Annotated Bibliography

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Akiyama, H., H. Tsuruta, et al. (2000). "N_2O and NO emissions from soils after the application of different chemical fertilizers." Chemosphere - Global Change Science **2**(3–4): 313–320.

> Three nitrogen chemical fertilizers were applied to soil - controlled-release urea (CU), a mixture of ammonium sulfate and urea with nitrification inhibitor (AM), and a mixture of ammonium sulfate and urea with no nitrification inhibitor (UA). N2O and NO fluxes from an Andosol soil in Japan were measured six times a day for three months with an automated flux monitoring system in lysimeters. The total amount of nitrogen applied was 20 g N m-2. The total N2O emissions from CU, AM and UA were 1.90, 12.7, and 16.4 mg N m-2, respectively. The total NO emissions from CU, AM and UA were 231, 152, and 238 mg N m-2, respectively. The total NO emission was 12-15 times higher than the total N2O emission. High peaks in N2O and NO emissions from UA occurred for one month after the basal fertilizer application. The N2O emissions from CU and AM during the peak period were 50% of those from UA, and the NO emissions were less than 50% of those from UA. After the peak period, the N2O and NO emissions from CU were the highest for two months. A negative correlation was found between the flux ratio of NO-N to N2O-N and the water-filled pore space. A diel pattern with increased N2O and NO fluxes during the day and with decreased fluxes during the night was observed.

Al-Sheikh, A., J. A. Delgado, et al. (2005). "Effects of potato-grain rotations on soil erosion, carbon dynamics and properties of rangeland sandy soils." Soil & Tillage Research **81**(2): 227–238.

> The potential for wind erosion in South Central Colorado is greatest in the spring, especially after harvesting of crops such as potato (Solanum tuberosum L.) that leave small amounts of crop residue in the surface after harvest. Therefore it is important to implement best management practices that reduce potential wind erosion and that we understand how cropping systems are impacting soil erosion, carbon dynamics, and properties of rangeland sandy soils. We evaluate the effects of cropping systems on soil physical and chemical properties of rangeland sandy soils. The cropping system included a small grain-potato rotation. An uncultivated rangeland site and three fields that two decades ago were converted from rangeland into cultivated center-pivot-irrigation-sprinkler fields were also sampled. Plant and soil samples were collected in the rangeland area and the three adjacent cultivated sites. The soils at these sites were classified as a Gunbarrel loamy sand (Mixed, frigid Typic Psammaquent). We found that for the rangeland site, soil where brush species were growing exhibited C

sequestration and increases in soil organic matter (SOM) while the bare soil areas of the rangeland are losing significant amounts of fine particles, nutrients and soil organic carbon (SOM-C) mainly due to wind erosion. When we compared the cultivated sites to the uncultivated rangeland, we found that the SOM-C and soil organic matter nitrogen (SOM-N) increased with increases in crop residue returned into the soils. Our results showed that even with potato crops, which are high intensity cultivated cropping systems, we can maintain the SOM-C with a rotation of two small grain crops (all residue incorporated) and one potato crop, or potentially increase the average SOM-C with a rotation of four small grain crops (all residue incorporated) and one potato crop. Erosion losses of fine silt and clay particles were reduced with the inclusion of small grains. Small grains have the potential to contribute to the conservation of SOM and/or sequester SOM-C and SOM-N for these rangeland systems that have very low C content and that are also losing C from their bare soils areas (40%). Cultivation of these rangelands using rotations with at least two small grain crops can reduce erosion and maintain SOM-C and increasing the number of small grain crops grown successfully in rotation above two will potentially contribute to C and N sequestration as SOM and to the sequestration of macro- and micro-nutrients.

Albrecht, A. and S. T. Kandji (2003). "Carbon sequestration in tropical agroforestry systems." Agriculture, Ecosystems & Environment **99**(1–3): 15–27.

Removing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate greenhouse gas (GHG) emissions. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and/or animals. Thus, the importance of agroforestry as a land-use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The objective of this paper was to analyse C storage data in some tropical agroforestry systems and to discuss the role they can play in reducing the concentration of CO_2 in the atmosphere. The C sequestration potential of agroforestry systems is estimated between 12 and 228 Mg ha-1 with a median value of 95 Mg ha-1. Therefore, based on the earth's area that is suitable for the practice (585-1215×106 ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years. Long rotation systems such as agroforests, homegardens and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil C sequestration constitutes another realistic option achievable in many agroforestry systems. In conclusion, the potential of agroforestry for CO_2 mitigation is well recognised. However, there are a number of shortcomings that need to be emphasised. These include the uncertainties related to future shifts in global climate, land-use and land cover, the poor performance of trees and crops on substandard soils and dry environments, pests and diseases such as nematodes. In addition, more efforts are needed to improve methods for estimating C stocks and trace gas balances such as nitrous oxide (N_2O) and methane (CH_4) to determine net benefits of agroforestry on the atmosphere.

Ali, M. A., C. H. Lee, et al. (2008). "Effect of silicate fertilizer on reducing methane emission during rice cultivation." Biology and Fertility of Soils **44**(4): 597–604.

Slag-type silicate fertilizer, which contains high amount of active iron oxide, a potential source of electron acceptor, was applied at the rate of 0, 2, 6, 10, and 20 Mg ha−1 to reduce methane

(CH_4) emission from rice planted in potted soils. Methane emission rates measured by closed chamber method decreased significantly with increasing levels of silicate fertilizer application during rice cultivation. Soil redox potential (Eh) decreased rapidly after flooding, but floodwater pH and soil pH increased significantly with increasing levels of silicate fertilizer application. Iron concentrations in potted soils and in percolated water significantly increased with the increasing levels of silicate fertilizer application, which acted as oxidizing agents and electron acceptors, and thereby suppressed CH_4 emissions. Silicate fertilization significantly decreased CH_4 production activity, while it increased carbon dioxide (CO_2) production activity. Rice plant growth, yield parameters, and grain yield were positively influenced by silicate application levels. The maximum increase in grain yield (17% yield increase over the control) was found with 10 Mg ha^{-1} silicate application along with 28% reduction in total CH_4 flux during rice cultivation. It is, therefore, concluded that slag-type silicate fertilizer could be a suitable soil amendment for reducing CH_4 emissions as well as sustaining rice productivity and restoring the soil nutrient balance in rice paddy soil.

Ali, M. A., J. H. Oh, et al. (2008). "Evaluation of silicate iron slag amendment on reducing methane emission from flood water rice farming." Agriculture, Ecosystems & Environment **128**(1–2): 21–26.

Application of electron acceptors such as ferric iron oxides and hydroxides for controlling methane (CH_4) emission from wetland rice fields deserves special attention due to its dominant role over all other redox species in wetland soils. Silicate iron slag (hereafter, silicate fertilizer), a byproduct of steel industry containing electron acceptors, was applied in paddy field (Agronomy Farm, Gyeongsang National University, South Korea) at the rate of 0, 1, 2 and 4 Mg ha^{-1} to investigate their effects on reducing CH_4 emissions from flood water rice (Oryza sativa, cv. Dongjinbyeo) farming during 2006-2007. CH_4 emission rates measured by closed-chamber method decreased significantly ($p < 0.05$) with increasing levels of silicate fertilizer application during rice cultivation. Soil redox potential (Eh) showed a contrasting response to CH_4 emission rates. The concentrations of dissolved iron materials in percolated water, and the active and free iron oxides in soil significantly increased with the applications of silicate fertilizer, which acted as oxidizing agents and electron acceptors, and eventually suppressed CH_4 emissions during the rice growing seasons. Total CH_4 emission was decreased by 16-20% with 4 Mg ha^{-1} silicate fertilizer application and simultaneously rice grain yield was increased by 13-18%. Silicate fertilization significantly stimulated rice plant growth, especially root biomass, root volume and porosity, which might have improved rhizosphere oxygen concentration, and then partially contributed to reduce CH_4 emission through enhancing methane oxidation. Therefore, silicate fertilizer could be a good soil amendment for reducing CH_4 emission as well as increasing rice productivity in wetland paddy field.

Allmaras, R. R., D. E. Wilkins, et al. (1998). Agricultural technology and adoption of conservation practices. Advances in Soil and Water Conservation. F. J. Pierce and W. W. Frye. Chelsea, MI, Ann Arbor Press**:** 158.

Alluvione, F., C. Bertora, et al. (2010). "Nitrous oxide and carbon dioxide emissions following green manure and compost fertilization in corn." Soil Science Society of America Journal **74**(2): 384–395.

Alternative N fertilizers that stimulate low greenhouse gas emissions from soil are needed to reduce the impact of agriculture on global warming. Corn (Zea mays L.) grown in a calcareous silt loam soil in northwestern Italy was fertilized with a municipal solid waste compost and vetch (Vicia villosa Roth.) green manure. Their potential to reduce N2O and CO2 emissions was compared with that of urea (130 kg N ha-1). Gaseous fluxes were measured for 2 yr in the spring (after soil incorporation of fertilizers) and in summer. In spring, the slow mineralization of compost reduced N2O emissions (0.11% of supplied N) relative to urea (3.4% of applied N), without an increase in CO2 fluxes. Nitrous oxide (2.31% of fixed N) and CO2 emissions from rapid vetch decomposition did not differ from urea. When N2O and CO2 fluxes were combined, compost reduced by 49% the CO2 equivalent emitted following urea application. Vetch did not show such an effect. In summer, no fertilizer effect was found on N2O and CO2 emissions. Compost proved to be potentially suitable to reduce the CO2 equivalent emitted after soil incorporation while vetch did not. For a thorough evaluation, net greenhouse gas emissions assessment should be extended to the entire N life cycle. Differences between calculated N2O emission factors and the default Tier 1 value of the Intergovernmental Panel on Climate Change (1%) confirmed the need for site- and fertilizer-specific estimations.

Alluvione, F., A. D. Halvorson, et al. (2009). "Nitrogen, tillage, and crop rotation effects on carbon dioxide and methane fluxes from irrigated cropping systems." Journal of Environmental Quality **38**(5): 2023–2033.

