting this added crop residue need [15].

Traditional Tillage (TT) or conventional tillage is a common practice of tilling the land using operations or techniques that are most commonly applied within a given location and have been used from generation to generation. This practice varies considerably and depends on the location and type of crop being grown. According to the CTIC [14], TT involves incorporating residue but leaving less than 30% of the surface covered with plant residue. The American Society of Agricultural and Biological Engineers (ASAE) [17], defines TT as a sequence of procedures, which is historically and commonly used in a given location to prepare seedbeds and produce crops. In China, conventional tillage mostly involves the use of mouldboard mechanized ploughing to a depth of about 20 cm followed by harrowing, hoeing, rolling, and finally leveling of the soil. Residues removed from the field are and mainly used as animal feed or fuel before the ploughing starts [18].

A no-tillage (no-till) system is the most common form of conservation tillage and as the name implies, it does not use tillage for the establishment of its seedbed. The soil is left undisturbed and the seeds are simply planted into the previous year’s crop residue. Minimal soil disturbance only occurs when applying fertilizers or during use of seed disk openers or drills, row cleaners, or seed furrow openers. No-till in principal should leave more (70%) of the surface cover with crop residue to be considered as a no-tillage system. According to He et al. [8], no-till makes about 50% of CT systems in China and this corresponds to 1.33 Mha of farmland under this practice. Among the many tillage types practiced in most parts of the world, the common ones still extensively being practiced especially in northern China include mulch tillage, controlled traffic tillage, reduced tillage/minimum tillage, and permanent raised bed tillage.

1.2. Importance and Need for Conservation Tillage

The practice of CT comes with numerous benefits to both the producer and the environment and this has been shown to be a sustainable way of agricultural production. The principal benefits of CT practice are improvement in soil tilth and water conservation [19]. Other benefits include reduction in soil erosion, fuel consumption, soil compaction, labor requirements, and flexibility of planting and harvesting [20–22]. CT increases soil biodiversity, enhances soil organic matter content, promotes higher soil aggregate stability, and increases infiltration and the soil’s ability to hold and provide root-layer moisture, which improve crop yields [23]. According to Cameron et al. [24] CT, especially no-tillage, in combination with crop residue retention and crop rotation notably increases crop production in dryer environments, implying it might become an important approach for adapting to climate change in dryer parts around the world as they become drier. Leys et al. [25] reported that CT practice enhances nutrient and water uptake as well as enhancing nutrient cycling, thereby reducing yield variability.

As reported by Brouder et al. [26], extensive implementation of CT in North and South America and Australia has revealed substantial farmer profitability attained by means of combined and sustained increase in agronomic productivity and reduced agro-input costs. While transitioning into CT practice
may require added capital investment at the initial stage, these costs are generally offset by reduced labor due to fewer activities, as well as reduced fuel and machinery maintenance cost. Studies from the Midwest of the USA have shown that no-till systems can cost less than half that of conventional tillage systems [15].

As a food basket, northern China has about 18 Mha of farmland representing 20% of the total food production in the country [27]. Due to population increase in China and increased demand for food, farmers have been forced to intensify cultivation and this has led to negative environmental consequences for the soil [28]. In the north China plains around Beijing, cropping patterns have changed from single cropping to double cropping for winter wheat and summer maize since the 1980’s. These areas have huge evaporation rates that exceed the annual rainfall. Also, in the ecotone of the Inner Mongolia regions of northern China, the transformation of grassland to cropland merged with inadequate rainfall and wind erosion has resulted in soil nutrient loss and soil structural deterioration, while in the northwest of China, high and varying evaporation rates (40–400 mm) have caused major water shortages affecting the production of spring wheat, which is a major cereal of the region [18].

According to Wang et al. [28], in order to mitigate these effects on agricultural production, the Chinese government has recognized the increasing rate of environmental degradation within northern China since 2002, and has since set up and promoted demonstration and extension of CT practices across regions to complement the research on CT started earlier. Reports on CT research have often focused on short-term outcomes from experiments. In northern China there has been on-going extensive long-term research work on CT [18,29]. Few studies have assessed or reviewed the effects of long-term CT practices on soil and other properties [30]. Despite the variation in research methodology used in the various experiments, this review aims to examine China’s approach to CT research and practice and also aims to determine the main outcomes from various long-term CT research experiments, and narrates in summarized and tabulated form conclusions from these research sites in comparison to TT.

2. Materials and Methods

2.1. Study Area

This review focused on long-term studies in the area of CT within northern China. The study area (Figure 1) accounts for more than 60% of the total farmland in China. These dryland areas are undergoing severe degradation and desertification. Sand storms in northern China in the recent decade have caused great havoc to farmlands and this has lead to a significant reduction of productivity [18]. The dryland farming areas in northern China are largely located in 16 provinces, and are characterized by low annual rainfall amount per year (<750 mm), low temperatures, a short frost-free period in a year (<750 days) and a high evaporation rate in a year (<1500 mm) [31]. For instance, in the Loess Plateau of northern China, a very complex terrain of severely cut slopes and fragile landscapes has made it the most severely degraded area in the world with more than 60% of its land cover exposed to soil and water erosion recording average annual soil loss of 20–35 t/ha [32].
2.2. Study Approach

Using the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) approach, data was collected from published works within the subject area and from secondary sources within state organizations such as the Conservation Tillage Research Center (CTRC) and the Ministry of Agriculture (MOA). Through the flow of information to conducting a systematic review, this study first identified available data on the subject matter (conservation tillage). This was followed by screening and selection of eligible data for inclusion in a quantitative synthesis (meta-analysis). Keywords used to search for data varied with different search engines and databases. Publications gathered were augmented with other data collected from notable databases from Chinese organizations such as the CTRC and MOA with others from FAO. Screening of available data both in English and Chinese was done to draw conclusions on the subject matter.

