Chapter 5

Agricultural Management Impact on Greenhouse Gas Emissions

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Additional information is available at the end of the chapter

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Abstract

Management practices used on croplands to enhance crop yields and quality can contribute about 10–20% of global greenhouse gases (GHGs: carbon dioxide [CO_2], nitrous oxide [N_2O], and methane [CH_4]). Some of these practices are tillage, cropping systems, N fertilization, organic fertilizer application, cover cropping, fallowing, liming, etc. The impact of these practices on GHGs in radiative forcing in the earth's atmosphere is quantitatively estimated by calculating net global warming potential (GWP) which accounts for all sources and sinks of CO_2 equivalents from farm operations, chemical inputs, soil carbon sequestration, and N_2O and CH_4 emissions. Net GWP for a crop production system is expressed as kg CO_2 eq. ha^{-1} $year.^{-1}$ Net GWP can also be expressed in terms of crop yield (kg CO_2 eq. kg^{-1} grain or biomass yield) which is referred to as net greenhouse gas intensity (GHGI) or yield-scaled GWP and is calculated by dividing net GWP by crop yield. This article discusses the literature review of the effects of various management practices on GWP and GHGI from croplands as well as different methods used to calculate net GWP and GHGI. The paper also discusses novel management techniques to mitigate net CO_2 emissions from croplands to the atmosphere. This information will be used to address the state of global carbon cycle.

Keywords: crop yield, greenhouse gas, global warming, potential, management practice, soil carbon sequestration

1. Overview

Management practices on croplands can contribute about 10–20% of global greenhouse gases (GHGs: carbon dioxide [CO_2], nitrous oxide [N_2O], and methane [CH_4]) [1, 2]. Quantitative estimate of the impact of these GHGs in radiative forcing in the earth's atmosphere is done by calculating net global warming potential (GWP) which accounts for all sources and sinks of CO_2 equivalents from farm operations, chemical inputs, soil carbon (C) sequestration, and N_2O and

CH_4 emissions [3, 4]. Net GWP for a crop production system is expressed as kg CO_2 eq. ha^{-1} $year.^{-1}$ Net GWP can also be expressed in terms of crop yield (kg CO_2 eq. kg^{-1} grain or biomass yield) which is referred to as net greenhouse gas intensity (GHGI) or yield-scaled GWP and is calculated by dividing net GWP by crop yield [3]. These values can be affected both by net GHG emissions and crop yields. Sources of GHGs in agroecosystems include N_2O and CH_4 emissions (or CH_4 uptake) as well as CO_2 emissions associated with farm machinery used for tillage, planting, harvesting, and manufacture, transportation, and applications of chemical inputs, such as fertilizers, herbicides, and pesticides, while soil carbon sequestration rate can be either a sink or source of CO_2 [4–6]. In the calculations of net GWP and GHGI, emissions of N_2O and CH_4 are converted into their CO_2 equivalents of global warming potentials which are 265 and 28, respectively, for a time horizon of 100 year [2]. The balance between soil carbon sequestration rate, N_2O and CH_4 emissions (or CH_4 uptake), and crop yield typically controls net GWP and GHGI [3, 4, 7].

Some of the improved management practices used for reducing net GWP and GHGI from croplands are no-till, increased cropping intensity, diversified crop rotation, cover cropping, and reduced N fertilization rates [3, 4, 7–10]. Soil organic carbon can usually be increased by adopting no-tillage practice which decreases microbial activity and CO_2 emissions as a result of reduced soil disturbance and residue incorporation compared with conventional tillage practice [3, 11]. Tillage, however, can interact with crop residue carbon input on soil carbon sequestration which varies by region [12]. When carbon input is <15% due to reduced crop yields, soil organic carbon is often lower with no-tillage than conventional tillage in regions with wetter and cooler climate, such as in eastern USA and Canada [12]. In such regions, tillage often redistributes crop residues in the soil profile, resulting in lower soil organic carbon in the surface soil and greater in the subsurface soil, with overall lower soil profile carbon is greater in conventional tillage than no-tillage [13, 14]. The reverse is true when carbon input is >15% [12]. With double rather than single crop in a year, Luo et al. [14] found that no-tillage increased soil organic carbon in the soil profile compared with conventional tillage. In regions with subtropical humid and semiarid climates, such as in southern USA and northern Great Plains, no-tillage can increase soil organic carbon compared with conventional tillage by increasing carbon input as well as reducing soil organic matter mineralization [12].

Soil organic carbon can also be increased by increasing the quality and quantity of crop residue returned to the soil due to diversified cropping systems, such as intensive cropping, crop rotation, and cover cropping, compared with non-diversified systems, such as crop-fallow, monocropping, and no cover crop [3, 15]. Crop rotation can increase soil organic carbon by increasing carbon input through increased crop yield compared with monocropping [3, 15, 16]. Similarly, cover cropping can increasing soil organic carbon by increasing the amount of crop residue returned to the soil [17]. In contrast, fallowing can reduce soil organic carbon by reducing carbon input and by increasing soil organic matter mineralization as a result of increased soil temperature and water content [16, 18]. The effect of nitrogen fertilization on soil organic carbon is variable [18–20].