Long-term effects of tillage intensity, N fertilization, and crop rotation on carbon dioxide (CO2) and methane (CH4) flux. from semiarid irrigated soils are poorly understood. We evaluated effects of. (i) tillage intensity [no-till (NT) and conventional moldboard plow tillage (CT)] in a Continuous corn rotation; (ii) N fertilization levels [0-246 kg N ha(-1) for corn (Zea mays L.); 0 and 56 kg N ha(-1) for dry bean (Phaseolus vulgaris W; 0 and 112 kg N ha(-1) for barley (Hordeum distichon L.)]; and (iii) crop rotation Under NT soil management [corn-barley (NTCB); continuous corn (NT-CC); corn-dry bean (NI-CDb)] on CO2 and CH4 flux from a clay loam soil. Carbon dioxide and CH4 fluxes were monitored one to three times per week using vented nonsready state closed chambers. No-till reduced (14%) growing season (154 d) cumulative CO2 emissions relative to CT (NT 2.08 Mg CO2-C ha(-1); CT 2.41 Mg CO2-C ha(-1)), while N fertilization had no effect. Significantly lower (18%) growing season CO2 fluxes were found in NT-CDb than NT-CC and NT-CB (11.4, 13.2 and 13.9 kg CO2-C ha(-1)d(-1) respectively). Growing season CH4 emissions were higher in NT (20.2 g CH4 ha(-1)) than in CT (1.2 g CH4 ha(-1)). Nitrogen fertilization and cropping rotation did not affect CH4 flux. Implementation of NT for 7 yr with no N fertilization was not adequate for restoring the CH4 oxidation capacity Of this clay learn soil relative to CT plowed and fertilized soil.

Alm, J., N. J. Shurpali, et al. (2007). "Emission factors and their uncertainty for the exchange of CO_2, CH_4 and N_2O in Finnish managed peatlands." Boreal Environment Research **12**(2): 191–209.

This paper summarises the results of several research groups participating in the research programme "Greenhouse Impacts of the use of Peat and Peatlands in Finland", and presents emission factors for peat-atmosphere fluxes of CO2, CH4, and N2O, filling gaps in knowledge concerning the afforestation of organic croplands and cutaways, and improves the emission assessment of peatlands drained for forestry. Forest drainage may result in net binding of soil carbon or net release, depending on site characteristics and the tree stand. Use of peatlands for

agriculture (48-4821 g CO2-eq. m(-2) a(-1)), even after the cultivation has ceased, or for milled peat harvesting (1948-2478 g CO2-eq. m(-2) a(-1)) can cause the highest overall emissions. Extremely high CO2 emissions are possible from peat harvesting areas during wet and warm summers. Afforestation of those peatlands abandoned from cultivation or peat harvesting can reduce the warming impact at least during the first tree generation. Heterotrophic soil respiration may have a systematic south-north difference in temperature response. More data must be collected before the information on peatland forest soil CO_2 emissions can be adapted for different climatic regions in Finland. A test of the model DNDC against measured data showed that DNDC has to be developed further before it can be used in estimating N2O emissions from boreal peatlands.

Alvarez, R. (2005). "A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage." Soil Use and Management **21**(1): 38–52.

The effects of nitrogen fertilizer and tillage systems on soil organic carbon (SOC) storage have been tested in many field experiments worldwide. The published results of this research are here compiled for evaluation of the impact of management practices on carbon sequestration. Paired data from 137 sites with varying nitrogen rates and 161 sites with contrasting tillage systems were included. Nitrogen fertilizer increased SOC but only when crop residues were returned to the soil; a multiple regression model accounted for just over half the variance (R2=0.56, P=0.001). The model included as independent variables: cumulative nitrogen fertilizer rate; rainfall; temperature; soil texture; and a cropping intensity index, calculated as a combination of the number of crops per year and percentage of corn in the rotation. Carbon sequestration increased as more nitrogen was applied to the system, and as rainfall or cropping intensity increased. At sites with higher mean temperatures and also in fine textured soils, carbon sequestration decreased. When the carbon costs of production, transportation and application of fertilizer are subtracted from the carbon sequestration predicted by the model, it appears that nitrogen fertilizer-use in tropical regions results in no additional carbon sequestration, whereas in temperate climates, it appears to promote net carbon sequestration. No differences in SOC were found between reduced till (chisel, disc, and sweep till) and no-till, whereas conventional tillage (mouldboard plough, disc plough) was associated with less SOC. The accumulation of SOC under conservation tillage (reduced and no till) was an S-shape time dependent process, which reached a steady state after 25-30 years, but this relationship only accounted for 26% of the variance. Averaging out SOC differences in all the experiments under conservation tillage, there was an increase of 2.1 t C ha-1 over ploughing. However, when only those cases that had apparently reached equilibrium were included (all no till vs. conventional tillage comparisons from temperate regions), mean SOC increased by approximately 12 t C ha-1. This estimate is larger than others previously reported. Carbon sequestration under conservation tillage was not significantly related to climate, soil texture or rotation.

Amos, B., T. J. Arkebauer, et al. (2005). "Soil surface fluxes of greenhouse gases in an irrigated maize-based agroecosystem." Soil Science Society of America Journal **69**: 387–395.

An understanding of the effect of fertility management on soil surface fluxes of CO2, N2O, and CH4 is essential in evaluating C sequestration measures that attempt to increase the amount of crop residue returned to the soil through increased fertilizer inputs. In this study, soil surface CO2 flux was measured over a 27-mo sampling period in continuous maize (Zea mays L.) plots managed under either an intensive fertility regime (M2) or recommended best management (M1). Flux was significantly higher in the M2 treatment on only 2 d during the first growing season. Annual estimates of soil surface CO_2 flux, based on a modified exponential equation that incorporates leaf area index (LAI) to predict temporal changes in soil respiration, averaged 11 550 kg C ha-1 yr-1 for both treatments (approximately 31.64 kg C ha-1 d-1 on average). Within row soil surface CO_2 flux was, on average, 64% higher than between row flux. Plant population did not significantly affect measured soil surface CO_2 flux. While fertility management had no significant effect on CH_4 flux, N_2O flux as measured on 3 d during the 2000 growing season was significantly higher in the M2 treatment. In 2001, no significant differences in N_2O flux were observed, possibly due to changes in N management and irrigation method. Electrical conductivity measured during the 2000 and 2001 growing seasons was significantly higher in the M2 treatment while pH measured during the 2001 season was significantly lower for M2.

Angers, D. A., M. H. Chantigny, et al. (2010). "Differential retention of carbon, nitrogen and phosphorus in grassland soil profiles with long-term manure application." Nutrient Cycling in Agroecosystems **86**(2): 225–229.

Liquid hog manure (LHM) is a valuable source of nutrients for farm production. Long-term experimental plots that had received LHM applications of 0, 50, and 100 m(3) ha(-1) annually for 20 years were analyzed for total soil C, N and P storage. Applications increased total soil N and P by 1,200 kg N ha(-1) and 850 kg P ha(-1) at 100 m(-3) LHM year(-1), compared to the control treatment. However, C storage did not increase with LHM rates and was lower in the 50 m(3) ha(-1) LHM treatment (86 Mg C ha(-1)) than in the 0 or 100 m(3) ha(-1) treatments (100 Mg C ha(-1)). In addition to the limited quantities and high decomposability of the C supplied by LHM, it is hypothesized that LHM stimulated the mineralization of both native soil C and fresh root-derived material. This priming effect was particularly apparent in deeper soil horizons where the decomposability of native C may be limited by the supply of fresh C. This study indicates that while LHM can be a significant source of crop nutrients, it has limited capacity for maintaining or increasing soil C.

Angers, D. A. and A. N'Dayegamiye (1991). "Effects of manure application on carbon, nitrogen, and carbohydrate contents of a silt loam and its particle-size fractions." Biology and Fertility of Soils **11**(1): 79–82.

Changes in the organic matter and carbohydrate contents of a silt loam and of its particle-size fractions were examined after 10 years of applying solid cattle manure. Relative to the unmanured soils, bi-annual applications of 40 and 80 Mg ha-1 manure increased C, N, and total carbohydrate contents of the whole soil and of all the particle-size fractions. The manure application had no effect on the composition of the carbohydrates. However, the organic matter of the soil with the high application rate (80 Mg ha-1) was enriched in carbohydrates. The distribution of carbohydrates in the particle-size fractions and the ratio (Ga + Ma):(Ar + Xy) indicated that carbohydrates of both plant and microbial origin were increased upon application of manure to the soil.

Archer, D. W., J. L. Pikul, et al. (2002). "Economic risk, returns and input use under ridge and conventional tillage in the northern Corn Belt, USA." Soil & Tillage Research **67**(1): 1–8.

> Ridge tillage (RT) has been proposed as an economically viable conservation tillage alternative for row crop production; however the long-term economic viability of RT in the northern Corn Belt of the USA is largely unknown. Economic returns, risk and input use were compared for RT and conventional tillage (CT) in a corn (Zea mays L.) and soybean (Glycine max (L.) Merr.) rotation with high, medium and low nitrogen treatments. The analysis was based on 10 years of experimental data from Brookings, SD on a Barnes clay loam (US soil taxonomy: fine-loamy, mixed, superactive, frigid Calcic Hapludoll; FAO classification: Chernozem). Economic returns were significantly higher at the highest nitrogen treatment levels. Highest average net returns to land and management were $ 78 per hectare for RT at the high nitrogen treatment level (RT-H) followed by $ 59 per hectare for CT at the high nitrogen treatment level (CT-H). Risk, measured as the standard deviation of net returns, was the lowest for CT at the medium nitrogen treatment level (CT-M) followed by RT-H and CT-H. However, net returns were substantially lower under CT-M at $ 32 per hectare. Average yields and average operating costs were not significantly different for RT-H and CT-H. Reduced equipment operating costs for CT-H were offset by increased herbicide costs for RT-H. Equipment ownership costs were significantly lower for RT-H than CT-H. There were no significant differences in fertilizer use for RT and CT. Pesticide use was significantly higher for RT-H than CT-H. Fuel use was 18-22% lower and labor use was 24-27% lower for RT-H than CT-H. Despite continued low adoption rates for RT in the northern Corn Belt, our analysis shows that RT is an economically viable alternative to CT.

Audsley, E., K. F. Stacey, et al. (2009). Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. Bedford, UK, Cranfield University.

Aulakh, M. S., R. Wassmann, et al. (2001). "Characterization of root exudates at different growth stages of ten rice (*Oryza sativa* L.) cultivars." Plant Biology **3**(3): 139–148.