According to Green and Higgins [34], a systematic review is one that clearly generates questions and uses a systematic and explicit method to identify, select, and analytically appraise important research ideas and to collect and analyze data from studies that are included in that review. This approach is becoming increasingly important in both the social and physical sciences. Yet as stated by Dore et al. [11] and Philibert et al. [35], this approach though promising is underutilized in most agricultural research. The reporting format may vary based on the clarity of reporting, what was done, found, collected, and analyzed [36].

This review acknowledges the limitation in variation to sources of data being collated as outcomes from CT research and irrespective of the study methodology as used by the different authors, conclusion and summaries were drawn as a general view of the authors as described and reported in the referenced work. Therefore further details about specific methodology can be accessed from the list of references provided at the end of this review.
3. Results

3.1. Effects of CT on Crop Yield

Results from CT research sites across the Loess Plateau have shown that wheat yields improved significantly under CT compared to conventional systems [37]. Despite the occasional lower (−0.6%) yield observed especially in the Boadi and Tianjin experimental sites, CT is effective in increasing yield because of its ability to improve soil properties and increase soil moisture, which is particularly significant in northern China where study conclusions by Li et al. [38] show between 4–6% of mean annual crop yield improvement in the mono cropping system of northeast and northwest China. As shown (Table 1), CT compared to TT can result in significantly higher crop yields of up to 54.4%, especially in dryer years as was reported by Wang et al. [39] in Chenghuang near Linfen of the Shanxi province. The trend in the yield outcomes of most long-term CT research fields also generally shows a slight increase within the initial first half and then improves (over double) at the second half of the study period.

Table 1. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on crop yield in northern China.

| Reference | Experimental Site | Start–End (Duration) | Crop Type | Long-Term Yield Outcome (CT Compared to TT) |
|-----------|-------------------|----------------------|-----------|--------------------------------------------|
| [40]      | Linfen of Shanxi   | 1998–2006 (8)        | Winter wheat | 9.8% higher yield |
| [41]      | Wuchuan, of Inner Mongolia | 1998–2007 (10) | Spring wheat and oats | 6% increase in first 4 years, 14% increase in subsequent 6 years |
| [42]      | Changping of Beijing | 2002–2007 (5) | Winter wheat | 12.9% significantly higher |
|           | Baodi and Tianjing | 2002–2007 (5) | Winter wheat | *−0.6% slight reduction in yield |
| [43]      | Chifeng of Inner Mongolia | 2002–2007 (5) | Millet | 13% higher |
|           | Xifeng of Gansu    | 2002–2007 (5)        | Winter wheat | 19.2% higher |
| [43]      | Gaocheng Southwest of Hebei | 1998–2009 (11) | Winter wheat | 3.5% higher in first 5 years then 6.2% in subsequent 6 years |
|           |                    |                      | Summer maize | 1.4% higher and more significant in last 6 years of experiment |
| [18]      | Chenghuang near Linfen of Shanxi | 1993–2006 (13) | Winter wheat | 9.2% increase in the first 5 years, 24.5% increase in subsequent 9 years |
| [28]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | Winter wheat | 15.5% higher during 2003 to 2007, 42.3% higher in 2005 |
| [39]      | Chenghuang near Linfen of Shanxi | 1998–2005 (7) | Winter wheat | 6.9% higher in 3 out of 7 years |
|           |                    |                      | Summer maize | No significant difference in first 3 years (1999–2002) |
| [44]      | Liaoning Province   | 1999–2011 (12)       | Spring maize | Unchanged in the following 4 years (2003–2006) in TT fields |
### Table 1. Cont.

| Reference | Experimental Site | Start–End (Duration) | Crop Type | Long-Term Yield Outcome (CT Compared to TT) |
|-----------|-------------------|----------------------|-----------|-------------------------------------------|
| [45]      | Linfen of Shanxi  | 1997–2007 (10)       | Winter wheat | 23.6% higher                              |
|           |                   |                      |           | 12.5% higher grain per spike              |
|           |                   |                      |           | 9.1% higher kernel weight                 |
| [46]      | Daxing near Beijing | 2000–2007 (7)       | Winter wheat | 7.46% higher (2004–2007)                     |
|           |                   |                      | Summer maize | 3.24% higher (2004–2007)                     |
|           | Changping near Beijing | 2000–2007 (7)     | Spring maize | 4.25% higher (2004–2007)                 |
|           |                   |                      |           | * Study outcomes where TT plots performed better. |

### 3.2. Effects of Long-Term CT on Soil Properties

#### 3.2.1. Effects of CT on Soil Bulk Density

It was observed that in most reviewed study sites across northern China, there was a general reduction in soil bulk density across the different studied soil depths (0–30 cm) of CT fields compared to TT fields (Table 2). Percentage reduction ranged from 2% to 7%. A few study areas recorded slight or significant increase in soil bulk density. Over the long term, soil bulk density was reported to be less.

