Croplands Research Group/ Conservation Agriculture Network

How Conservation Agriculture can mitigate greenhouse gas emissions and enhance soil carbon storage in croplands

GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

What is the issue?

Conservation agriculture was originally developed to combat wind and soil erosion in the USA (Baveye et al., 2011) and it has since expanded to include a more holistic approach to managing soils and crops in a sustainable manner.

The three facets of conservation agriculture include reduced tillage systems, permanent soil cover and effective use of crop rotations including intercrops and cover crops and reducing the fallow period. The intent of conservation agriculture practices is to optimize crop production while promoting soil health and providing ecosystem services (i.e. improved soil, water, and air quality).

Conservation agriculture systems utilize soils for the production of crops with the aim of reducing excessive mixing of the soil and maintaining crop residues on the soil surface in order to minimize damage to the environment (FAO, 2014).

Conservation agriculture can serve to mitigate greenhouse gas (GHG) emissions from agriculture by enhancing soil C sequestration, improving soil quality, N-use efficiency and water use efficiencies, and reducing fuel consumption. Realizing GHG mitigation benefits, however, requires tailoring conservation agriculture principles within unique constraints (and opportunities) of working farms in varying climatic conditions. Research is needed to develop nuanced management approaches for mitigating GHG emissions from conservation agriculture systems.

What are the factors controlling responses?

1. Conservation agriculture and GHG emissions:

Agricultural production practices contributes to carbon and nitrogen dynamics through the flux of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), the three main GHGs from agriculture (Paustian et al., 2016; Greenhouse Gas Working Group, 2010).

Fluxes of N_2O from agriculture are typically unidirectional through processes of nitrification or denitrification, with emissions most prevalent from cultivated and fertilized soils, livestock manure, and biomass burning. In addition to direct emissions, nitrogen losses from volatilization and leaching contribute to 'indirect' N_2O emissions downwind or downstream. Nitrous oxide is emitted from soils when there is ample nitrate, soluble organic C and wet soil conditions Conservation agriculture can regulate these three factors by:

a) Maximizing the time period where growing crops are actively taking up applied N. Soil nitrate levels are elevated following N fertilizer and manure application and/or incorporation of a leguminous crop (e.g. alfalfa). If the crop has recently been established, nitrogen uptake would be limited until the crops reach a rapid growth phase. Hence maintaining a crop cover or synchronizing the timing of N release or N application with crop N uptake would minimize losses in the event of a heavy rain and/or irrigation. This is one of the reasons why N cycling is tighter in perennial crops than annual crops as they generally lower the risk of high levels of nitrate

b) Minimizing tillage reduces the decomposition rate of crop residues and soil organic matter. Soluble organic C levels generally increase following tillage as the mixing of the soil enhances crop residue decomposition and microbial activity. Therefore when tillage is minimized or eliminated (no-tillage) then slow decomposition process will occur, however it should be recognized that the breakdown of crop residues is a normal part of C cycling. Indeed, the microbial communities in soil depend on this decay.

c) Increasing net primary production with soil and climate-appropriate conservation tillage practices can increase SOC-stocks (Virto et al. 2012).

Conservation agriculture can affect CH_4 fluxes from soil through the alteration of physical properties affecting water movement and retention. Agricultural practices can induce CH_4 emissions from flooded rice paddies, ruminant livestock, livestock manure, wetlands, and burned biomass. Conversely, CH_4 uptake by methanotrophic bacteria in soil can occur under aerobic conditions.

2. Conservation agriculture and soil organic C:

Soil organic C is, in simplistic terms, the net difference between carbon inputs (photosynthesis, organic amendments such as manure) and outputs (decomposition, soil erosion) in agroecosystems. Soil C sequestration could be enhanced by:

a) Extending the effective growing season by growing perennial crops or by including intercrops or cover crops in the crop rotation would enhance the capture of CO_2 through photosynthesis and thereby increase the C inputs into the soil. Increasing the time periods where crops are actively growing would enhance C sequestration as long as there are no limiting factors (e.g. nutrient deficiencies, salinity, excess or insufficient water, soil pH).

b) Reducing or eliminating tillage can reduce the mixing of the crop residues in the soil and thereby result in lower decomposition rates and CO_2 emissions. Soil organic C outputs are a function of residue characteristics (e.g. C:N) and their decomposition rates which is often enhanced when the soil is cultivated.

c) Maximizing the return of C, by minimizing residue removal or burning can bolster soil carbon. Soil organic C can be maximized by growing crops with high biomass production (e.g., corn vs. soybean) or by using deep rooted crops (e.g., alfalfa) and by reducing the fallow period.

d) Adopting improved irrigation techniques (e.g. deficit irrigation) can reduce CO_2 emissions in arid and semiarid environments (Zornoza et al., 2016)

What are expected responses?