> Plant root exudates play important roles in the rhizosphere. We tested three media (nutrient solution, deionized water and CaSO4 solution) for three periods of time (2, 4 and 6 h) for collecting root exudates of soil-grown rice plants. Nutrient culture solution created complications in the analyses of exudates for total organic C (TOC) by the wet digestion method and of organic acids by HPLC due to the interference by its components. Deionized water excluded such interference in analytical analyses but affected the turgor of root cells: roots of four widely different rice cultivars excreted 20 to 60% more TOC in deionized water than in 0.01 M CaSO4. Furthermore, the proportion of carbohydrates in TOC was also enhanced. Calcium sulfate solution maintained the osmotic environment for root cells and did not interfere in analytical procedures. Collection for 2 h avoided under-estimation of TOC and its components exuded by rice roots, which occurred during prolonged exposure. By placing plants in 0.01 M CaSO4 for 2 h, root exudates of soil-grown traditional, tall rice cultivars (Dular, B40 and Intan), high-yielding dwarf cultivars (IR72, IR52, IR64 and PSBRc 20), new plant type cultivars (IR65598 and IR65600) and a hybrid (Magat) were collected at seedling, panicle initiation, flowering and maturity and characterized for TOC and organic acids. The exudation rates were, in general, lowest at seedling stage, increased until flowering but decreased at maturity. Among organic acids, malic acid showed the highest concentration followed by tartaric, succinic, citric and lactic acids. With advancing plant growth, exudation of organic acids substituted exudation of sugars.

Root and shoot biomass were positively correlated with carbon exudation suggesting that it is driven by plant biomass. As root exudates provide substrates for methanogenesis in rice fields, large variations in root exudation by cultivars and at different growth stages could greatly influence CH4 emissions. Therefore, the use of high-yielding cultivars with lowest root excretions, for example IR65598 and IR65600, would mediate low exudate-induced CH4 production. The screening of exciting rice cultivars and breeding of new cultivars with low exudation rates could offer an important option for mitigation of CH4 emission from rice agriculture to the atmosphere.

Aulakh, M. S., R. Wassmann, et al. (2001). "Impact of root exudates of different cultivars and plant development stages of rice (Oryza sativa L.) on methane production in a paddy soil." Plant and Soil **230**(1): 77–86.

The impact of root exudates, collected from five rice cultivars, on methane (CH4) production was studied in a paddy soil under anaerobic conditions. Root exudates of the cultivars Dular, IR72 and IR65598 collected at four growth stages and of B40 and IR65600 collected at two growth stages showed that (a) CH4 production was commenced rapidly within 2 h upon exudate addition and reached a maximum within a day of addition, and (b) 7-d incubation periods were sufficient to study exudate-induced CH4 production potentials. Among different cultivars, high C releases from roots, increased the methanogenic source strength of the soil, which finally controlled CH4 production. The relationship of the amount of CH4 produced was stronger for the amount of total organic C (r = 0.920) than for the amount of organic acids (r = 0.868) added through exudates. Apparently, CH4 production and CH4 emission are more closely related to the release pattern of root exudate-C than to its individual components. The proportion of exudate-C converted to CH4 ranged between 61 and 83% and remained unaffected by cultivars and growth stages suggesting that the majority of exudate-C served as a methanogenic substrate in the anoxic rice soils. These observations indicate that the use of high-yielding cultivars with lowest excretion (for example IR65598, IR65600) would result in lowest exudate-induced CH4 production. Therefore, cultivar choice could greatly influence regional and global CH4 emissions and screening/selection of exiting rice cultivars, and/or breeding new cultivars with low exudation rates could offer an important methane mitigation option as long as yields are not compromised.

Badiou, P., D. Pennock, et al. (2010). Wetland Drainage and Restoration: Implications for Carbon Sequestration & GHG Emissions on the Canadian Prairies. Edmonton, AB, Ducks Unlimited Canada.

Bailey, N., P. Motavalli, et al. (2009). "Soil CO_2 emissions in agricultural watersheds with agroforestry and grass contour buffer strips." Agroforestry Systems **77**(2): 143–158.

The potential for agricultural soils to act as a sink and sequester carbon (C) or a source and emit carbon dioxide (CO2) is largely dependent upon the agricultural management system. The establishment of permanent vegetation, such as trees and grass contour buffer strips, may cause accumulation of above- and below-ground C over time, thereby acting as a sink for tropospheric CO2. However, the effects of contour grass strips and grass-tree strips (agroforestry) on soil CO2 emissions have not been extensively studied in row-crop watersheds in the temperate regions. The objective of this study was to determine the effects of agroforestry and grass contour buffer strips and landscape position on soil surface efflux rate of CO_2 in three adjacent agricultural watersheds with claypan soils in northeast Missouri. The three watersheds were in a corn-soybean rotation, and contained (1) cropped only (CR), (2) cropped with grass contour strips (GR), or (3) cropped with tree-grass contour strips (AF) management systems. Soil surface CO_2 efflux was measured throughout the 2004 growing season at the upper (UBS), middle (MBS), and lower (LBS) backslope landscape positions within the three watersheds. The cumulative soil CO_2 production was lowest in the CR (0.9 kg CO_2-C m^{-2}) compared to the AF (1.5 kg CO_2-C m^{-2}) and GR watersheds (1.5 kg CO_2-C m^{-2}). The lower backslope position (1.6 kg CO_2-C m^{-2}) across all three watersheds produced 32 and 40% greater cumulative soil CO_2 than the upper and middle backslope positions, respectively. A 72-day incubation study determined the effects of 40, 60, 80, and 100% soil water-filled pore space (WFPS) and N rate (0 and 1.39 g KNO_3 kg $soil^{-1}$) on soil CO_2 efflux from bulk soil collected under each management system. The cumulative CO_2 production was highest in the grass soil (1,279 mg CO_2-C kg $soil^{-1}$) compared to the agroforestry (661 mg CO_2-C kg $soil^{-1}$) and cropped (483 mg CO_2-C kg $soil^{-1}$) soils regardless of WFPS and N rate. The highest cumulative CO_2 production for the grass soil (1,279 mg CO_2-C kg $soil^{-1}$) occurred at 80% WFPS, and was approximately 2 to 2.6 times greater than the agroforestry and cropped soils at 80% WFPS. The results of this study indicate that conservation management practices, such as grass and grass-tree contour buffer strips, and landscape position affect soil surface CO_2 production and accumulation of soil organic C that may influence soil C sequestration.

Baker, J. M., T. E. Ochsner, et al. (2007). "Tillage and soil carbon sequestration – What do we really know?" Agriculture, Ecosystems & Environment **118**(1–4): 1–5.

It is widely believed that soil disturbance by tillage was a primary cause of the historical loss of soil organic carbon (SOC) in North America, and that substantial SOC sequestration can be accomplished by changing from conventional plowing to less intensive methods known as conservation tillage. This is based on experiments where changes in carbon storage have been estimated through soil sampling of tillage trials. However, sampling protocol may have biased the results. In essentially all cases where conservation tillage was found to sequester C, soils were only sampled to a depth of 30 cm or less, even though crop roots often extend much deeper. In the few studies where sampling extended deeper than 30 cm, conservation tillage has shown no consistent accrual of SOC, instead showing a difference in the distribution of SOC, with higher concentrations near the surface in conservation tillage and higher concentrations in deeper layers under conventional tillage. These contrasting results may be due to tillage-induced differences in thermal and physical conditions that affect root growth and distribution. Long-term, continuous gas exchange measurements have also been unable to detect C gain due to reduced tillage. Though there are other good reasons to use conservation tillage, evidence that it promotes C sequestration is not compelling.

Balmford, A., R. E. Green, et al. (2005). "Sparing land for nature: exploring the potential impact of changes in agricultural yield on the area needed for crop production." Global Change Biology **11**(10): 1594–1605.

How can rapidly growing food demands be met with least adverse impact on nature? Two very different sorts of suggestions predominate in the literature: wildlife-friendly farming, whereby on-farm practices are made as benign to wildlife as possible (at the potential cost of decreasing yields); and land-sparing, in which farm yields are increased and pressure to convert land for agriculture thereby reduced (at the potential cost of decreasing wildlife populations on farmland). This paper is about one important aspect of the land-sparing idea – the sensitivity of future requirements for cropland to plausible variation in yield increases, relative to other variables. Focusing on the 23 most energetically important food crops, we use data from the Food and Agriculture Organisation (FAO) and the United Nations Population Division (UNPD) to project plausible values for 2050 for population size, diet, yield, and trade, and then look at their effect on the area needed to meet demand for the 23 crops, for the developing and developed worlds in turn. Our calculations suggest that across developing countries, the area under those crops will need to increase very considerably by 2050 (by 23% under intermediate projections), and that plausible variation in average yield has as much bearing on the extent of that expansion as does variation in population size or per capita consumption;future cropland area varies far less under foreseeable variation in the net import of food from the rest of the world. By contrast, cropland area in developed countries is likely to decrease slightly by 2050 (by 4% under intermediate projections for those 23 crops), and will be less sensitive to variation in population growth, diet, yield, or trade. Other contentious aspects of the land-sparing idea require further scrutiny, but these results confirm its potential significance and suggest that conservationists should be as concerned about future agricultural yields as they are about population growth and rising per capita consumption.

Baron, V. and J. Basarb (2010). Total greenhouse gas emission from perennial cropland under intensive management. Supplementary Workshop on Greenhouse Gases in Grassland and Perennial Croplands, Alberta Soil Science Workshop. K. Haugen-Kozyra. Lethbridge, Alberta.

Can intensity of land use impact potential land use alternatives for carbon sequestration in grassland-livestock systems? Estimating the net global warming potential (GWP) of grassland – livestock systems on a land area as well as an animal basis is essential in the understanding the role of land management in reducing greenhouse gas emission. The presentation will compare beef stocker systems with varying grazing management intensity based on research at Lacombe Research Centre and on industry survey data for GWP per unit land area used and intensity per unit beef produced. Scenarios were taken from results of research pastures that were rotationally grazed, using managed intensive grazing with fertilizer application (High Input) or continuously grazed without fertilizer application (Low Input) with heifers, initially 340 kg hd-1 for an average of 91 d from 1999 until 2005. Pastures were stocked so that on a seasonal basis they had the same average daily dry matter allocation. Consequently average daily live wt. gain was almost identical. Average daily gains were 1.0 and 0.9 kg d-1, for Low Input and High Input systems respectively. A third scenario was developed from an industry survey of stocker cattle operations, which had mean rates of gain of 0.86 kg d-1 over 119 pasture days. Mean stocking rates for High Input, Low Input and Industry examples were 4.4, 1.78 and 1.98 hd ha-1, respectively. The fact that daily gain was similar meant that daily gross energy intakes of forage per animal could be estimated and was assumed similar among scenarios; forage nutritive value data was available fro the Lacombe pastures. A combination of empirical soil based data scaled to farm level and IPPC (2006) Tier 2 equations based on estimated excreted-N per animal was used to determine N2O emission. Methane emission per animal d-1 was estimated from daily gross energy intake hd-1 using IPPC (2006) Tier 2 equations. Ecosystem and soil organic-C sequestration rates were uncertain across management systems, so whole-system sequestration levels were estimated at high and low or equilibrium levels. Other inputs such as fertilizer-N were accounted for. Total emissions were determined on an animal basis and then converted to a land area basis, if necessary, using a modest carbon sequestration rate of equilibrium for Industry and Low Input systems and -206 CO2 equiv. for the High Input system. Absolute emissions for Industry and Low input systems were 47% and 36% of the High Input system, respectively. However, on a GWP intensity basis per kg beef produced, the Industry and High Input systems were identical. On a land area basis the High Input system required 139 ha less than industry to manage 500 hd or 140 ha less than Industry to produce 50,000 kg beef. In this case the Industry and Low Input systems had lower absolute emissions on an area basis but required double the land to produce similar amounts of live beef. The advantage of the High Input system is that the extra land could be used to produce alternative carbon sequestering crops such as forest or biofuel crops to offset emission of beef production on the whole-farm basis.