### Table 2. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on soil bulk density in northern China.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Soil Bulk Density Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|-----------------------------------------------------|
| [41]      | Wuchuan, Inner Mongolia | 1998–2007 (10) | Greatest at 30 cm soil layer in first 5 years (1998–2002) |
|           |                   |                      | Generally less at later years. (After 9 years)       |
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | 6.7%, significantly lower at 20–30 cm soil layer CT: 1.40 Mg m\(^{-3}\) TT: 1.41 Mg m\(^{-3}\) |
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | 2% lower CT: 1.33 g.cm\(^{-3}\)                   |
| [43]      | Gaocheng Southwest of Hebei | 1998–2009 (11) | 2.1% and 4.7% lower in 0–10 and 10–20 cm soil layers |
|           |                   |                      | ** No significant difference in the 20–30 cm soil layer |
| [18]      | Chenghuang near Linfen of Shanxi | 1992–2006 (15) | * 3% significantly higher CT: 1.36 Mg/m\(^{-3}\) TT: 1.31 Mg/m\(^{-3}\) |
| [39]      | Chenghuang near Linfen of Shanxi | 1998–2005 (7) | * Significantly higher at the 10–20 cm soil layer |
| [28]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | 2.2–6.0% lower in the 20–30 cm soil layer |
| [44]      | Liaoning province | 1999–2011 (12) | 5.44–11.98% reduction in the 0–30 cm soil layer |
|           |                   |                      | 20% reduction in the 30–40 cm soil layer CT: 1.47 g/cm\(^{-3}\) |
| [45]      | Linfen of Shanxi  | 1998–2007 (9)       | 3.8% significantly lower at 0–15 cm soil layer       |
### Table 2. Cont.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Soil Bulk Density Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|----------------------------------------------------|
|           |                   |                      | 5.2% and 4.0% significantly lower at 15–40 cm soil layer |
|           |                   |                      | 5.0% and 4.0% significantly lower at 40–60 cm soil layer |
| [46]      | Daxing near Beijing | 2000–2007 (7)       | 1.4% reduction at 0–30 cm soil layer (2003 to 2007) |
|           | Changping near Beijing |                | 1.2% reduction at 0–30 cm soil layer (2002 to 2007) |

* Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed.

### 3.2.2. Effects of CT on Soil Aggregates, Soil Pore Size, and Infiltration Rate

Review outcomes from the long-term research varied, but revealed (Table 3) that CT fields had a much larger aggregate size class (>2 mm) than in TT fields at soil depths of less than 30 cm. This could reach 100% or twice as high as TT fields. In soil layers of 0–30 cm, proportions of micro-aggregates (<0.25 mm) ranged between 19–59% higher in CT fields, except for one study in Liaoning province where a 12-year study as reported by Wang et al. [43] showed a significantly lower (9.8–23.2%) smallest size class (<0.25 mm).

With regards to soil pore size and its distribution, outcomes of CT research show (Table 4) that for most long-term CT practices, there is a general improvement in mesoporosity and macroporosity across different soil depths with only one site recording a reduction (3.8%) in microporosity in the 0–10 cm soil layer. However, no significant difference was recorded in total porosity and capillarity porosity as recorded in Gaocheng of the Southwest Hebei province and Chenghuang near Linfen of the Shanxi province.

### Table 3. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on soil aggregates in northern China.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Soil Aggregates (Wet) Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|-------------------------------------------------------------|
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15)     | Proportion of micro-aggregates (<0.25 mm) ranged between 51% and 55% in the 0–30 cm soil layer in CT |
|           |                   |                      | Proportion of micro-aggregates (<0.25 mm) ranged between 32% and 43% in the 0–30 cm soil layer in TT |
|           |                   |                      | Percentage of >2 mm water-stable aggregates was significantly higher in all soil layers |
| [41]      | Wuchuan, Inner Mongolia | 1998–2007 (10)     | 13–37% more macro-aggregates |
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15)     | 25–59% more micro-aggregates |
|           |                   |                      | 100% higher at the largest size class (>2 mm) CT: 160 g kg⁻¹ |
|           |                   |                      | 32.6% higher at the smallest size class (<0.25 mm) |
| [42]      | Gaocheng Southwest Hebei province | 1998–2009 (11)     | Within the largest size class (>2 mm) in the 0–10, 10–20, and 20–30 cm soil layers, CT were 46.7%, 33.2%, and 27.3% higher, respectively |
|           |                   |                      | Within the smallest size class (<0.25 mm) in the 0–10 and 10–20 cm soil layers, CT were 19.3% and 24.3% lower, respectively |
Table 3. Cont.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Soil Aggregates (Wet) Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|-----------------------------------------------------------|
| [18]      | Chenghuang near Linfen of Shanxi | 1992–2006 (14) | Twice as higher (%) at the largest size class (>2 mm) in the 0–10 and 10–20 cm soil layers |
|           |                    |                      | * Lower % at the largest size class (>2 mm) in the 0–10 and 10–20 cm soil layers |
|           |                    |                      | 58.6% and 53.5% in the 0–10 and 10–20 cm soil layers, respectively, for CT macro-aggregates |
|           |                    |                      | 45.1% and 47.4% in the 0–10 and 10–20 cm soil layers, respectively, for TT macro-aggregates |
| [44]      | Liaoning Province | 1999–2011 (12) | 63.1–80.3% higher at the largest size class (>2 mm) in the 0–5, 5–10, 10–20, and 20–30 cm soil layers |
|           |                    |                      | * 9.8–23.2% significantly lower at the smallest size class (<0.25 mm) in the 0–5, 5–10, 10–20, and 20–30 cm soil layers |
| [46]      | Daxing near Beijing | 2000–2007 (7) | 50.0–104.2% higher at the largest size class (>2 mm) in the 0–10, 10–20, and 20–30 cm soil layers |
|           | Changping near Beijing |             | 109.9% and 40.0% higher at the largest size class (>2 mm) in the 10–20 and 20–30 cm soil layers, respectively |
|           |                    |                      | * Lower at the 0–10 cm soil layer |
|           |                    |                      | Higher % with straw treatment at the smallest size class (<0.25 mm) |
|           |                    |                      | ** Non-significant improvement in the largest size class (>2 mm) |
|           |                    |                      | * Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed. |