Nitrogen is usually required in large amounts to sustain crop yield and quality compared with other nutrients, such as phosphorus and potassium. Nitrogen fertilization typically stimulates N_2O emissions when the amount of applied nitrogen exceeds crop nitrogen demand [3, 8–10, 21]. Nitrogen fertilization, however, can have a variable effect on CO_2 and CH_4 emissions [15, 22]. Because N_2O emissions has a large effect on net GWP and GHGI, practices that can reduce N fertilization rates without influencing crop yields can substantially reduce net GHG emissions [3, 4]. Other factors that can influence N_2O emissions are type, placement, and method of application of nitrogen fertilizers. Applying nitrogen fertilizer in the spring compared with autumn and using split application compared with one single application at planting can reduce N_2O emissions in some cases [23–25]. Applying N fertilizer at various depths can have variable effects on N_2O emissions [26–29]. Anhydrous ammonia can increase N_2O emissions compared with urea [27, 30, 31]. Similarly, chemical additives to reduce nitrification from nitrogen fertilizers, such as polymer-coated urea and nitrification inhibitors, can substantially reduce N_2O emissions compared with ordinary urea and non-nitrification inhibitors fertilizers [32–34]. Some nitrogen fertilizers, such as urea, emit both CO_2 and N_2O. Nitrogen fertilizers also indirectly emit N_2O through ammonia volatilization and nitrate leaching [31].

Some management practices used for reducing GHG emissions can have adverse effects. Examples of such practices are no-tillage systems where denitrification resulting from higher soil water content can increase N_2O emissions compared with conventional tillage systems in humid regions, thereby reducing the GHG mitigation potential [35]. In contrast, N_2O emissions can be similar [36] or lower [3, 37] with no-tillage compared with conventional tillage in semiarid and arid regions. Sainju et al. [37] reported that crop rotation had no effect on N_2O emissions, but CH_4 uptake was greater with barley-pea rotation than continuous barley in the semiarid region. Cover crops also have variable effect on N_2O emissions [38]. Legume cover crops can increase N_2O emissions compared with nonlegume cover crops during their growth, but emissions can be similar among cover crops when measured over the entire year [38]. Similarly, root respiration and mineralization of crop residue and soil organic carbon can have negative impacts on GHG mitigation, although greater root biomass and distribution can increase carbon sequestration [15, 39]. Therefore, while calculating net GWP and GHGI, all of these factors should be accounted for, regardless of management practices used [3, 4, 40].

Several methods have been used to calculate net GWP and GHGI. Some have used the sum of CO_2 equivalents of N_2O and CH_4 emissions [21, 41, 42], while others [43, 44] have included CO_2 equivalents of all three GHGs. Still others have used CO_2 equivalents of N_2O and CH_4 emissions and soil carbon sequestration rate [45–47]. A full accounting of all sources and sinks of CO_2 emissions to calculate net GWP and GHGI includes CO_2 equivalents from farm operations, N fertilization, and other inputs in addition to above parameters [3, 7, 9, 10, 40, 48–51]. Several researchers have used DAYCENT and GREET models to estimate GWP and GHGI [52, 53]. Some have excluded N_2O and CH_4 emissions, but used CO_2 equivalents of all other sources and sinks [6]. An alternative method of calculating net GWP and GHGI includes substituting soil carbon sequestration rate by soil respiration and the amount of previous year's crop residue returned to the soil [3, 9, 10, 50, 51, 54]. Each method has its own advantages and drawbacks.

2. Impact of management practices

2.1. Tillage

Various studies have shown that both net GWP and GHGI were lower with no-tillage than conventional tillage, regardless of soil and climatic conditions, cropping systems, and methods of calculations [3, 7, 44, 47, 49, 55]; Sainju [56] observed that reductions in net GWP and GHGI due to no-tillage vs. conventional tillage vary among regions with various soil and climatic conditions, but largest difference occurred in sandy soil under moderate annual precipitation (900 mm). Net GWP values, however, increased in regions with higher air temperature. A meta-analysis of nine experiments by the same author on the effect of tillage showed that no-tillage reduced net GWP by 55% and net GHGI by 58% compared with conventional tillage when all sources and sinks of CO_2 were accounted for. With the partial accounting of sources and sinks, the reductions in net GWP and GHGI due to no-tillage vs. conventional tillage were 81 and 73%, respectively, indicating that partial accounting can inflate net GWP and GHGI values [56]. Differences in crop yields among cropping systems and regions resulted in different proportion of reductions in net GWP and GHGI due to no-tillage vs. conventional tillage [56]. Increased soil carbon sequestration rate due to reduced soil disturbance and carbon mineralization reduces net GWP and GHGI in no-tillage [4, 40, 57]. In contrast, increased crop residue incorporation and aeration increases microbial activity which reduces carbon sequestration, thereby reducing net GWP and GHGI in conventional tillage [3, 7, 9]. Reduction in tillage intensity can also reduce net GWP and GHGI [58].