Bhandral, R., S. Saggar, et al. (2007). "Transformation of nitrogen and nitrous oxide emission from grassland soils as affected by compaction." Soil & Tillage Research **94**(2): 482–492.

Animal trampling is one of the main factors responsible for soil compaction under grazed pastures. Soil compaction is known to change the physical properties of the soil thereby affecting the transformation of nitrogen (N) and the subsequent of release of N as nitrous oxide (N2O). The form of N source added to these compacted soils further affects N emissions. Here we determine the interactive effects of soil compaction and form of N sources (cattle urine and ammonium, nitrate and urea fertilizers) on the loss of N through N2O emission from grassland soil. Overall, soil compaction caused a seven-fold increase in the N2O flux, the total N2O fluxes for the entire experimental period ranged from 2.62 to 61.74 kg N2O-N ha-1 for the compacted soil and 1.12 to 4.37 kg N2O-N ha-1 for the uncompacted soil. Among the N sources, the highest emissions were measured with nitrate application, emissions being 10 times more than those from other N sources for compacted soil, suggesting that the choice of N fertilizer can go a long way in mitigating N2O emissions in compacted grasslands.

Bhatia, A., S. Sasmal, et al. (2010). "Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors." Agriculture, Ecosystems & Environment **136**(3–4): 247–253.

No-till farming in wheat is being practiced in the rice-wheat system of the Indo-Gangetic plains of south Asia for resource conservation. No-tillage leads to mitigation of carbon dioxide emission, but may emit more nitrous oxide (N2O) as compared to conventional tillage reducing mitigation benefit. The aim of this study was assessment of N2O emission in wheat grown under conventional and no-tillage and its mitigation using two new nitrification inhibitors, viz. S-benzylisothiouronium butanoate (SBT-butanoate) and S-benzylisothiouronium furoate (SBT-furoate). Cumulative emission of N2O-N was higher under no-tillage by 12.2% with urea fertilization and from 4.1 to 4.8% for the inhibitor treatments as compared to the conventional tillage. In no-tillage total emission of N2O-N reduced from 0.43% of applied N with urea to 0.29% of applied N with SBT-furoate treatment. The N2O-N emissions in SBT-butanoate treatment were at par with the standard dicyandiamide (DCD) inhibitor treatment. Water-filled pore space (WFPS) was higher on most days under no-tillage, with the largest emissions (>1000 mu g N2O-N m(-2) day(-1)) coming with nitrification of ammonium-N present in soil below 60%

WFPS. Carbon efficiency ratio was highest (48.1) from SBT-furoate treatment under conventional tillage. The nitrification inhibitors used in the study increased yield of wheat, reduced global warming potential by 8.9-19.5% over urea treatment and may be used to mitigate N2O emission.

Blum, A. (2005). "Drought resistance, water-use efficiency, and yield potential – are they compatible, dissonant, or mutually exclusive?" Australian Journal of Agricultural Research **56**(11): 1159–1168.

This presentation is a concept review paper dealing with a central dilemma in understanding, designing, and acting upon crop plant improvement programs for drought conditions. The association among yield potential (YP), drought resistance (DR), and water-use efficiency (WUE) is often misunderstood, which in turn can lead to conceptual oversight and wrong decisions in implementing breeding programs for drought-prone environments. Although high YP is the target of most crop breeding programs, it might not be compatible with superior DR. On the other hand, high YP can contribute to yield in moderate stress environments. Plant production in water-limited environments is very often affected by constitutive plant traits that allow maintenance of a high plant water status (dehydration avoidance). Osmotic adjustment (OA) is a major cellular stress adaptive response in certain crop plants that enhances dehydration avoidance and supports yield under stress. Despite past voiced speculations, there is no proof that OA entails a cost in terms of reduced YP. WUE for yield is often equated in a simplistic manner with DR. The large accumulation of knowledge on crop WUE as derived from research on carbon isotope discrimination allows some conclusions on the relations between WUE on the one hand, and DR and YP on the other, to be made. Briefly, apparent genotypic variations in WUE are normally expressed mainly due to variations in water use (WU; the denominator). Reduced WU, which is reflected in higher WUE, is generally achieved by plant traits and environmental responses that reduce YP. Improved WUE on the basis of reduced WU is expressed in improved yield under water-limited conditions only when there is need to balance crop water use against a limited and known soil moisture reserve. However, under most dryland situations where crops depend on unpredictable seasonal rainfall, the maximisation of soil moisture use is a crucial component of drought resistance (avoidance), which is generally expressed in lower WUE. It is concluded that the effect of a single 'drought adaptive' gene on crop performance in water-limited environments can be assessed only when the whole system is considered in terms of YP, DR, and WUE.

Boehm, M., B. Junkins, et al. (2004). "Sink potential of Canadian agricultural soils." Climatic Change **65**(3): 297–314.

Net greenhouse gas (GHG) emissions from Canadian crop and livestock production were estimated for 1990, 1996 and 2001 and projected to 2008. Net emissions were also estimated for three scenarios (low (L), medium (M) and high (H)) of adoption of sink enhancing practices above the projected 2008 level. Carbon sequestration estimates were based on four sink-enhancing activities: conversion from conventional to zero tillage (ZT), reduced frequency of summerfallow (SF), the conversion of cropland to permanent cover crops (PC), and improved grazing land management (GM). GHG emissions were estimated with the Canadian Economic and Emissions Model for Agriculture (CEEMA). CEEMA estimates levels of production activities within the Canadian agriculture sector and calculates the emissions and removals associated with those levels of activities. The estimates indicate a decline in net emissions from 54 Tg CO2–

Eq yr-1 in1990 to 52 Tg CO_2–Eq yr-1 in 2008. Adoption of thesink-enhancing practices above the level projected for 2008 resulted in further declines in emissions to 48 Tg CO_2–Eq yr-1 (L), 42 TgCO_2–Eq yr-1 (M) or 36 Tg CO_2–Eq yr-1 (H). Among thesink-enhancing practices, the conversion from conventional tillage to ZT provided the largest C sequestration potential and net reduction in GHG emissions among the scenarios. Although rates of C sequestration were generally higher for conversion of cropland to PC and adoption of improved GM, those scenarios involved smaller areas of land and therefore less C sequestration. Also, increased areas of PC were associated with an increase in livestock numbers and CH_4 and N_2O emissions from enteric fermentation andmanure, which partially offset the carbon sink. The CEEMA estimates indicate that soil C sinks are a viable option for achieving the UNFCCC objective of protecting and enhancing GHG sinks and reservoirs as a means of reducing GHG emissions (UNFCCC, 1992).

Bordovsky, D. G., M. Choudhary, et al. (1999). "Effect of tillage, cropping, and residue management on soil properties in the Texas rolling plains." Soil Science **164**(5): 331–340.

In the Texas Rolling Plains, low rainfall results in low crop residue production and low soil organic matter. Low soil organic matter, coupled with low levels of silt and clay, give soils poor structure. An 11-year (1979-1989) field experiment was conducted to determine the effects of tillage (reduced vs. conventional), cropping, and residue management (with residue vs. without residue) on soil properties under dryland and irrigated systems. Cropping included a grain sorghum (Sorghum bicolor (L.) Moench.) and wheat (Triticum aestivum L.) monoculture and doublecropped, reduced tillage wheat-grain sorghum under irrigation only. Surface soil organic matter in plots with irrigated grain sorghum and wheat increased with time. Reduced-tillage irrigated grain sorghum and wheat, and especially reduced-tillage, double-cropped grain sorghum and wheat plots, had significantly higher organic matter content than conventional-tillage grain sorghum and wheat plots. Bulk density under the reduced tillage system was higher than with the conventional tillage system. However, saturated hydraulic conductivity (Ks) of the surface soil was increased by reduced tillage practices compared with conventional tillage. This may have been attributable to higher amounts of microaggregates and larger macropores under the reduced tillage system. Residue removal decreased the Ks of surface soil, especially in reduced-tillage grain sorghum and wheat plots. Microaggregation values were higher with residue retained than with residue removed (27.1 vs. 23.5 g kg-1 in dryland and 32.3 vs. 27.1 g kg-1 in irrigation). Results indicate that residue removal from Rolling Plains soils should be discouraged. Because of higher bulk density, use of a reduced tillage system may result in the need for occasional deep chiseling to reduce the effects of compaction.

Bosch, D. J. and K. B. Napit (1992). "Economics of transporting poultry litter to achieve more effective use as fertilizer." Journal of Soil and Water Conservation **47**(4): 342–346.

Rapid expansion of the Virginia poultry industry has resulted in poultry litter production that in certain areas exceeds the potential for use in crop agriculture. If land application exceeds crop requirements, litter production may result in environmental damage. In this study, potential litter surpluses in intensive poultry-producing Virginia counties were quantified. The costs of transferring such surpluses to litter-deficient areas were compared with the economic value of litter as fertilizer. Estimates of potential cropland and pasture for spreading litter took dairy manure production into account. Use of litter surpluses by transfer was found to be economically viable. Public policy actions are needed, however, to promote such transfer.

Bosch, D. J., K. Stephenson, et al. (2008). "Farm returns to carbon credit creation with intensive rotational grazing." <u>Journal of Soil and Water Conservation</u> **63**(2): 91–98.