Table 4. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on soil pore size in northern China.

| Reference | Experimental Site       | Start–End (Duration) | Long-Term Effect (CT Compared to TT) |
|-----------|-------------------------|----------------------|---------------------------------------|
| [41]      | Wuchuan, Inner Mongolia | 1998–2007 (10)      | 14% higher macroporosity in the 0–10 cm soil layer: 42% for CT and 38% for TT |
|           |                         |                      | 4.6% higher mesoporosity in the 0–10 cm soil layer |
|           |                         |                      | 75% higher macroporosity in the 10–20 cm soil layer |
|           |                         |                      | 17% higher mesoporosity in the 20–30 cm soil layer |
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | ** No Significant difference observed in total porosity, macroporosity, and mesoporosity in the 0–15 cm layer for CT and TT |
|           |                         |                      | 18% increase of mesoporosity in the 15–30 cm soil layer |
| [43]      | Gaocheng Southwest of Hebei | 1998–2009 (11) | Macroporosity (51.2%) and Mesoporosity (4.6%) higher in the 0–10 cm soil layer |
|           |                         |                      | * 3.8% less microporosity in the 0–10 cm soil layer |
|           |                         |                      | 61.6% higher macroporosity in 10–20 cm soil layer |
|           |                         |                      | 17.8% higher mesoporosity in the 20–30 cm soil layer |
|           |                         |                      | 9.0% higher mean total porosity |
Table 4. Cont.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|-------------------------------------|
| [18]      | Chenghuang near Linfen of Shanxi | 1992–2006 (14)       | Slightly higher mean aeration porosity |
|           |                    |                      | Slightly higher mean capillary porosity |
|           |                    |                      | ** No significant difference observed in aeration and capillary porosity |
| [45]      | Linfen of Shanxi   | 1997–2007 (10)       | 14% improvement at all sampled layers; CT: 5 (36Y41) cm$^3$/100 cm$^{-3}$ |
|           |                    |                      | 21.7–35.5% improvement in capillary porosity |
| [44]      | Liaoning province  | 1999–2011 (12)       | 17.2% increase at all soil layers; CT: 42.8 cm$^3$/100 cm$^{-3}$ |
| [46]      | Daxing near Beijing | 2000–2007 (7)        | 10.6% higher aeration porosity |
|           | Changping near Beijing |               | 8.6% higher aeration porosity |
|           | Daxing and Changping near Beijing |    | Significantly higher total porosity |

* Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed.

This review revealed that soil infiltration rate decreases with time in CT and TT fields. Shifting from TT to CT can reduce soil losses by up to 79% through the protection of the soil surface, increased infiltration rate, and reduced runoff [47,48]. Outcomes of CT research show (Table 5) that significant improvements can be attained on CT plots. However, similar infiltration rates at both tillage types were reported, especially within the initial 20 min of soil infiltration. The cumulative infiltration rate could reach 47.3 cm/h after 120 min as recorded at the long-term study site at Lifen of Shanxi province.

Table 5. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on infiltration rate in northern China.

| Reference | Experimental Site | Start–End (Duration) | Long-Term Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|-------------------------------------|
| [8]       | Chenghuang near Linfen of Shanxi | 1992–2007 (15)       | ** Negligible infiltration rate differences between CT and TT in the first 3 min |
|           |                    |                      | Significantly higher infiltration rates in deeper soil layers |
|           |                    |                      | Higher total infiltration was steady with final infiltration rate for CT 17.0 mm/min and for TT 4.25 mm/min |
| [45]      | Linfen of Shanxi   | 1997–2007 (10)       | ** Same initial infiltration rates (at 20 min) |
|           |                    |                      | Twice the final infiltration rate TT: 9.5 cm/h |
|           |                    |                      | Collective infiltration after 120 min was 30%. CT: 47.3 cm/h |

** Study outcomes where no significant difference was observed.

3.2.3. Effects of CT on Soil Organic Matter and Microbial Biomass

Research outcomes (Table 6) from the different study sites of long-term CT fields revealed a higher organic matter content in the soil than TT fields. Ranging from 7% to 45% higher at the different soil layers. Only one record of a reduction was reported at a soil depth of 20 cm at Wuchua, in the Inner Mongolian region by He et al. [41]. Results show a similar trend with microbial biomass C and N. However, no significant effect was noticed below a 10 cm soil depth between tillage types at the
long-term experiment at Chenghuang near Linfen in the Shanxi province (Table 6). Long-term CT practice is therefore valuable to improving microbial biomass and soil organic matter content of soils, especially within the top layers of soil depths.