The duration of study can also have a profound influence on net GWP and GHGI with no-tillage vs. conventional tillage. Under corn-soybean rotation in clay loam soil in Colorado, Mosier et al. [3, 7] found that net GWP with no-tillage vs. conventional tillage was lower after 1 year than after 3 year due to differences in soil carbon sequestration rates. In contrast, Six et al. [57] reported that reduction in net GWP with no-tillage vs. conventional tillage was realized only after 10 year in the humid region and 20 year in the dry region due to increased soil aggregation, reduced aeration, and increased soil carbon sequestration. In a meta-analysis of nine experiments, Sainju [56] found that changes in net GWP and GHGI due to no-tillage vs. conventional tillage increased with the duration of the experiment, regardless of the method used for calculation. When soil and climatic conditions, such as soil texture, annual precipitation, and average air temperature of the experimental sites were included in the multiple linear regressions, the relationships were further improved. While air temperature had a negative effect on net GWP and GHGI, the effect of soil texture varied. This could be explained by several factors: (1) no-till can some time increases N_2O emissions due to increased soil water content and denitrification compared with conventional till, especially in the humid region, thereby reducing net GWP and GHGI [4, 40, 57], (2) the potential for soil carbon sequestration using no-tillage decreases and reaches a steady state as the duration of the experiment increases [57, 59], and (3) there is a high uncertainty in spatial and temporal variability in GHG emissions within and among regions due to variations in soil and climatic conditions and management practices [7, 9, 10, 40]. Nevertheless, more long-term experiments are needed to relate the effect of tillage with the duration of experiment on net GWP and GHGI.

2.2. Cropping system

Crop type and cropping systems can affect net GWP and GHGI. Various researchers [3, 7, 48, 49] reported that both net GWP and GHGI were lower with continuous corn than corn-soybean rotation, but net GHGI was lower with soybean than corn when grown alone [53].

Increased soil carbon sequestration due to greater amount of crop residue returned to the soil reduced net GWP and GHGI under continuous corn compared with corn-soybean rotation, although nitrogen fertilization rate to produce sustainable yield was higher in continuous corn [3, 7, 48, 49]. In contrast, greater N_2O emissions following soybean increased net GWP and GHGI in corn-soybean rotation [3, 7, 48, 49]. Under small grain crops, however, several researchers [9, 10, 60, 61] have found that including legumes, such as pea and lentil, in rotation with nonlegumes, such as wheat and barley, reduced net GWP and GHGI compared with continuous nonlegumes. They observed this because (1) no nitrogen fertilizer was applied to legumes compared with nonlegumes which required large amount of nitrogen fertilizers to sustain yields, as nitrogen fertilizer stimulates N_2O emissions and (2) legumes supplied greater amount of nitrogen to succeeding crops due to higher nitrogen concentration when above- and belowground residues were returned to the soil and reduced nitrogen fertilization rate compared with nonlegumes. Sainju et al. [9, 10] also found that legume-nonlegume rotation increased soil carbon sequestration because of increased turnover rate of plant carbon to soil carbon compared to continuous nonlegume.

In a meta-analysis of 11 experiments on the effect of crop rotation containing small and large grain crops on net GWP and GHGI, Sainju [56] reported that crop rotation increased net GWP by 46% and net GHGI by 41% compared with monocropping. This was especially true for large grain crops, such as corn and soybean where net GWP and GHGI were 215 and 325%, respectively, greater under corn-soybean than continuous corn. In contrast, for small grain crops, such as barley and pea, net GWP was 22% lower under barley-pea than continuous barley. Both net GWP and GHGI were 168 and 215%, respectively, lower with perennial than annual crops. Greater number of experiments and magnitude of changes, however, resulted in higher net GWP and GHGI in monocropping than crop rotation under large than small grain crops when values were averaged across experiments during data analysis [56].

As cropping intensity increased, net GWP and GHGI reduced [56]. Greater amount of crop residue returned to the soil and increased carbon sequestration reduced net GWP and GHGI when cropping intensity was increased [9, 50]. Increased carbon sequestration with increased cropping intensity in the semiarid regions with limited precipitation is well known [18, 62]. Several researchers [7, 9, 50] have found that fallowing or crop-fallow rotation increased GHG emissions and therefore net GWP and GHGI compared with continuous cropping due to increased soil temperature and water content that enhanced microbial activity and absence of crops to utilize mineralized nitrogen during fallow. Using partial accounting of CO_2 sources and sinks, Liebig et al. [63], however, did not found significant difference in net GWP between alternate-year fallow and continuous cropping in North Dakota. Perennial crops can reduce net GWP and GHGI compared with annual crops [7, 44, 50] due to higher root biomass production [64, 65] and increased soil carbon sequestration [55]. Because land under perennial crops is not tilled and perennial crops are not applied with fertilizers, herbicides, and pesticides, GHG emissions are usually lower with perennial than annual crops [4].

