Conservation Agriculture

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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.

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

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][3][4][5][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][16][17].

2. CA has been delivering positive results on improving soil water conservation

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 [18]. 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 [19][20][21][22]. In addition, the retention of crop residues on the soil surface decreases rates of soil water evaporation [23], 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.

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 [24][25]. 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 [24][26], while worldwide, approximately 75 billion tonnes of soil is eroded from arable land each year [25].

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][27]. Improvement in soil aggregate stability and water storage under CA also directly or indirectly affects runoff and soil losses [19][28][29]. 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% .

In addition, the increased infiltration of water into the soil profile under CA can also increase rates of profile leaching [30] and potentially increase the transport of nitrate into groundwater. Some studies have found increased rates of nitrate leaching from NT profiles [30][31], although others have also found that NT had no effect on nitrate loss [32] or could reduce nitrate concentration in groundwater [33]. 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 [34]. 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 [35].

Conservation agriculture can also affect the transportation of pesticides to waterbodies. Crop residues can intercept pesticides, especially apolar pesticides or those with low polarity [36]. 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 [37]. Moreover, these crop residues have 10 to 60 times more sorption capacity than soil [38]. 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 [39]. Conservation agriculture can enhance the soil organic matter content, especially in the top surface layers [2][19], which can increase the retention of pesticides and limit their susceptibility to microbial degradation. However, Alletto et al. [40] 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 [41].

4. 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 [42]. Consequently, agriculture has been identified as one of the four important sectors that could contribute to reducing global GHGs emissions [43]. 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 [44].

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, 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][45]. 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 [46][47].

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 [48]. 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) [49]. 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 [49].

5. 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 [50]. 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 [51]. Full implementation of CA components has been reported to increase the diversity of both fungal and bacterial populations [52], with NT in particular favoring the increase in fungal diversity due to the absence of tillage [53]. 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 [54]. Microbial-induced enzymes associated with nutrient cycling are also found in greater amounts under CA, leading to higher nutrient availability under CA [55].

CA has the potential to not only improve microbial diversity but also to influence such soil macro-fauna as earthworms, ants, termites and beetles [56]. These macro-fauna improve soil health by breaking down plant residues, increasing macroporosity, and improving water infiltration, soil aggregation and nutrient cycling [57]. 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) [56].

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