Table 6. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on Soil Organic Matter (SOM) and Microbial Biomass within northern China.

| Effect Factor | Reference | Experimental Site | Start–End (Duration) | Long-Term Effect (CT Compared to TT) |
|---------------|-----------|-------------------|----------------------|-------------------------------------|
| SOM           | [41]      | Wuchuan, Inner Mongolia | 1998–2008 (10)       | 20.1% higher at the 0–5 cm soil layer CT: 17.9 g/kg |
|               |           |                   |                      | * Reduced in soil layers deeper than 20 cm |
|               | [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | 25% higher. CT: 18.2 g/kg |
|               | [43]      | Gaocheng Southwest Hebei province | 1998–2009 (11) | 7.7% higher in the 0–30 cm soil layer |
|               | [18]      | Chenghuang near Linfen of Shanxi | 1992–2006 (14) | 10–30% improvement in the 0–10 and 10–20 cm soil layers |
|               |           |                   |                      | CT: no earthworms at start of experiment (1992); 6 years later, there were 5 earthworms/m² while there were 19 earthworms/m² at the end of the experiment. TT: no earthworms observed throughout the experiment period |
|               | [28]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | 2.3% higher at the 0–30 cm soil layer ** Not significant at the beginning of the experiment in 1992 |
|               |           |                   |                      | 1.5% higher after 16 years |
|               |           |                   |                      | 33.6% and 9.8% higher in the 0–5 and 5–10 cm soil layers, respectively |
|               | [44]      | Liaoning province | 1999–2011 (12) | 45.7% higher at the 0–5 cm soil layer |
|               |           |                   |                      | 34.7% higher at the 5–10 cm soil layer |
|               |           |                   |                      | 25.3% higher at the 10–20 cm soil layer |
|               |           |                   |                      | 21.1% higher at the 20–30 cm soil layer |
|               | [45]      | Linfen of Shanxi | 1998–2007 (9) | 25% improvement CT: 18.2 g kg⁻¹ |
|               |           |                   |                      | 14% higher at the 5–10 cm soil layer |
|               |           |                   |                      | 38.3% higher at the 10–30 cm layer |
|               | [46]      | Daxing near Beijing | 2000–2007 (7) | 10.5% higher at the 0–10 cm soil layer |
|               |           |                   |                      | 13.6% higher at the 10–20 cm soil layer |
|               |           |                   |                      | ** No significant difference at the 20–30 cm soil layer between tillage types |
|               |           |                   |                      | 15.3% higher at the 0–10 cm soil layer |
|               |           |                   |                      | 10.5% higher at the 10–20 cm soil layer |
|               |           |                   |                      | ** No significant difference at the 20–30 cm soil layer between tillage types |
| Microbial Biomass | [28]   | Chenghuang near Linfen of Shanxi | 1992–2007 (15) | Significantly higher microbial biomass C and microbial biomass N in the 0–5 cm and 5–10 cm soil layers |
|               |           |                   |                      | ** No Significant difference below the 10 cm soil layer |

* Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed.
3.2.4. Effects of CT on Soil Total N and Available P

Review outcomes from the different study sites show (Table 7) varying outcomes of the effect of long-term research of CT on total N. Improvement in total N from a low (4%) to a high (81%) level was reported at different soil depths, while some study sites recorded no significant difference. There was a significant reduction (76.2% and 70%) reported within Chenghuang near Linfen of the Shanxi province. A similar result trend (Table 8) was observed with available P across study sites, with two reports of reduction (12% and 54%). Available P in soils of the study sites showed no significant difference observed among tillage types especially in deeper soil depths. Long-term CT practice has therefore shown that despite the varying improvement in soil nutrients, there are significant chances of no changes in soil nutrient levels with regards to total N and available P.

Table 7. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on total N in northern China.

| Reference | Experimental Site | Start–End (Duration) | Long-Term N Effect (CT Compared to TT) |
|-----------|-------------------|----------------------|---------------------------------------|
| [41]      | Wuchuan, Inner Mongolia | 1998–2008 (10)      | 34.5% higher in the 0–5 cm soil layer. (Olsen’s P) |
|           |                   |                      | * 8.0–24% less at below the 5 cm soil layer. (Olsen’s P) |
| [42]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15)      | 17% higher CT: 0.668 g/kg |
| [43]      | Gaocheng Southwest Hebei province | 1998–2009 (11)      | 4.1% improvement at CT in the 0–30 cm soil layer |
|           |                   |                      | 7.1% reduction at TT in the 0–30 cm soil layer |
|           |                   |                      | 31.0% significantly higher in the 0–10 cm soil layer |
|           |                   |                      | ** No significant difference in the 10–20 cm and 20–30 cm soil layers |
| [28]      | Chenghuang near Linfen of Shanxi | 1992–2007 (15)      | 21.3% improvement in CT |
|           |                   |                      | 11.9% decrease in TT |
|           |                   |                      | 81.3% increase at CT in the 0–5 cm soil layer |
|           |                   |                      | 16.4% increase at TT in the 0–5 cm soil layer |
|           |                   |                      | ** No significant difference at higher soil layers |
| [44]      | Liaoning province | 1999–2011 (12)      | * 76.2% lower at the 0–5 cm soil layer |
|           |                   |                      | * 70% lower at the 5–10 cm soil layer |
| [45]      | Linfen of Shanxi  | 1998–2007 (9)       | 15% higher at the 5–10 cm soil layer |
| [46]      | Daxing near Beijing | 2000–2007 (7)      | 45.8% higher at the 0–10 cm soil layer |
|           |                   |                      | 17.1% higher at the 10–20 cm soil layer |
|           |                   |                      | ** No Sig. difference at the 20–30 cm soil layer between tillage types |
| Changping near Beijing | 2000–2007 (7) | 45.2% higher at the 0–10 cm soil layer |
|           |                   |                      | 30.5% higher at the 10–20 cm soil layer |
|           |                   |                      | ** No significant difference at the 20–30 cm soil layer between tillage types |

* Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed.
Table 8. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on available P in northern China.