Sainju [56] found that changes in net GWP and GHGI due to crop rotation vs. monocrop and corn-soybean vs. continuous corn decreased with increased duration of experiment, but increased due to annual vs. perennial cropping systems. The relationships were further improved when soil and climatic conditions were accounted for in the multiple linear regressions of net GWP and GHGI with the duration of the experiment. He observed that soil texture had a positive effect on net GWP and GHGI for cropping intensity, but negative effect on net GWP for crop rotation vs. monocrop and perennial vs. annual crop. The trend was opposite for mean air temperature while annual precipitation had small effect. Because the magnitude of carbon sequestration rate is lower and time for carbon saturation is longer for the effect of cropping systems than for tillage systems [57, 59], reduced net GWP and GHGI for increased cropping intensity and crop rotation vs. monocrop with increased duration of experiment was due to increased carbon sequestration. Sainju [56] reported that crop rotation had a greater potential to reduce net GWP and GHGI compared with monocropping in the long run, but the potential can vary for perennial vs. annual cropping systems.

2.3. Nitrogen fertilization

Nitrogen fertilizer application rate, source, and timing and method of application can influence net GWP and GHGI. Increased nitrogen fertilization rate enhanced net GWP and GHGI due to increased N_2O emissions and CO_2 emissions associated with manufacture, transport, and application of nitrogen fertilizers, regardless of cropping systems and methods of calculations [3, 7, 21, 33, 42, 55]. In a meta-analysis of 12 experiments, Sainju [56], after accounting for all sources and sinks of CO_2 emissions, reported that net GWP decreased from 0 to ≤45 kg N ha^{-1} and net GHGI from 0 to ≤145 kg N ha^{-1} and then increased with increased nitrogen fertilization rate. Using partial accounting, net GWP decreased from 0 to 88 kg N ha^{-1} and net GHGI from 0 to ≤213 kg N ha^{-1} and then increased with increased nitrogen rate. These nitrogen rates probably corresponded to crop nitrogen demand when crops used most of the soil available nitrogen, leaving little residual nitrogen in the soil that reduced N_2O emissions and therefore net GWP and GHGI. When nitrogen rates exceeded crop nitrogen demand, net GWP and GHGI increased linearly [56], suggesting that excessive application of nitrogen fertilizers can induce net GHG emissions. Similar results have been reported by several researchers [8, 66, 67]. Therefore, nitrogen fertilizers should be applied at optimum rates to reduce net GWP and GHGI while sustaining crop yields. The optimum nitrogen rates, however, depended on net GWP measured either per unit area or per unit crop yield.

Sainju [56] observed that the relationships between net GWP, net GHGI, and nitrogen rate were further improved when the duration of the experiment and soil and climatic conditions were taken into account in the multiple linear regressions. Duration of experiment and annual precipitation had positive effects, but air temperature and soil texture had negative effects on net GWP when all sources and sinks of CO_2 emissions were accounted for. With partial accounting, only air temperature had positive effect on net GWP, but other factors had negative effects. For net GHGI, the factors having negative effects were air temperature using the complete accounting of CO_2 emissions and annual precipitation and soil texture using the partial accounting.

Alder et al. [58] reported that anhydrous ammonia reduced net GHGI compared with urea, urea ammonium nitrate, and polymer-coated urea under corn, wheat and switchgrass due to lower energy requirement for fertilizer production. They found that polymer-coated urea reduced net GHGI by slowly releasing nitrogen to the soil and reducing indirect N_2O emissions compared with urea ammonium nitrate. Little is known about the placement and methods of nitrogen fertilizer applications on net GWP and GHGI, although various results have been reported on N_2O emissions using these practices [23–29]. More research is needed about the effects of source, placement, and timing of nitrogen fertilizer application on net GWP and GHGI.

2.4. Other fertilizers

Application of combination of nitrogen, phosphorus, and potassium increased net GWP compared with no application and net GWP further increased as these nutrients were applied with a combination of inorganic fertilizer, green manure, and farmyard manure, although total amount of nutrients applied from various sources were similar under rice in China and India [43, 46]. They found that increased substrate availability from fertilizers and organic amendments increased N_2O and CH_4 emissions and therefore net GWP. Shang et al. [46], however, found lower net GHGI with these nutrient applications than without due to increased crop yield. Adviento-Borbe et al. [48] also observed increased net GWP and GHGI with combined application of nitrogen, phosphorus, and potassium compared with no application under corn in Nebraska.

2.5. Miscellaneous practices

Burning of crop residue increased net GWP and GHGI compared with residue retained in the soil due to reduced carbon input and soil carbon sequestration in upland crop production [40, 47]. Sainju et al. [55] found that irrigation increased net GWP and GHGI compared with no irrigation due to lower soil carbon sequestration as a result of increased carbon mineralization and loss of water soluble carbon from increased soil water availability. Under lowland rice, Li et al. [68] found that midseason and shallow drainage reduced net GWP and GHGI by 21–205% compared with continuous flooding. Under upland rice where flooding is minimized, they found that drainage reduced net GWP and GHGI from 17 to 322% compared with no drainage. They also found that application of nitrogen fertilizer and straw in flooded rice reduced net GWP and GHGI from 16 to 91% compared with no application, but net GWP increased by 18% by using slow N release fertilizer compared with normal nitrogen fertilizer.