> Intensive rotational grazing systems may produce multiple environmental services, including reduction of the emissions of greenhouse gases (GHG). This study investigates potential GHG emission reduction credits obtained by converting Virginia cow-calf and dairy farm operations from conventional grazing operations to rotational grazing. The quantity and value of the change in GHG emissions are estimated using new US Department of Energy guidelines. Credits are estimated under three boundary conditions and two accounting metrics. Results suggest conversion to rotational grazing can generate GHG reduction credits, but the financial benefits farms receive from emissions reductions are modest. The amount of credits received is sensitive to choice of accounting metric and boundary definition.

Bossio, D. A., W. R. Horwath, et al. (1999). "Methane pool and flux dynamics in a rice field following straw incorporation." <u>Soil Biology & Biochemistry</u> **31**: 1313–1322.

> Concerns for air quality have led to legislation restricting rice straw burning in some parts of the world. Consequently, growers must dispose of large amounts of residual rice straw by incorporation into the soil, which may have large effects on CH4 emissions from those fields. Our objective was to characterize how this recent change in management has affected overall CH4 emissions in a California rice field and establish relationships between organic matter availability, CH4 pool sizes and CH4 fluxes. Closed chamber measurements were used to monitor diurnal and post drain fluxes, to describe the seasonal pattern of CH4 emissions and estimate total CH4 fluxes on a large on-farm ®eld trial during the 1997 growing season. Soil redox, temperature and plant growth and yield were also monitored. To establish relationships between CH4 pool sizes and fluxes, soil interstitial CH4 concentrations were monitored in the field and available organic matter in the spring was estimated with a laboratory incubation. Redox values in the soil were found to be 50 mV lower in plots in which straw had been incorporated (-275 mV) than those in which it had been burned (-225 mV). No significant treatment differences were seen in total soil organic matter contents in the spring. However, available organic matter was 1.5 times higher in straw incorporated than straw burned plots. Methane emissions peaked between 22.00 and 23.00 h on two different diurnal sampling dates. Methane emission after draining was about 10% of the flooded period total. A 5-fold increase in total CH4 emissions over the rice growing season was observed in plots in which rice straw had been incorporated each fall for 4 yr. Total cumulative CH4 flux, 1 May-1 October 1997, was 8.87 g C m-2 in incorporated, winter flooded plots; 9.52 g C m-2 in incorporated, non-winter flooded plots; 1.63 g C m-2 in burned, winter flooded plots; and 2.25 g C m-2 in burned, non-winter flooded plots. Soil CH4 concentrations at 10±15 cm depth was strongly associated with emissions to the atmosphere (r=0.89). A model developed by Nouchi et al. (1994) [Nouchi, I., Hosono, T., Aodi, K., Minami, K., 1994. Seasonal variation in methane flux from rice paddies associated with methane concentration in soil water, rice biomass and temperature and it's modeling. Plant and Soil 161, 195-208.] which could predict the CH4 flux based on soil CH4 concentrations and temperature was fit to our data. The model was very successful at predicting flux rates and cumulative fluxes because conductance (CH4 flux divided by CH4 concentration in soil water) was highly correlated with soil temperature (r=0.88) throughout the period of high CH4 emissions. Organic matter availability and CH4 pool and flux dynamics were altered by straw incorporation practices as evidenced by increased conductance at the same interstitial

CH4 concentration and increased emissions per unit available organic matter in rice straw incorporated plots.

Bouwman, A. F., L. J. M. Boumans, et al. (2002). "Emissions of N_2O and NO from fertilized fields: Summary of available measurement data." Global Biogeochemical Cycles **16**(4): 6–1 to 6–13.

Information from 846 N2O emission measurements in agricultural fields and 99 measurements for NO emissions was summarized to assess the influence of various factors regulating emissions from mineral soils. The data indicate that there is a strong increase of both N2O and NO emissions accompanying N application rates, and soils with high organic-C content show higher emissions than less fertile soils. A fine soil texture, restricted drainage, and neutral to slightly acidic conditions favor N2O emission, while (though not significant) a good soil drainage, coarse texture, and neutral soil reaction favor NO emission. Fertilizer type and crop type are important factors for N2O but not for NO, while the fertilizer application mode has a significant influence on NO only. Regarding the measurements, longer measurement periods yield more of the fertilization effect on N2O and NO emissions, and intensive measurements (greater than or equal to 1 per day) yield lower emissions than less intensive measurements (2 - 3 per week). The available data can be used to develop simple models based on the major regulating factors which describe the spatial variability of emissions of N2O and NO with less uncertainty than emission factor approaches based on country N inputs, as currently used in national emission inventories.

Breitenbeck, G. A. and J. M. Bremner (1986). "Effects of rate and depth of fertilizer application on emission of nitrous-oxide from soil fertilized with anhydrous ammonia." Biology and Fertility of Soils **2**(4): 201–204.

Field studies to determine the effect of different rates of fertilization on emission of nitrous oxide (N2O) from soil fertilized with anhydrous ammonia showed that the fertilizer-induced emission of N2O-N in 116 days increased from 1.22 to 4.09 kg ha–1 as the rate of anhydrous ammonia N application was increased from 75 to 450 kg ha–1. When expressed as a percentage of the N applied, the fertilizer-induced emission of N2O-N in 116 days decreased from 1.6% to 0.9% as the rate of fertilizer N application was increased from 75 to 450 kg N ha–1. The data obtained showed that a 100% increase in the rate of application of anhydrous ammonia led to about a 60% increase in the fertilizer-induced emission of N2O. Field studies to determine the effect of depth of fertilizer injection on emission of N2O from soil fertilized with anhydrous ammonia showed that the emission of N2O-N in 156 days induced by injection of 112 kg anhydrous ammonia N ha–1 at a depth of 30 cm was 107% and 21 % greater than those induced by injection of the same amount of N at depths of 10 cm and 20 cm, respectively. The effect of depth of application of anhydrous ammonia on emission of N2O was less when this fertilizer was applied at a rate of 225 kg N ha–1.

Bremer, D. (2006). Effects of nitrogen fertilizer types and rates and irrigation on nitrous oxide fluxes in turfgrass Manhattan, KS, Kansas State University**:** 7.

1) Quantify the magnitude and patterns of nitrous oxide (N2O) fluxes in turfgrass; and 2) determine how nitrogen (N)-fertilization rates, N-fertilizer types, and irrigation affect N2O fluxes.

Bremer, E. (2009). Potential for Reductions in Greenhouse Gas Emissions from Native Rangelands in Alberta - Technical Scoping Document. Edmonton, AB, Symbio Ag Consulting for Alberta Agriculture and Rural Development**:** 24.

Native rangelands in Alberta contain large reservoirs of organic carbon and may be sequestering additional atmospheric CO2 through their response to elevated CO2 levels. Mitigation practices to increase atmospheric CO2 sequestration or otherwise reduce greenhouse gas (GHG) emissions were evaluated in this report. Improving range health through the effective application of rangeland management principles may increase C storage on rangelands that are currently rated as unhealthy or healthy with problems. However, the potential to reduce GHG emissions by this mechanism is small because most native rangelands in Alberta are healthy and the few estimates of C gain due to improved range health are small and inconsistent. Conversion of annual cropland to rangeland has the potential to increase C sequestration substantially, but this practice is most appropriately considered as a mitigation practice for annual cropland. Inclusion of legumes in seeding mixes and application of compost have good potential to increase C storage when annual cropland or degraded lands is converted to rangeland, but have limited potential to reduce GHG emissions on healthy rangelands. Overall, the potential to adopt practices that reduce GHG emissions on existing Alberta rangelands is small.

Bremner, J. M., G. A. Breitenbeck, et al. (1981). "Effect of anhydrous ammonia fertilization on emission of nitrous oxide from soils." Journal of Environmental Quality **10**(1): 77–80.

A simple method was developed for accurate injection of anhydrous ammonia in field studies to assess the effects of this fertilizer on emissions of nitrous oxide (N2O) from soils. Use of this method and of a chamber technique for measurement of N2O emissions showed that fertilization of three Iowa soils with anhydrous ammonia (250 kg N/ha) led to a very marked increase in emission of N2O. Emissions of N2O-N from the fertilized soils in 139 days ranged from 12.1 to 19.6 kg/ha and averaged 15.6 kg/ha. The corresponding emissions from the unfertilized soils ranged from 1.7 to 2.5 kg/ha and averaged 2.0 kg/ha. Most of the N2O evolved from the fertilized soils was produced within 42 days after fertilization, and N2O emissions from these soils 96 days after fertilization were not appreciably greater than those from the corresponding unfertilized soils. The fertilizer-induced emissions of N2O-N observed after application of anhydrous ammonia greatly exceeded those detected in similar field studies using other N fertilizers and represented 4.0–6.8% of the fertilizer N applied.

Bridgham, S. D., J. P. Megonigal, et al. (2006). "The carbon balance of North American wetlands." Wetlands **26**(4): 889–916.

We examine the carbon balance of North American wetlands by reviewing and synthesizing the published literature and soil databases. North American wetlands contain about 220 Pg C, most of which is in peat. They are a small to moderate carbon sink of about 49 Tg C yr(-1), although the uncertainty around this estimate is greater than 100%, with the largest unknown being the role of carbon sequestration by sedimentation in freshwater mineral-soil wetlands. We estimate that North American wetlands emit 9 Tg methane (CH4) yr(-1); however, the uncertainty of this estimate is also greater than 100%. With the exception of estuarine wetlands, CH4 emissions from wetlands may largely offset any positive benefits of carbon sequestration in soils and plants in terms of climate forcing. Historically, the destruction of wetlands through land-use changes has had the largest effects on the carbon fluxes and consequent radiative forcing of North American wetlands. The primary effects have been a reduction in their ability to sequester carbon (a small to moderate increase in radiative forcing), oxidation of their soil carbon reserves upon drainage (a small increase in radiative forcing), and reduction in CH4 emissions (a small to large decrease in radiative forcing). It is uncertain how global changes will affect the carbon pools and fluxes of North American wetlands. We will not be able to predict accurately the role of wetlands as potential positive or negative feedbacks to anthropogenic global change without knowing the integrative effects of changes in temperature, precipitation, atmospheric carbon dioxide concentrations, and atmospheric deposition of nitrogen and sulfur on the carbon balance of North American wetlands.

Briske, D. D., J. D. Derner, et al. (2008). "Rotational grazing on rangelands: Reconciliation of perception and experimental evidence." Rangeland Ecology & Management **61**(1): 3–17.