| Reference | Experimental Site                  | Start–End (Duration) | Long-Term P Effect (CT Compared to TT)                      |
|-----------|-----------------------------------|----------------------|-------------------------------------------------------------|
| [43]      | Gaocheng Southwest Hebei province | 1998–2009 (11)       | 29.6% higher in the 0–10 cm soil layer                      |
|           |                                   |                      | 19.1% lower in the 10–20 cm soil layer                      |
| [18]      | Chenghuang near Linfen of Shanxi   | 1992–2006 (14)       | * Reduction in the 0-10 and 10-20 cm soil layers            |
| [28]      | Chenghuang near Linfen of Shanxi   | 1992–2007 (15)       | 97.5% higher in the 0–5 cm soil layer                      |
|           |                                   |                      | 19.7% higher in the 5–10 cm soil layer                      |
|           |                                   |                      | 54.1% higher in the 10–20 cm soil layer                     |
|           |                                   |                      | ** No significant difference in the 20–30 cm layer          |
| [44]      | Liaoning province                 | 1999–2011 (12)       | 28.13% higher at the 0–5 cm soil layer                     |
|           |                                   |                      | 32.9% higher at the 5–10 cm soil layer                      |
|           |                                   |                      | ** No significant difference at deeper soil layers          |
| [45]      | Linfen of Shanxi                  | 1998–2007 (9)        | 84.2% higher at the 5–10 cm layer                          |
|           |                                   |                      | * 12.7% to 54.7% lower below the 5 cm layer                 |
| [46]      | Daxing near Beijing               | 2000–2007 (7)        | 48.7% higher at the 0–10 cm soil layer                     |
|           |                                   |                      | 21.6% higher at the 10–20 cm soil layer                     |
|           |                                   |                      | ** No significant difference at the 20-30 cm soil layer     |
|           | Changping near Beijing            | 2000–2007 (7)        | 50.6% higher at the 10–20 cm soil layer                     |
|           |                                   |                      | 17.1% higher at the 10–20 cm soil layer                     |
|           |                                   |                      | ** No significant difference at the 20–30 cm soil layer     |

* Study outcomes where TT plots performed better. ** Study outcomes where no significant difference was observed.

3.2.5. Effects of CT on Water Use Efficiency and Soil Water Storage

Effects of CT practice on soil water use efficiency show, on average, a significant improvement of 2.6% up to 28.5% across all long-term CT fields (Table 9). Wang et al. [39] recorded a significantly lower efficiency only in the first year of a nine-year long-term study. Water storage was generally higher, up to 19% across soil depths in all study sites.

3.3. Effects of CT on Wind and Water Erosion

CT research outcomes show (Table 10) that wind erosion based on the reduction of dust blowing sediments could be reduced from 12.1% to up to 70%, and an up to 80% decrease in runoff and soil loss via water erosion. The practice of long-term CT on fields has a significant effect in protecting the environment through soil loss.
Table 9. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on water use efficiency (WUE) and soil water storage in northern China.

| Effect Factor              | Reference | Experimental Site                          | Start–End (Duration) | Long-Term Effect (CT Compared to TT) |
|----------------------------|-----------|-------------------------------------------|----------------------|--------------------------------------|
| WUE                        | [44]      | Liaoning province                         | 1999–2011 (12)       | 24.3% and 28.5%, significantly higher in later years of experiment |
|                            | [41]      | Wuchuan, Inner Mongolia                   | 1998–2007 (10)       | 5.0% in CT                              |
|                            |           |                                           |                      | * 16.5% in TT                           |
|                            |           |                                           |                      | CT: 3.8 to 5.4 kg/ha/mm                |
|                            |           |                                           |                      | TT: 3.6 to 4.5 kg/ha/mm                |
|                            | [39]      | Chenghuang near Linfen of Shanxi          | 1998–2005 (7)        | * Significantly lower in first year.    |
|                            |           |                                           |                      | 2.6% and 7.9% higher on average over the 7 years |
| Soil Water Storage        | [41]      | Wuchuan, Inner Mongolia                   | 1998–2007 (10)       | 10% higher in the 0–30 cm soil layer CT: 59 mm |
|                            |           |                                           |                      | CT: 54 mm                              |
|                            | [8]       | Chenghuang near Linfen of Shanxi          | 1992–2007 (15)       | 19% increase during the dry years of 2003, 2006, and 2007 |
|                            |           |                                           |                      | CT: 8 mm                               |
|                            | [43]      | Gaocheng Southwest Hebei province         | 1998–2009 (11)       | 6.3% improvement at the 20–30 cm soil layer |
|                            |           |                                           |                      | 10.4% and 16.4% higher soil moisture content |
|                            | [18]      | Chenghuang near Linfen of Shanxi          | 1993–2006 (13)       | 19.3% improvement across CT treatments in the 0–30 cm soil layer. |
|                            |           |                                           |                      | CT: 60.0 mm and TT: 55.8 mm            |
|                            | [39]      | Chenghuang near Linfen of Shanxi          | 1998–2005 (7)        | 7.7% higher                              |
|                            |           |                                           |                      | TT: 35.9 mm                             |
|                            |           |                                           |                      | CT: 38.9 mm                             |
|                            |           |                                           |                      | 20% improvement during the dryer years of 1998, 2000, and 2005 |
|                            | [39]      | Chenghuang near Linfen of Shanxi          | 1998–2005 (7)        | 14.2% increase                           |
|                            |           |                                           |                      | 9.3% and 9.6% higher at sowing          |

* Study outcomes where TT plots performed better.