2.6. Combined management practices

Using combined effects of tillage, crop rotation, and nitrogen fertilization rates, various researchers [3, 7, 49] found that net GWP and GHGI were lower with no-tillage continuous corn with reduced nitrogen rate than conventional tillage corn-soybean rotation with recommended nitrogen rate. They attributed this to increased soil carbon sequestration and reduced N_2O emissions, as corn used most of nitrogen during growth, leaving little soil residual nitrogen. They found that soybean increased N_2O emissions compared with corn, thereby increasing net GWP and GHGI with corn-soybean compared with corn. Similarly, Adviento-Borbe et al. [48] reported that net GWP and GHGI were lower with lower rates of nitrogen, phosphorus, and potassium applied to continuous corn than lower or higher rates applied to corn-soybean. Johnson et al. [51] reported that minimum till diversified crop rotation with appropriate rates of nitrogen, phosphorus, and potassium reduced net GWP and GHGI compared with conventional tillage with less diversified crop rotation and high rates of nutrients. In small grain cropping systems, Sainju et al. [9, 55] observed that net GWP and GHGI were lower with no-tillage malt-barley pea with reduced nitrogen fertilization rate than conventional tillage continuous malt barley or malt barley-fallow with recommended nitrogen rate. They attributed this to increased soil carbon sequestration, reduced N_2O emissions, and sustained crop yields.

Using a meta-analysis of nine experiments, Sainju [56] reported that the improved combined management practice that included no-tillage, diversified cropping system (crop rotation, increased cropping intensity, cover crop, and perennial cropping system) and reduced nitrogen rate reduced net GWP and GHGI by 70–88% compared with the traditional combined practice that included conventional till, less diversified cropping system (monocropping, crop-fallow, no cover crop, and annual cropping system) and recommended nitrogen rate. He also found that combined management practice further reduced net GWP and GHGI compared with individual management practices. He found that changes in net GWP and GHGI due to improved vs. traditional combined management practice increased with the duration of the experiment. The relationships were further improved by including soil and climatic factors in the multiple linear regressions. Some of the possible reasons for increased net GWP and GHGI for improved vs. traditional combined management with increased duration of the experiment are: (1) high spatial and temporal variations of GHG emissions due to differences in soil and climatic conditions and management practices, (2) reduced potential for soil C sequestration with increasing duration of the experiment, (3) use of full or partial accounting of sources and sinks of GHG emissions, and (4) uncertainty in the methods of measuring GHG emissions, such as variations in type and size of static chambers, placement of chamber in the plot (row vs. inter-row or including vs. excluding plants in the chamber), time of GHG measurement during the day, and calculation of GHG fluxes (linear or nonlinear emissions with time).

When crop residue was burned compared with residue retained in the soil under wheat applied with or without nitrogen fertilizer with various tillage practices, Wang et al. [47] found that net GWP and GHGI were lower in conventional tillage wheat without nitrogen fertilizer where residue was burned than conventional tillage or no-tillage wheat with nitrogen fertilizer where reside was either burned or retained in the soil. They found that the larger impact of N_2O emissions than soil carbon sequestration on global warming potential increased net GWP and GHGI with N fertilization than without.

Using an alternative method where soil respiration and previous year's crop residue returned to the soil are used in place of soil carbon sequestration rate to calculate net GWP and GHGI, Mosier et al. [3] observed that no-tillage continuous corn with reduced nitrogen fertilization rate reduced net GWP and GHGI compared with conventional tillage corn-soybean with recommended N rate, a case similar to that calculated by the regular method above. They attributed this to increased amount of crop residue returned to the soil and grain yield. Similarly, using this method, Sainju et al. [55] found lower net GHGI in nonirrigated no-tillage barley-pea with nitrogen fertilizer than conventional tillage continuous barley with nitrogen fertilizer, a case similar to that obtained for the regular method. They, however, observed different trends for net GWP. Similarly, using the alternative method, Johnson et al. [51] found lower net GWP and GHGI in conventional tillage corn-soybean with nitrogen and phosphorus fertilizers than no-tillage continuous corn with the same fertilizers, a case different to that obtained by using the regular method. Popp et al. [54] using the alternative method, found that net GWP was lower with nonirrigated corn than irrigated and nonirrigated cotton, soybean, sorghum, irrigated rice, and nonirrigated wheat. The magnitude of net GWP and GHGI obtained by two methods can be different, but both methods showed that no-till with continuous cropping produced lower net GWP and GHGI compared with conventional tillage with crop fallow [3, 9].

2.7. Implications of management practices

These studies showed that no-tillage systems, in general, can reduce net GWP and GHGI compared with conventional tillage systems. Perennial crops can reduce net GWP and GHGI compared with annual crops and wheat can reduce net GWP and GHGI compared with rice and corn. Inclusion of legumes in rotation with nonlegumes has variable effects on net GWP and GHGI compared with continuous nonlegumes. Inclusion of fallow in the crop rotation, however, can increase net GWP and GHGI compared with continuous cropping. Crops adequately fertilized with nitrogen, phosphorus, and potassium fertilizers can reduce net GWP and GHGI compared with no fertilized treatments, but excessive nitrogen fertilization beyond crop nitrogen demand can increase net GWP and GHGI. Burning of crop residue slightly can increase net GWP and GHGI compared with residue retained in the soil, but irrigation has minor effect compared with non-irrigation. Improving drainage or using shallow flooding in rice can lower net GWP and GHGI compared with continuous flooding. Values of net GWP and GHGI measured by the regular and alternative methods are variable, depending on soil and climatic conditions and management practices. Both methods, however, showed that the improved management practice can reduce net GHG emissions compared with the traditional management practice. Changes in net GWP and GHGI due to improved vs. traditional management varied with duration of the experiment and inclusion of soil and climatic factors improved their relationships. Also, combined management practice can lower net GWP and GHGI compared with the individual practice. Net GWP and GHGI values can be more reliable by accounting full than partial sources and sinks of CO_2 emissions. Because of the limited data, further studies are needed to evaluate the effects of management practices on net GWP and GHGI.