In spite of overwhelming experimental evidence to the contrary, rotational grazing continues to be promoted and implemented as the only viable grazing strategy. The goals of this synthesis are to 1) reevaluate the complexity, underlying assumptions, and ecological processes of grazed ecosystems, 2) summarize plant and animal production responses to rotational and continuous grazing, 3) characterize the prevailing perceptions influencing the assessment of rotational and continuous grazing, and 4) attempt to direct the profession toward a reconciliation of perceptions advocating support for rotational grazing systems with that of the experimental evidence. The ecological relationships of grazing systems have been reasonably well resolved, at the scales investigated, and a continuation of costly grazing experiments adhering to conventional research protocols will yield little additional information. Plant production was equal or greater in continuous compared to rotational grazing in 87% (20 of 23) of the experiments. Similarly, animal production per head and per area were equal or greater in continuous compared to rotational grazing in 92% (35 of 38) and 84% (27 of 32) of the experiments, respectively. These experimental data demonstrate that a set of potentially effective grazing strategies exist, none of which have unique properties that set one apart from the other in terms of ecological effectiveness. The performance of rangeland grazing strategies are similarly constrained by several ecological variables establishing that differences among them are dependent on the effectiveness of management models, rather than the occurrence of unique ecological phenomena. Continued advocacy for rotational grazing as a superior strategy of grazing on rangelands is founded on perception and anecdotal interpretations, rather than an objective assessment of the vast experimental evidence. We recommend that these evidence-based conclusions be explicitly incorporated into management and policy decisions addressing this predominant land use on rangelands.

Brittan, K. L., J. L. Schmierer, et al. (2008). Sample Costs to Produce Field Corn on MIneral Soils in the Sacramento Valley. Davis, CA, University of California Cooperative Extension.

Bronson, K. F., A. R. Mosier, et al. (1992). "Nitrous oxide emissions in irrigated corn as affected by nitrification inhibitors." Soil Science Society of America Journal **56**(1): 161–165.

> Nitrous oxide and N_2 are the major denitriflcation products in irrigated corn (lea mays L.). In addition, N_2O is considered a gas that contributes to global warming and stratospheric O_3 depletion. Minimizing NjO emissions in cropping systems is therefore an economic as well as an important environmental concern. In a 1989 field experiment, the nitrification inhibitor encapsulated calcium carbide (ECC) (0,20, or 40 kg CaC_2 ha-1) or nitrapyrin (0.5 L a.i. ha-1) was banded with urea (218 kg N ha-1) 7 wk after planting com. Between 1 and 14 wk after fertilization in 1989, N_2O losses of 3226, 1109,1017, and 1005 g N_2O-N ha-1 from urea alone, urea plus nitrapyrin, urea plus 20 kg ECC ha-1, and urea plus 40 kg ECC ha-1, respectively, were measured from vented chambers. Nitrous oxide fluxes were positively correlated with soil NO, levels, indicating that the nitrification inhibitors indirectly controlled N_2O emissions by preventing NO_3 from accumulating in the soil. Carbon dioxide emissions from the root zone were generally not affected by ECC or nitrapyrin. In 1990, losses of N_2O were less than in 1989 (1651 g N ha-1 with urea alone), probably because there were fewer irrigations. Nitrapyrin and ECC addition to urea resulted in 980 and 459 g N ha-1 N_2O being emitted the second year. Nitrification inhibitors appear to be a useful tool in mitigating N_2O emissions in agricultural systems.

Brookes, G. and P. Barfoot (2010). "Global impact of biotech crops: Environmental effects, 1996–2006." AgBioForum **13**(1): 76–94.

> This article updates the assessment of the impact commercialized agricultural biotechnology is having on global agriculture from an environmental perspective. It focuses on the impact of changes in pesticide use and greenhouse gas emissions arising from the use of biotech crops. The technology has reduced pesticide spraying by 352 million kg (-8.4%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator the environmental impact quotient) by 16.3%. The technology has also significantly reduced the release of greenhouse gas emissions from this cropping area, which, in 2008, was equivalent to removing 6.9 million cars from the roads.

Brown, S., C. Kruger, et al. (2008). "Greenhouse gas balance for composting operations." Journal of Environmental Quality **37**(4): 1396–1410.

> The greenhouse gas (GHG) impact of composting a range of potential feedstocks was evaluated through a review of the existing literature with a focus on methane (CH_4) avoidance by composting and GHG emissions during composting. The primary carbon credits associated with composting are through CH_4 avoidance when feedstocks are composted instead of landfilled (municipal solid waste and biosolids) or lagooned (animal manures). Methane generation potential is given based on total volatile solids, expected volatile solids destruction, and CH_4 generation from lab and field incubations. For example, a facility that composts an equal mixture of manure, newsprint, and food waste could conserve the equivalent of 3.1 Mg CO_2 per 1 dry Mg of feedstocks composted. if feedstocks were diverted from anaerobic storage lagoons and landfills with no gas collection mechanisms. The composting process is a source of GHG emissions from the use of electricity and fossil fuels and through GHG emissions during composting. Greenhouse gas emissions during composting are highest for high-nitrogen

materials with high moisture contents. These debits are minimal in comparison to avoidance credits and can be further minimized through the use of higher carbon:nitrogen feedstock mixtures and lower-moisture-content mixtures. Compost end use has the potential to generate carbon credits through avoidance and sequestration of carbon; however, these are highly project specific and need to be quantified on an individual project basis.

Bruce, J. P., M. Frome, et al. (1999). "Carbon sequestration in soils." Journal of Soil and Water Conservation **54**(1): 382–389.

Burger, M., J. Assa, et al. (2009). Greenhouse Gas Emissions from California Cropping Systems. Davis, CA, University of California Davis.

Burger, M., L. E. Jackson, et al. (2005). "Microbial responses and nitrous oxide emissions from wetting and drying of organically and conventionally managed soil under tomatoes." Biology and Fertility in Soils **42**(2): 109–118.

The types and amounts of carbon (C) and nitrogen (N) inputs, as well as irrigation management are likely to influence gaseous emissions and microbial ecology of agricultural soil. Carbon dioxide (CO2) and nitrous oxide (N2O) efflux, with and without acetylene inhibition, inorganic N, and microbial biomass C were measured after irrigation or simulated rainfall in two agricultural fields under tomatoes (Lycopersicon esculentum). The two fields, located in the California Central Valley, had either a history of high organic matter (OM) inputs ("organic" management) or one of low OM and inorganic fertilizer inputs ("conventional" management). In microcosms, where shortterm microbial responses to wetting and drying were studied, the highest CO2 efflux took place at about 60% water-filled pore space (WFPS). At this moisture level, phospholipid fatty acids (PLFA) indicative of microbial nutrient availability were elevated and a PLFA stress indicator was depressed, suggesting peakmicrobial activity. The highest N2O efflux in the organically managed soil (0.94 mg N2O-N m−2 h−1) occurred after manure and legume cover crop incorporation, and in the conventionally managed soil (2.12 mg N2O-N m−2 h−1) after inorganic N fertilizer inputs. Elevated N2O emissions occurred at a WFPS >60% and lasted <2 days after wetting, probably because the top layer (0–150 mm) of this silt loam soil dried quickly. Therefore, in these cropping systems, irrigation management might control the duration of elevated N2O efflux, even when C and inorganic N availability are high, whereas inorganic N concentrations should be kept low during times when soil moisture cannot be controlled.

Burke, I. C., W. K. Lauenroth, et al. (1995). "Soil organic matter recovery in semiarid grasslands: implications for the conservation reserve program." Ecological Applications **5**(3): 793–801.

Burney, J. A., S. J. Davis, et al. (2010). "Greenhouse gas mitigation by agricultural intensification." Proceedings of the National Academy of Sciences **107**(26): 12052–12057.

As efforts to mitigate climate change increase, there is a need to identify cost-effective ways to avoid emissions of greenhouse gases (GHGs). Agriculture is rightly recognized as a source of considerable emissions, with concomitant opportunities for mitigation. Although future agricultural productivity is critical, as it will shape emissions from conversion of native landscapes to food and biofuel crops, investment in agricultural research is rarely mentioned as a mitigation strategy. Here we estimate the net effect on GHG emissions of historical agricultural intensification between 1961 and 2005. We find that while emissions from factors such as fertilizer production and application have increased, the net effect of higher yields has avoided emissions of up to 161 gigatons of carbon (GtC) (590 GtCO2e) since 1961. We estimate that each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 kgCO2e) emissions relative to 1961 technology ($14.74/tC, or ~$4/tCO2e), avoiding 3.6 GtC (13.1 GtCO2e) per year. Our analysis indicates that investment in yield improvements compares favorably with other commonly proposed mitigation strategies. Further yield improvements should therefore be prominent among efforts to reduce future GHG emissions.

Burton, D. L., X. H. Li, et al. (2008). "Influence of fertilizer nitrogen source and management practice on N_2O emissions from two Black Chernozemic soils." Canadian Journal of Soil Science **88**(2): 219–227.

Fertilizer nitrogen use is estimated to be a significant source of nitrous oxide (N2O) emissions in western Canada. These estimates are based primarily on modeled data, as there are relatively few studies that provide direct measures of the magnitude of N2O emissions and the influence of N source on N2O emissions. This study examined the influence of nitrogen source (urea, coated urea, urea with urease inhibitor, and anhydrous ammonia), time of application (spring, fall) and method of application (broadcast, banded) on nitrous oxide emissions on two Black Chemozemic soils located near Winnipeg and Brandon Manitoba. The results of this 3-yr study demonstrated consistently that the rate of fertilizer-induced N2O emissions under Manitoba conditions was lower than the emissions estimated using Intergovernmental Panel on Climate Change (IPCC) coefficients. The Winnipeg site tended to have higher overall NO emissions (1.7 kg N ha(-1)) and fertilizer-induced emissions (-0.8% of applied N) than did the Brandon site (0.5 kg N ha(-1)), representing similar to 0.2% of applied N. N2O emissions in the first year of the study were much higher than in subsequent years. Both the site and year effects likely reflected differences in annual precipitation. The N2O emissions associated with the use of anhydrous ammonia as a fertilizer source were no greater than emissions with urea. Fall application of nitrogen fertilizer tended to result in marginally greater N2O emissions than did spring application, but these differences were neither large nor consistent.

Burton, D. L., B. J. Zebarth, et al. (2008). "Effect of split application of fertilizer nitrogen on N_2O emissions from potatoes." Canadian Journal of Soil Science **88**(2): 229–239.