Table 10. Effects of long-term Conservation Tillage (CT) and Traditional Tillage (TT) on environmental protection in northern China.

| Effect Factor              | Reference | Experimental Site                          | Start–End (Duration) | Long-Term Environmental Protection Effect (CT Compared to TT) |
|----------------------------|-----------|-------------------------------------------|----------------------|-------------------------------------------------------------|
| Wind Erosion               | [42]      | Fengning of Hebei                         | 2002–2005 (3)        | 70% reduction in wind-blown sediment                         |
|                            |           | Wuchuan                                  |                      | 61.6% less dust                                             |
|                            |           | Chifeng                                  |                      | 34.2% less dust                                             |
|                            |           | Lingyuan                                 |                      | 37.3% less dust                                             |
|                            |           | Changping                                |                      | 12.1% less dust                                             |
| Water Erosion              | [42]      | Shouyang of Shanxi                       | 2003–2007 (4)        | 40.9% reduction in cumulative runoff in both heavy and normal storm years |
|                            |           | Chenghuang near Linfen of Shanxi         | 1993–2006 (13)       | 50–80% reduction in runoff and soil loss                    |

* Study outcomes where TT plots performed better.
3.4. Effects of CT on Greenhouse Gas Emissions

In a 10-year research in northern China, He et al. [49] reported that CO$_2$ fluxes were considerably larger (47.2%) on CT fields than in TT plots within the cropping zone. Lu et al. [50] in a study of no-till with straw return on croplands concluded that between 5.96 and 9.76 Tg C per year could be sequestered. Li et al. [18] during a 13-year study (1993–2006) in Chenghuang near Linfen in Shanxi province reported a 200 kg/ha reduction in CO$_2$ emission. It was also estimated that close to 32.5 Tg C per year can be sequestered in croplands if CT with about 50% of residue cover returned to the soil [51].

Most research studies on CT adaptation have found no significant effect or in some cases recorded a decrease in CH$_4$ emission [52,53]. Long-term research on CT effects on CH$_4$ emission in China has been focused on rice fields, where the relationship between CH$_4$ and tillage types has been studied [53]. In one such study, Ahmad et al. [54] found that in rice paddy fields, CT plots significantly reduced CH$_4$ emission compared to TT plots.

Data gathered from study sites on the effects of N$_2$O emission from CT plots confirm that there is a larger N$_2$O emissions from CT plots compared to TT plots. Lu and Cheng [55] in a research in China postulated that global warming in the future might result in a larger increase in N$_2$O emission from CT fields compared to TT fields.

3.5. Economic Benefits of CT

CT practice has shown (Table 11) that significant savings can be made compared to TT practice. Except in one study site as reported by Wang et al. [44], at Chenghuang near Linfen of Shanxi province were agronomic input cost was reported to be higher than TT, most study sites recorded significant reduction in production costs ranging from 35.6–44.4% and relating to about US$ 65.5–106 per ha$^{-1}$ based on the cropping type. Farmer profit margins at certain study sites were reported to be double and reached up to US$ 157.9 per ha$^{-1}$ in single cropping areas.

Comparing tillage operations as practiced in China, He et al. [49] outlined that a typical TT has about eight operations: (1) stubble chopping, (2) ploughing, (3) harrowing, (4) leveling, (5) planting, (6) fertilizer application, (7) weeding, and (8) harvesting; while CT has only five operations: (1) stubble chopping, (2) planting, (3) fertilizer application, (4) weeding, and (5) harvesting. Cost is cut down and savings made with the practice of CT, and this translates to huge economic benefits to the farmer in the long term.

| Reference | Experimental Site | Start–End (Duration) | Crop Type | Long-Term Economic Benefit (CT Compared to TT) |
|-----------|------------------|---------------------|-----------|---------------------------------------------|
| [42]      | Arid northern China (10 sites) | 2002–2007 (5) | Double cropping; winter wheat and maize | Reduced total input by US$ 106.1 per ha$^{-1}$ |
|           |                   |                     |           | Reduced total input by US$ 102.5 per ha$^{-1}$ |
|           |                   |                     | Single cropping; maize | Reduced total input by US$ 65.5 per ha$^{-1}$ |
|           |                   |                     | Single cropping; wheat | Reduced total input by US$ 33.6 per ha$^{-1}$ |
|           |                   |                     | Double cropping; winter wheat and maize | Higher income average by US$ 142.1 per ha$^{-1}$ |
| [39]      | Chenghuang near Linfen of Shanxi | 1998–2005 (7) | Winter wheat | Higher income average by US$ 157.9 per ha$^{-1}$ |

* Higher agronomic input cost (Due to the use of chemicals to control weeds)
### Table 11. Cont.

| Reference | Experimental Site | Start–End (Duration) | Crop Type | Long-Term Economic Benefit (CT Compared to TT) |
|-----------|-------------------|----------------------|-----------|---------------------------------------------|
|           |                   |                      |           | 35.6% to 44.4% lower production costs (Due to tillage and labor operation costs) |
| Hebei Province |                      |                      |           | 30–40% reduction in fuel consumption |
|           |                   |                      |           | Double profit margins |
| [46]      | Daxing near Beijing | 2000–2007 (7)        |           | 35.8% higher farmer profits |
|           | Changping near Beijing |                   |           | CT: US$ 766/ha annual input cost TT: US$ 979/ha annual input cost |
|           |                   |                      |           | 24.2% higher farmer profits |
|           |                   |                      |           | CT: US$ 511/ha annual input cost TT: $415/ha annual input cost |

* Study outcomes where TT plots performed better.

### 4. Discussion and Conclusions

There is documented evidence across northern China of improvements in crop yields where conservation tillage was used [38]. This higher yield confirms that CT practice can be beneficial in drier areas. Long-term practice of CT has also shown to be a sustainable way to improve soil structure, including bulk density and soil organic matter. Tillage effect on soil bulk density is considered the first approximation and indicator of any potential changes in soil structure and water retention capacity with improved management of different tillage modes [56]. As reported by Chen et al. [40] crop stubble retention under no-till and controlled traffic has increased soil organic matter and other biotic activities, which resulted in a reduction in bulk density on the soil surface layer.