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References

[1] Cole CV, Duxbury J, Freney J, Heinemeyer O, Minami K, Mosier A, Paustian K, Rosenberg N, Sampson N, Sauerbeck D, Zhao Q. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems. 1997;**49**:221-228

[2] Intergovernment Panel on Climate Change (IPCC). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2014

[3] Mosier AR, Halvorson AD, Reule CA, Liu XJ. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. Journal of Environmental Quality. 2006;**35**:1584-1598

[4] Robertson GP, Paul E, Harwood R. Greenhouse gases in intensive agriculture: Contribution of individual gases to the radiative forcing of the atmosphere. Science. 2000;**289**: 1922-1925

[5] Schlesinger WH. Carbon sequestration in soils. Science. 1999;**284**:2095-2097

[6] West TO, Marland G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. Agriculture, Ecosystems and Environment. 2002;**91**:217-232

[7] Mosier AR, Halvorson AD, Peterson GA, Robertson GP, Sherrod L. Measurement of net global warming potential in three agroecosystems. Nutrient Cycling in Agroecosystems. 2005;**72**:67-76

[8] Li B, Fan CH, Zhang H, Chen ZZ, Sun LY, Xiong ZQ. Combined effects of nitrogen fertilization and biochar on the net global warming potential, greenhouse gas intensity, and net ecosystem budget in intensive vegetable agriculture in Southeastern China. Agriculture, Ecosystems and Environment. 2015;**100**:10-19

[9] Sainju UM, Stevens WB, Caesar-TonThat T, Liebig MA, Wang J. Net global warming potential and greenhouse gas intensity influenced by irrigation, tillage, crop rotation, and nitrogen fertilization. Journal of Environmental Quality. 2014;**43**:777-788

[10] Sainju UM, Wang J, Barsotti JL. Net global warming potential and greenhouse gas intensity affected by cropping sequence and nitrogen fertilization. Soil Science Society of America Journal. 2014;**78**:248-261

[11] Lemke RL, Izaurralde RC, Nyborg M, Solberg ED. Tillage and nitrogen source influence soil-emitted nitrous oxide in the Alberta parkland region. Canadian Journal of Soil Science. 1999;**79**:15-24

[12] Ogle SM, Swan A, Paustian K. No-till management impacts on crop productivity, carbon input, and soil carbon sequestration. Agriculture, Ecosystems and Environment. 2012;**149**:37-49

[13] Angers DA, Ericksen-Hamel NS. Full-inversion tillage and organic carbon distribution in a soil profile: A meta-analysis. Soil Science Society of America Journal. 2008;**72**: 1370-1374

[14] Luo Z, Wang E, Sun OJ. Can no-till stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agriculture, Ecosystems and Environment. 2010;**139**:224-231

[15] Sainju UM, Jabro JD, Caesar-TonThat T. Tillage, cropping sequence, and nitrogen fertilization effects on dryland soil carbon dioxide emission and carbon content. Journal of Environmental Quality. 2010;**37**:98-106

[16] Sainju UM, Allen BL, Caesar-TonThat T, Lenssen AW. Dryland soil carbon and nitrogen after thirty years of tillage and cropping sequence. Agronomy Journal. 2015;**107**: 1822-1830

[17] Kuo S, Sainju UM, Jellum EJ. Winter cover crop effects on soil organic carbon and carbohydrate. Soil Science Society of America Journal. 1997;**61**:145-152

[18] Halvorson AD, Wienhold BJ, Black AL. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Science Society of America Journal. 2002;**66**:906-912

[19] Gregorich EG, Ellert BH, Drury CF, Liang BC. Fertilization effects on soil organic matter turnover and corn residue carbon storage. Soil Science Society of America Journal. 1996;**60**:472-476

[20] Russell AE, Laird DA, Parkin TB, Mallarino AP. Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern mollisols. Soil Science Society of America Journal. 2005;**69**:413-422

[21] Adviento-Borbe MA, Pittelkow CM, Anders M, van Kissel C, Hill JE, Clung AM, Six J, Linquist BA. Optimal fertilizer nitrogen rates and yield-scaled global warming potential in drill-seeded rice. Journal of Environmental Quality. 2013;**42**:1623-1634

[22] Bronson KF, Mosier AR. Suppression of methane oxidation in aerobic soil by nitrogen fertilizers, nitrification inhibitors, and urease inhibitors. Biology and Fertility of Soils. 1994;**17**:263-268