The timing of fertilizer nitrogen (N) application influences the availability of NOT as a substrate for denitrification. This study examined the effect of split application of fertilizer N on N2O emissions and denitrification rate in potato (Solanum tuberosum L.) production over 2 yr. Three treatments were used: 0 or 200 kg N ha(-1) at planting, and 120 kg N ha(-1) at planting plus 80 kg N ha(-1) at final hilling. Fertilizer N application increased cumulative N2O emissions. Split fertilizer N application decreased cumulative N2O emissions in 2003, but not in 2002, compared with all fertilizer N applied at planting. A greater proportion of N2O emissions occurred between planting and hilling in 2003 (67%) compared with 2002 (17%). In 2003, the higher emissions during this period resulted from the coincidence of high soil NOT availability and increased rainfall resulting in reduced aeration. Split N application was effective in reducing N2O emissions by minimizing the supply of NOT when demand for terminal electron acceptors was high. v emissions were higher in the potato hill relative to the furrow; however, denitrification rate was

higher in the furrow. Nitrate intensity (NI) expresses the exposure of the soil microbial population to NO3- and was calculated as the summation of daily soil nitrate concentration over the monitoring period. Cumulative N2O emissions were positively related to NI across year, N fertility treatment and row location. Denitrification was not related to NI, reflecting the primary role of NOT in influencing the N2O:N-2 ratio of denitrification rather than the magnitude of the overall process. Split N application was an effective strategy for reducing N2O emissions in years where there was significant rainfall during the period between planting and hilling.

Buttazzoni, M. (2009). GHG Emission Reductions With Industrial Biotechnology: Assessing the Opportunities. WWF. Palmetto, FL, Sustainability 3.0 LLC.

Buyanovsky, G. A. and G. H. Wagner (1998). "Carbon cycling in cultivated land and its global significance." Global Change Biology **4**(2): 131–141.

Long-term data from Sanborn Field, one of the oldest experimental fields in the USA, were used to determine the direction of soil organic carbon (SOC) dynamics in cultivated land. Changes in agriculture in the last 50 years including introduction of more productive varieties, wide scale use of mineral fertilizers and reduced tillage caused increases in total net annual production (TNAP), yields and SOC content. TNAP of winter wheat more than doubled during the last century, rising from 2.0-2.5 to 5-6 Mg ha(-1) of carbon, TNAP of corn rose from 3-4 to 9.5-11.0 Mg ha(-1) of carbon. Amounts of carbon returned annually with crop residues increased even more drastically, from less than 1 Mg ha(-1) in the beginning of the century to 33.5 Mg ha(-1) for wheat and 5-6 Mg ha(-1) for corn in the 90s. These amounts increased in a higher proportion because in the early 509 removal of postharvest residues from the field was discontinued. SOC during the first half of the century, when carbon input was low, was mineralized at a high rate: 89 and 114 g m(-2) y(-1) under untreated wheat and corn, respectively. Application of manure decreased losses by half, but still the SOC balance remained negative. Since 1950, the direction of the carbon dynamics has reversed: soil under wheat monocrop (with mineral fertilizer) accumulated carbon at a rate about 50 g m(-2) y(-1), three year rotation (corn/wheat/clover) with manure and nitrogen applications sequestered 150 g m(2) y(-1) of carbon. Applying conservative estimates of carbon sequestration documented on Sanborn Field to the wheat and corn production area in the USA, suggests that carbon losses to the atmosphere from these soils were decreased by at least 32 Tg annually during the last 40-50 years. Our computations prove that cultivated soils under proper management exercise a positive influence in the current imbalance in the global carbon budget.

Camp, C. R. (1998). "Subsurface drip irrigation: a review." Transactions of the ASAE **41**(5): 1353–1367.

A comprehensive review of published information on subsurface drip irrigation was performed to determine the state of the art on the subject. Subsurface drip irrigation has been a part of drip irrigation development in the USA since its beginning about 1960, but interest has escalated since the early 1980s. Yield response for over 30 crops indicated that crop yield for subsurface drip was greater than or equal to that for other irrigation methods, including surface drip, and required less water in most cases. Lateral depths ranged from 0.02 to 0.70 m and lateral spacings ranged from 0.25 to 5.0 m. Several irrigation scheduling techniques, management strategies, crop water requirements, and water use efficiencies were discussed. Injection of

nutrients, pesticides, and other chemicals to modify water and soil conditions is an important component of subsurface drip irrigation. Some mathematical models that simulate water movement in subsurface drip systems were included Uniformity measurements and methods, a limited assessment of root intrusion into emitters, and estimates of overall system longevity were also discussed. Sufficient information exists to provide general guidance with regard to design, installation, and management of subsurface drip irrigation systems. A significant body of information is available to assist in determining relative advantages and disadvantages of this technology in comparison with other irrigation types. Subsurface drip provides a more efficient delivery system if water and nutrient applications are managed properly. Waste water application, especially for turf and landscape plants, offers great potential Profitability and economic aspects have not been determined conclusively and will depend greatly on local conditions and constraints, especially availability and cost of water.

Campbell, C. A., H. H. Janzen, et al. (2005). "Carbon storage in soils of the North American Great Plains: Effect of cropping frequency." Journal of Agronomy **97**(2): 349–363.

Summer fallow (fallow) is still widely used on the North American Great Plains to replenish soil moisture between crops. Our objective was to examine how fallowing affects soil organic carbon (SOC) in various agronomic and climate settings by reviewing long-term studies in the midwestern USA (five sites) and the Canadian prairies (17 sites). In most soils, SOC increased with cropping frequency though not usually in a linear fashion. In the Canadian studies, SOC response to tillage and cropping frequency varied with climate--in semiarid conditions, SOC gains under no-till were about 250 kg ha-1 yr-1 greater than for tilled systems regardless of cropping frequency; in subhumid environments, the advantage was about 50 kg ha-1 yr-1 for rotations with fallow but 250 kg ha-1 yr-1 with continuous cropping. Specific crops also influenced SOC: Replacing wheat (Triticum aestivum L.) with lentil (Lens culinaris Medikus) had little effect; replacing wheat with lower-yielding flax (Linum usitatismum L.) reduced SOC gains; and replacing wheat with erosion-preventing fall rye (Secale cereale L.) increased SOC gains. In unfertilized systems, cropping frequency did not affect SOC gains, but in fertilized systems, SOC gains often increased with cropping frequency. In a Colorado study (three sites each with three slope positions), SOC gains increased with cropping frequency, but the response tended to be highest at the lowest potential evaporation site (where residue C inputs were greatest) and least in the toeslope positions (despite their high residue C inputs). The Century and the Campbell et al. SOC models satisfactorily simulated the relative responses of SOC although they underestimated gains by about one-third.

Campbell, C. A., B. G. McConkey, et al. (2002). Efficiencies of conversion of residue C to soil C Agricultural Practices and Policies for Carbon Sequestration in Soil. J. M. Kimble, R. Lal and R. F. Follett. Boca Raton, FL, CRC Press**:** 305–314.

Carpenter, J. E. (2010). "Peer-reviewed surveys indicate positive impact of commercialized GM crops." Nature Biotechnology **28**(4): 319–321.

Carter, M. R. (2002). "Soil quality for sustainable land management: Organic matter and aggregation interactions that maintain soil functions." Agronomy Journal **94**(1): 38–47.

Soil quality concepts are commonly used to evaluate sustainable land management in agroecosystems. The objectives of this review were to trace the importance of soil organic matter (SOM) in Canadian sustainable land management studies and illustrate the role of SOM and aggregation in sustaining soil functions. Canadian studies on soil quality were initiated in the early 1980s and showed that loss of SOM and soil aggregate stability were standard features of nonsustainable land use. Subsequent studies have evaluated SOM quality using the following logical sequence: soil purpose and function, processes, properties and indicators, and methodology. Limiting steps in this soil quality framework are the questions of critical limits and standardization for soil properties. At present, critical limits for SOM are selected using a commonly accepted reference value or based on empirically derived relations between SOM and a specific soil process or function (e.g., soil fertility, productivity, or erodibility). Organic matter fractions (e.g., macro-organic matter, light fraction, microbial biomass, and mineralizable C) describe the quality of SOM. These fractions have biological significance for several soil functions and processes and are sensitive indicators of changes in total SOM. Total SOM influences soil compactibility, friability, and soil water-holding capacity while aggregated SOM has major implications for the functioning of soil in regulating air and water infiltration, conserving nutrients, and influencing soil permeability and erodibility. Overall, organic matter inputs, the dynamics of the sand-sized macro-organic matter, and the soil aggregation process are important factors in maintaining and regulating organic matter functioning in soil.

Castiglioni, P., D. Warner, et al. (2008). "Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions." Plant Physiology **147**(2): 446–455.

Chang, C., T. G. Sommerfeldt, et al. (1991). "Soil chemistry after eleven annual applications of cattle feedlot manure." Journal of Environmental Quality **20**(2): 475–480.

In a long-term experiment at Lethbridge, AB, the effects of cattle (Bos sp.) manure on soil characteristics were determined after 11 annual applications. Manure, incorporated by cultivating, rototilling, or plowing, was applied annually from 1973 to 1983 at 30, 60, and 90 Mg ha−1 (wet wt.) and 60, 120, and 180 Mg ha−1, respectively, to nonirrigated and irrigated dark brown Chernozemic (Typic Haploborolls) clay loam soil. On both the nonirrigated and irrigated soil, the effects from manure, applied annually at greater than recommended rates for 11 yr, were minimal on Cu and NH4 content and substantial on other parameters determined. There were no significant effects due to tillage methods on these soil parameters. The effects on these soil parameters extended to greater depths under irrigation than under nonirrigation. Most of the applied NH4 was nitrified, volatilized, or fixed. The accumulation of organic matter, total N, NO3, total P, available P, soluble Na, Ca + Mg, Cl, SO4, HCO3, and Zn in the soil increased with increasing rates of manure applied. The electrical conductivity and sodium adsorption ratio of the soil increased and the soil pH in the surface 60 cm of nonirrigated and 90 cm of irrigated decreased with increased manure rates. The total NO3 accumulation in the 150-cm soil depth was near 1 Mg ha−1, even at recommended rates, and was high enough to potentially cause soil and water pollution. The available P accumulated mostly in the surface soil and might be sufficient to interfere with the nutrient balance of some crops. Long-term annual application of cattle manure to southern Alberta soils at maximum recommended rates [30 mg ha−1 and 60 Mg ha−1 (wet wt.) for nonirrigated and irrigated land, respectively] is not advisable.