Soil organic C / CO_2 emissions: Management practices that increase carbon inputs while reducing carbon losses can serve to enhance soil C sequestration. Enhancement of soil C sequestration can be achieved by maintaining plant residues on the soil surface, minimizing soil disturbance and erosion, improving the irrigation efficiency, adopting complex cropping systems that provide increased root biomass and/or continuous ground cover, reducing fallow periods, breeding crops for traits with larger root systems and applying C-rich substrates to soil (Lal and Follett, 2009).

Fig.1 Cover crop and elimination of fallow can enhance C accretion.

Adoption of no-tillage can increase soil C sequestration (Franzluebbers and Follett, 2005), though increases in soil C may be limited to near-surface depths (Kravchenko et al., 2011; Baker et al., 2007, De Vita et al., 2007). A multi-site study in the humid regions of Canada found that no-till increased surface C levels compared to conventional tillage, however when C in the entire soil profile was taken into consideration, there were no differences in carbon sequestration rates between tillage systems (Angers et al, 1997). Limited or no effects of NT on SOC have been observed in other (humid) temperate countries [e.g. Finland (Singh et al., 2015), Switzerland (Martinez et al., 2016), U.K (Sun et al., 2010), France (Dimassi et al., 2014)], however this depends on climatic conditions (e.g., humid regions vs. semiarid regions) and C saturation of the soil profile

Fig. 2. Soil C dynamics must consider the entire profile.

No-tillage has generally been effective at sequestering carbon in semi-arid areas (exceptions do occur – see Franzluebbers et al., 2010), but there can be issues associated with conservation tillage in humid regions especially on clay and clay loam textured soils. Further, the surface residues of soils under no-tillage tend to result in wetter and cooler soils in the spring which may reduce germination and ultimately crop yields. In these situations alternative conservation tillage practices can be adopted to overcome these issues.

For example zone tillage (also referred to as strip tillage) has been found to alleviate crop emergence and increase yields which in turn increases SOC sequestration (Shi et al., 2011). Zone tillage is typically used for row crops such as corn in which a narrow zone (~20 cm) is cultivated in the fall and subsequently planted in the spring. The surface area between zones (~ 75% of the land surface) is left virtually undisturbed.

Fig 3. Fall zone tillage prior to planting corn.

CH_4 emissions: Alterations of drainage regimes and residue incorporation in rice production systems can reduce CH_4 emissions. Crop management practices that increase soil organic C in semiarid region reduce CH_4 emissions. However, wetting and drying of soils may also enhance N_2O emissions and soil C mineralization, thereby reducing net GHG mitigation potential (Paustian et al., 2016).

N_2O emissions: Management practices that increase N-use efficiency result in less reactive N available for potential conversion to N_2O. Reducing the frequency of high N demanding crops and including non-leguminous cover crops in rotation can reduce reactive N and thereby N_2O emissions (Cavigelli et al., 2012). Moreover, inclusion of cover crops in rotation can contribute to increased C sequestration, representing an important GHG mitigation co-benefit (Robertson and Vitousek, 2009). Zone tillage has been found to increase SOC and the improved physical properties have contributed to the reduced N_2O emissions compared to both conventional and no-tillage in Eastern Canada (Drury et al. 2006, 2012). No-tillage can, in some soils and climates, increase N_2O emissions compared with conventional tillage by increasing soil water content and denitrification rates.

Fig.4.Cover crops can provide multiple GHG benefits but much research is needed to ensure their efficient use in conservation agriculture.

How can research help in refining mitigation estimates?

Research opportunities to develop GHG-friendly conservation agriculture systems abound. Possible priority areas include:

- Quantifying contributions of crop diversity, intercropping, and cover crops on GHG flux and soil C.

- Determining the optimal cover crop type for a particular soil, climatic region and crop rotation.
- Determining effects of episodic tillage on GHG balance.
- Minimizing GHG emissions and loss of C following the cultivation of perennial crops.
- Assessing GHG outcomes from multi-intervention management practices.
- Quantifying tradeoffs associated with adoption of practices that mitigate GHGs.
- Determining effects of in-season N fertilization effect on N_2O emissions.
- Improving the establishment of intercrops.
- Improving crop rotations to optimize SOC sequestration
- Identifying alternative conservation tillage practices when problems arise using no-tillage
- Reducing N fertilization rates by using legumes in the crop rotation or legume cover crops while sustaining crop yields.
- Reducing or eliminating fallow periods by increasing cropping intensity and continuous cropping, especially in dryland cropping systems.

Synthesis / recommendations

Conservation agriculture has many attributes that can use applied nitrogen more efficiently and reduce the risk of high N_2O emissions from soils. Carbon sequestration can be increased by extending the amount of time crops are growing on the land by using perennial crops, intercrops or cover crops. There are however research opportunities to overcome some of the challenges with conservation agriculture.

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