[23] Burton DL, Zebarth BJ, Gillarn KM, MacLeod JA. Effect of split application of fertilizer nitrogen on N_2O emissions from potatoes. Canadian Journal of Soil Science. 2008; **88**:229-239

[24] Phillips RL, Tanaka DL, Archer DW, Hanson JD. Fertilizer application timing influences greenhouse gas fluxes over a growing season. Journal of Environmental Quality. 2009;**38**: 1569-1579

[25] Zebarth BJ, Rochette P, Burton DL, Price M. Effect of fertilizer nitrogen management on N_2O emissions in commercial corn fields. Canadian Journal of Soil Science. 2008;**88**: 189-195

[26] Drury CF, Reynolds WD, Tan CS, Welacky TW, Calder W, McLaughlin NB. Emissions of nitrous oxide and carbon dioxide: Influence of tillage type and nitrogen placement depth. Soil Science Society of America Journal. 2006;**70**:570-581

[27] Fujinuma R, Venterea RT, Rosen C. Broadcast urea reduces N_2O but increases NO emissions compared with conventional and shallow applied anhydrous ammonia in a coarse-textured soil. Journal of Environmental Quality. 2011;**40**:1806-1815

[28] Hosen Y, Paisancharoen K, Tsuruta H. Effects of deep application of urea on NO and N_2O emissions from an Andisol. Nutrient Cycling in Agroecosystems. 2002;**63**:197-206

[29] Liu X, Mosier A, Halvorson A, Zhang F. The impact of nitrogen placement and tillage on NO, N_2O, CH_4; and CO_2; fluxes from a clay loam soil. Plant and Soil. 2006;**280**: 177-188

[30] Thornton FC, Bock BR, Tyler DD. Soil emissions of nitric oxide and nitrous oxide from injected anhydrous ammonium and urea. Journal of Environmental Quality. 1996;**25**: 1378-1384

[31] Venterea RT, Burger M, Spokas KA. Nitrogen oxide and methane emissions under varying tillage and fertilizer management. Journal of Environmental Quality. 2005;**34**:1467-1477

[32] Akiyama H, Yan X, Yagi K. Evaluation of effectiveness of enhanced-efficiency fertilizers as mitigation options for N_2O and NO emissions from agricultural soils: Meta-analysis. Global Change Biology. 2010;**16**:1837-1846

[33] Halvorson AD, Del Grosso SJ, Alluvione F. Nitrogen source effects on nitrous oxide emissions from irrigated no-till corn. Journal of Environmental Quality. 2010;**39**:1554-1562

[34] Hyatt CR, Venterea RT, Rosen CJ, McNearney M, et al. Polymer-coated urea maintains potato yields and reduces nitrous oxide emissions in a Minnesota loamy sand. Soil Science Society of America Journal. 2010;**74**:419-428

[35] Robertson GP. Keeping track of carbon. Science. 1999;**285**:1849

[36] Decock C. Mitigating nitrous oxide emissions from corn cropping systems in the Midwestern U.S.: Potential and data gaps. Environmental Science & Technology. 2014;**48**: 4247-4256

[37] Sainju UM, Stevens WB, Caesar-TonThat T, Liebig MA. Soil greenhouse gas emissions affected by irrigation, tillage, crop rotation, and nitrogen fertilization. Journal of Environmental Quality. 2012;**41**:1774-1786

[38] Basche AD, Miguez FE, Kaspar TC, Castellano MJ. Do cover crops increase or decrease nitrous oxide emissions? A meta-analysis. Journal of Soil and Water Conservation. 2014; **69**:471-482

[39] Curtin D, Wang H, Selles F, McConkey BG, Campbell CA. Tillage effects on carbon dioxide fluxes in continuous wheat and fallow-wheat rotations. Soil Science Society of America Journal. 2000;**64**:2080-2086

[40] Robertson GP, Grace PR. Greenhouse gas fluxes in tropical and temperate agriculture: The need for a full-cost accounting of global warming potentials. Environment, Development and Sustainability. 2004;**6**:51-63

[41] Linquist B, van Groenigen KJ, Adviento-Borbe MA, Pittelkow C, van Kissel C. An agronomic assessment of greenhouse gas emissions from major cereal crops. Global Change Biology. 2012;**18**:194-209

[42] Pittelkow CM, Adviento-Borbe MA, Hill JE, Six J, van Kissel C, Linquist BA. Yield-scaled global warming potential of annual nitrous oxide and methane emissions from continuously flooded rice in response to nitrogen input. Agriculture, Ecosystems and Environment. 2013;**177**:10-20

[43] Bhatia A, Pathak H, Jain N, Singh PK, Singh AK. Global warming potential of manure-amended soils under rice-wheat system in the indo-Gangetic Plains. Atmospheric Environment. 2005;**39**:6976-6984

[44] Ruan L, Robertson GP. Initial nitrous oxide, carbon dioxide, and methane costs of converting conservation reserve program grassland to row crops under no-till vs. conventional tillage. Global Change Biology. 2013;**19**:2478-2489