Soil aggregate stability is a valuable variable influenced by soil organic matter and the presence of soil organisms in the soil, in addition to the soil structural profile, crop rotation, soil erosion, and the tillage practice [57]. Significant improvement in soil aggregate stability and pore size was evident in most reviewed long-term CT sites. Several studies have indicated a significant effect of tillage system on soil pore size distribution [58].

Tillage type influences soil organic matter and this tends to be stable at certain levels of the soil. CT practice, especially no-till and ridge till, has been reported to be rich in soil organic matter at the upper layers of its soil surface after many years of practice due to the slow decomposition rates of the left-over residue on its soil surface [59]. Benefits of increased soil organic matter in the soil include its ability to conserve water and nutrients and create a more suitable environment for plant growth [59]. Long-term CT practice has been reported to improve soil microbial biomass and carbon and nitrogen ratio within the topsoil compared to conventional tillage where residue cover is removed [60].

Long-term CT practice was shown to improve water shortage through improved runoff and infiltration rates, which have significantly improved water use efficiency. This can be attributed to the improvement in soil aggregation as this is important for the resistance of soil surfaces to erosion and helps in making soil more productive [61]. Improved infiltration rate in CT fields is an essential indicator of its adaptability in degraded and vulnerable soils types. CT systems with residue cover of 30% or more decrease the total amount of water evaporated from the soil surface and increase infiltration rates, as well as improving water storage in the soil depths [62]. CT fields with sufficient residue cover protect the soil from the impacts of raindrops that can affect surface aggregates and crust formation, thus lowering surface runoff for enhanced soil water storage [62]. The practice of CT especially in dryer lands is therefore necessary in order to conserve and utilize water efficiently.
The benefits of CT practice to soil nutrients are diverse; although not significantly different at deeper depths in most study sites, it is better in the upper layers of CT compared to TT fields. Significant improvement in available P and total N was observed. However, there is a significant possibility of reduction in total N in CT fields. Long-term CT, especially no-till systems, mainly leads to the stratification of available P in soils [63]. The accumulation of P in the topsoil of CT systems has been ascribed to the limited down movement of P particles and the upward movement of nutrients from deeper depths through nutrient uptake by the roots [64]. Roldan et al. [65] and Rhoton [66] reported a reduction in total N in some study sites and as reported in previous studies, by Chowdhury et al. [67] and Embacher et al. [68], this could be attributed to leaching due to the increased drainage capacity of some CT types like no-till with straw cover, which is aided by the highly mobile nature of N in the soil. Wang et al. [69] reported that nitrogen could also be consumed by microbial activity when maize residues are retained on the soil surface. Therefore it is necessary to consider during production an increase in the amounts of N to be applied in the initial years to compensate for the initial shortfall in total N available to plants.

Northern China is prone to environmental hazards but CT practice has shown significant effect as one of the techniques for protecting the environment. Wind erosion for instance is a common phenomenon and many studies have focused on monitoring the three main routes moved by dust storms in northern China [70]. Chen et al. [71] revealed that CT in combination with residue mulching efficiently improved both soil and environmental sustainability within the Loess plateau of northern China. Due to the effect of CT in reducing water runoff especially in heavily stormy years, this has effectively reduced and controlled the incidence of water erosion by up to 80% as observed within Shouyang of the Shanxi province in northern China. This effect of CT concurs with earlier studies by Wang et al. [72] within the northern arid areas of the Loess plateau that found that CT fields effectively controlled water erosion.

CT practice reduces greenhouse gas emissions, especially for CO₂ and CH₄, except for N₂O where there is recorded evidence of increases in emission. Tillage systems have an important influence on soil C emissions. Intensive soil tillage breaks down soil organic matter, therefore producing more CO₂ and consequently reducing total C content in soil [73]. It is evident that the long-term CT practice as shown in several study sites across northern China especially with the incorporation of additional straw above the normal 30% threshold can significantly reduce emission and improve sequestration of CO₂. However, the non-significant effect of CH₄ emission on CT fields as reported in this review can be attributed to reasons as discussed by Hutsch [74], that soils under CT systems are more stable and are porous in structure, which facilitates CH₄ diffusion into oxidizing zones with high methanotrophic activity. However, as revealed from this review, the larger N₂O emissions from CT plots can be associated with soil characteristics, temperature, soil moisture, and the duration of the CT practice [75]. Studies across the world show diverse and opposing results on N₂O fluxes from CT fields, with either a small [76] or a similar effect [77,78].

Practicing CT was shown to be economically beneficial due to improved income based on lower production costs. CT practice is reported to have lower operational costs and this can primarily be attributed to the lower use of inputs in CT systems, less labor, and lower machinery operating costs during production. However, attention should be paid to customization of the practice to suit regional needs so as to maximize its benefits.

Decades of research on CT as shown in this review has generated convincing evidence that CT practice can benefit crop production both ecologically and economically. CT practice in China has been well developed with the implementation of policies and programs to cover most parts of the country. Its adaptation is widespread across northern China, which is faced with harsh environmental challenges. Research in CT has mainly focused on degraded landscapes where long-term research has been undertaken by various institutions. Outcomes of this research are varied and cover a wide range of ecological interests. CT practice overall has shown to be most beneficial and, despite the few setbacks
and reported cases of insignificant improvements especially at initially stages of implementation, it is worth implementing.

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