[45] Piva JT, Diekow J, Bayer C, Zanatta JA, de Moraes A, Pauletti V, Tomazi M, Pergher M. No-till reduces global warming potential in a subtropical Ferrasol. Plant and Soil. 2012; **361**:359-373

[46] Shang Q, Yang X, Gao C, Wu P, Liu J, Xu Y, Shen Q, Zou J, Gao S. Net annual global warming potential and greenhouse gas intensity in Chinese double rice cropping systems: A 3 year field measurement in the long-term fertilizer experiments. Global Change Biology. 2011;**17**:2196-2210

[47] Wang W, Dalal RC, Reeves SH, Butterbach-Bahl K, Kiese R. Greenhouse gas fluxes from an Australian subtropical cropland under long-term contrasting management regimes. Global Change Biology. 2011;**17**:3089-3101

[48] Adviento-Borbe MA, Haddix ML, Binder DL, Walters DT, Dobermann A. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. Global Change Biology. 2007;**13**:1972-1988

[49] Archer DW, Halvorson AD. Greenhouse gas mitigation economics for irrigated cropping systems in northeastern Colorado. Soil Science Society of America Journal. 2010;**74**: 446-452

[50] Barsotti JL, Sainju UM, Lenssen AW, Montagne C, Hatfield PG. Net greenhouse gas emissions affected by sheep grazing in dryland cropping systems. Soil Science Society of America Journal. 2013;**77**:1012-1025

[51] Johnson JMF, Archer DW, Weyers SL, Barbour NW. Do mitigation strategies reduce global warming potential in the northern U.S. Cornbelt? Journal of Environmental Quality. 2011;**40**:1551-1559

[52] Kim S, Dale BE. Cumulative energy and global warming impact from the production of biomass for biofuel products. Journal of Industrial Ecology. 2004;**7**:147-162

[53] Kim S, Dale BF, Jenkins R. Life-cycle assessment of corn grain and corn stover in the United States. International Journal of Life Cycle Assessment. 2009;**14**:160-174

[54] Popp M, Nalley L, Fortin C, Smith A, Brye K. Estimating net carbon emissions and agricultural response to potential carbon offset policies. Agronomy Journal. 2011;**103**:1132-1143

[55] Sainju UM, Stevens WB, Caesar-TonThat T. Soil carbon and crop yields affected by irrigation, tillage, crop rotation, and nitrogen fertilization. Soil Science Society of America Journal. 2014;**78**:936-948

[56] Sainju UM. A global meta-analysis on the impact of management practices on net global warming potential and greenhouse gas intensity from cropland soils. PLoS One. 2016;**11**:1, e0148527-26. DOI: 10.1371/journal.pone.0148527

[57] Six J, Ogle SM, Breidt FJ, Conant RT, Mosier AR, Paustian K. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. Global Change Biology. 2004;**10**:155-160

[58] Adler PK, Del Grosso SJ, Inman D, Jenkins RE, Spatari S, Jhang Y. Mitigation opportunities for life-cycle greenhouse gas emissions furing feedstock productions across heterogeneous landscapes. In: Liebig A, Franzluebbers AJ, Follett RF, editors. Managing Agricultural Greenhouse Gases. Academic Press; 2012. pp. 203-219

[59] West TO, Post WM. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Science Society of America Journal. 2002;**66**:1930-1946

[60] Jensen ES, Peoples MB, Boddey RM, Gresshoff PM, Hauggard-Nelson H, Alves BJR, Morrison MJ. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. Agronomy for Sustainable Development. 2012;**32**:329-364

[61] Lemke RL, Zhong Z, Campbell CA, Zentner R. Can pulse crops play a role in mitigating greenhouse gases from north American agriculture? Agronomy Journal. 2007;**99**: 1719-1725

[62] Peterson GA, Halvorson AD, Havlin JL, Jones OR, Lyon DG, Tanaka DL. Reduced tillage and increasing cropping intensity in the Great Plains conserve soil carbon. Soil and Tillage Research. 1998;**47**:207-218

[63] Liebig MA, Tanaka DL, Gross JR. Fallow effects on soil carbon and greenhouse gas flux in central North Dakota. Soil Science Society of America Journal. 2010;**74**:358-365

[64] Ma Z, Wood C, Bransby DI. Impacts of soil management on root characteristics of switchgrass. Biomass and Bioenergy. 2000;**18**:105-112

[65] Qin R, Stamp P, Richner W. Impact of tillage on root systems of winter wheat. Soil Science Society of America Journal. 2004;**96**:1523-1530

[66] Huang T, Gao B, Christie P, Ju X. Net global warming potential and greenhouse gas intensity in a double-cropping cereal rotation as affected by nitrogen and straw management. Biogeosciences. 2013;**10**:7897-7911

[67] Ma YC, Kong XW, Yang B, Yang XL, Yang JC, Xiong ZQ. Net global warming potential and greenhouse gas intensity of annual rice-wheat rotations with integrated soil-crop system management. Agriculture, Ecosystems and Environment. 2013;**164**:200-219

[68] Li C, Salas W, Angelo B, Rose S. Assessing alternatives for mitigating net greenhouse gas emissions and increasing yields from rice production in China over the next twenty years. Journal of Environmental Quality. 2006;**35**:1554-1565