Chantigny, M. H., P. Rochette, et al. (2010). "Soil nitrous oxide emissions following band-incorporation of fertilizer nitrogen and swine manure." Journal of Environmental Quality **39**(5): 1545–1553.

Treatment of liquid swine manure (LSM) offers opportunities to improve manure nutrient management. However, N2O fluxes and cumulative emissions resulting from application of treated LSM are nor well documented. Nitrous oxide emissions were monitored following band-incorporation of 100 kg N ha(-1) of either mineral fertilizer, raw LSM, or four pretreated LSMs (anaerobic digestion; anaerobic digestion + flocculation; filtration; decantation) at the four-leaf stage of corn (Zea mays L.). In a clay soil, a larger proportion of applied N was lost as N2O with the mineral fertilizer (average of 6.6%) than with LSMs (3.1-5.0%), whereas in a loam soil, the proportion of applied N lost as N2O was lower with the mineral fertilizer (average of 0.4%) than with LSMs (1.2-2.4%). Emissions were related to soil NO3 intensity in the clay soil, whereas they were related to water-extractable organic C in the loam soil. This suggests that N2O production was N limited in the clay soil and C limited in the loam soil, and would explain the interaction found between N sources and soil type. The large N2O emission coefficients measured in many treatments, and the contradicting responses among N sources depending on soil type, indicate that (i) the Intergovernmental Panel on Climate Change (IPCC) default value (1%) may seriously underestimate N2O emissions from fine-textured soils where fertilizer N and manure are band-incorporated, and (ii) site-specific factors, such as drainage conditions and soil properties (e.g., texture, organic matter content), have a differential influence on emissions depending on N source.

Chesworth, W., Ed. (2008). Encyclopedia of Soil Science. Dordrecht, The Netherlands, Springer.

Clapp, C. E., R. R. Allmaras, et al. (2000). "Soil organic carbon and ^{13}C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota." Soil & Tillage Research **55**(3–4): 127–142.

Long-term field experiments are among the best means to predict soil management impacts on soil carbon storage. Soil organic carbon (SOC) and natural abundance 13C ([delta]13C) were sensitive to tillage, stover harvest, and nitrogen (N) management during 13 years of continuous corn (Zea mays L.), grown on a Haplic Chernozem soil in Minnesota. Contents of SOC in the 0-15 cm layer in the annually-tilled [moldboard (MB) and chisel (CH)] plots decreased slightly with years of corn after a low input mixture of alfalfa (Medicago sativum L.) and oat (Avena sativa L.) for pasture; stover harvest had no effect. Storage of SOC in no-till (NT) plots with stover harvested remained nearly unchanged at 55 Mg ha-1 with time, while that with stover returned increased about 14%. The measured [delta]13C increased steadily with years of corn cropping in all treatments; the NT with stover return had the highest increase. The N fertilization effects on SOC and [delta]13C were most evident when stover was returned to NT plots. In the 15-30 cm depth, SOC storage decreased and [delta]13C values increased with years of corn cropping under NT, especially when stover was harvested. There was no consistent temporal trend in SOC storage and [delta]13C values in the 15-30 cm depth when plots received annual MB or CH tillage. The amount of available corn residue that was retained in SOC storage was influenced by all three management factors. Corn-derived SOC in the 0-15 cm and the 15-30 cm layers of the NT system combined was largest with 200 kg N ha-1 and no stover harvest. The MB and CH tillage systems did not influence soil storage of corn-derived SOC in either the 0-15 or 15-30 cm layers. The corn-derived SOC as a fraction of SOC after 13 years fell into three ranges: 0.05 for the NT with stover harvested, 0.15 for the NT with no stover harvest, and 0.09-0.10 for treatments with annual tillage; N rate had no effect on this fraction. Corn-derived SOC expressed as a fraction of C returned was positively biased when C returned in the roots was estimated from recovery of root biomass. The half-life for decomposition of the original or relic SOC was longer when stover was returned, shortened when stover was harvested and N applied, and sharply lengthened when stover was not harvested and N was partially mixed with the stover. Separating SOC storage into relic and current crop sources has significantly improved our understanding of the main and interacting effects of tillage, crop residue, and N fertilization for managing SOC accumulation in soil.

Clark, M. S., H. Ferris, et al. (1998). "Agronomic, economic, and environmental comparison of pest management in conventional and alternative tomato and corn systems in northern California." Agriculture, Ecosystems & Environment **68**(1–2): 51–71.

The effectiveness, economic efficiency, and environmental impact of pest management practices was compared in conventional, low-input, and organic processing tomato and field corn systems in northern California. Pests, including arthropods, weeds, pathogens, and nematodes, were monitored over an 8-year period. Although both crops responded agronomically to the production-system treatments, arthropods, pathogens, and nematodes were found to play a relatively small role in influencing yields. In contrast, weed abundance was negatively correlated with tomato and corn yields and appeared to partially account for lower yields in the alternative systems compared to the conventional systems. Lower pesticide use in the organic and low-input systems resulted in considerably less potential environmental impact but the economic feasibility of reducing pesticide use differed dramatically between the two crops. The performances of the organic and low-input systems indicate that pesticide use could be reduced by 50% or more in corn with little or no yield reduction. Furthermore, the substitution of mechanical cultivation for herbicide applications in corn could reduce pest management costs. By contrast, pesticide reductions in tomato would be economically costly due to the dependence on hand hoeing as a substitution for herbicides. Based on the performance of the low-input and organic tomato systems, a 50% pesticide reduction would increase average pest management costs by 50%.

Clark, M. S., W. R. Horwath, et al. (1998). "Changes in soil chemical properties resulting from organic and low-input farming practices." Agronomy Journal **90**(5): 662–671.

Soil chemical properties during the transition from conventional to organic and low-input farming practices were studied over 8 yr in California's Sacramento Valley to document changes in soil fertility status and nutrient storage. Four fanning systems differing in crop rotation and external inputs were established on land previously managed conventionally. Fertility in the organic system depended on animal manure applications and winter cover crops; the two conventional systems received synthetic fertilizer inputs; the low-input system used cover crops and animal manure during the first 3 yr and cover crops and synthetic fertilizer for the remaining 5 yr. At 4 and 8 yr after establishment, most changes in soil chemical properties were consistent with predictions based on nutrient budgets. Inputs of C, P, K, Ca, and Mg were higher in the organic and low-input systems as a result of manure applications and cover crop incorporations. After 4 yr, soils in the organic and low-input systems had higher soil organic C, soluble P,

exchangeable K, and pH. Ceasing manure applications in the low-input system in Year 4 resulted in declining levels of organic C, soluble P, and exchangeable K. Crop rotation (the presence or absence of corn) also had a significant effect on organic C levels. Differences in total N appeared to be related in part to inputs, but perhaps also to differing efficiency of the farming systems at storing excess N inputs: the low-input system appeared to be most efficient, and the conventional systems were least efficient. Electrical conductivity (EC), soluble Ca, and soluble Mg levels were tightly linked but not consistently different among treatments. Relatively stable EC levels in the organic system indicate that animal manures did not increase salinity. Overall, our findings indicate that organic and lowinput farming in the Sacramento Valley result in small but important increases in soil organic C and larger pools of stored nutrients, which are critical for long-term fertility maintenance.

Clayton, H., I. P. McTaggart, et al. (1997). "Nitrous oxide emissions from fertilised grassland: A 2-year study of the effects of N fertiliser form and environmental conditions." Biology and Fertility of Soils **25**(3): 252–260.

The aim was to investigate the effects of different N fertilisers on nitrous oxide (N2O) flux from agricultural grassland, with a view to suggesting fertiliser practices least likely to cause substantial N2O emissions, and to assess the influence of soil and environmental factors on the emissions. Replicate plots on a clay loam grassland were fertilised with ammonium sulphate (AS), urea (U), calcium nitrate (CN), ammonium nitrate (AN), or cattle slurry supplemented with AN on three occasions in each of 2 years. Frequent measurements were made of N2O flux and soil and environmental variables. The loss of N2O-N as a percentage of N fertiliser applied was highest from the supplemented slurry (SS) treatment and U, and lowest from AS. The temporal pattern of losses was different for the different fertilisers and between years. Losses from U were lower than those from AN and CN in the spring, but higher in the summer. The high summer fluxes were associated with high water-filled pore space (WFPS) values. Fluxes also rose steeply with temperature where WFPS or mineral N values were not limiting. Total annual loss was higher in the 2nd year, probably because of the rainfall pattern: the percentage losses were 2.2, 1.4, 1.2, 1.1 and 0.4 from SS, U, AN, CN and AS, respectively. Application of U in the spring and AN twice in the summer in the 2nd year gave an average emission factor of 0.8% – lower than from application of either individual fertiliser. We suggest that similar varied fertilisation practices, modified according to soil and crop type and climatic conditions, might be employed to minimise N2O emissions from agricultural land.

Climate Action Reserve (2010). Organic Waste Composting: Project Protocol. Los Angeles, CA, Climate Action Reserve**:** 76.

Clough, T. J., J. E. Bertram, et al. (2010). "Unweathered wood biochar impact on nitrous oxide emissions from a bovine-urine-amended pasture soil." Soil Science Society of America Journal **74**(3): 852–860.

Low-temperature pyrolysis of biomass produces a product known as biochar. Th e incorporation of this material into the soil has been advocated as a C sequestration method. Biochar also has the potential to infl uence the soil N cycle by altering nitrifi cation rates and by adsorbing NH4 + or NH3. Biochar can be incorporated into the soil during renovation of intensively managed pasture soils. Th ese managed pastures are a signifi cant source of N2O, a greenhouse gas,

produced in ruminant urine patches. We hypothesized that biochar eff ects on the N cycle could reduce the soil inorganic-N pool available for N2O-producing mechanisms. A laboratory study was performed to examine the effect of biochar incorporation into soil (20 Mg ha–1) on N2O-N and NH3–N fl uxes, and inorganic-N transformations, following the application of bovine urine (760 kg N ha–1). Treatments included controls (soil only and soil plus biochar), and two urine treatments (soil plus urine and soil plus biochar plus urine). Fluxes of N2O from the biochar plus urine treatment were generally higher than from urine alone during the first 30 d, but after 50 d there was no signifi cant diff erence (P = 0.11) in terms of cumulative N2O-N emitted as a percentage of the urine N applied during the 53-d period; however, NH3–N fl uxes were enhanced by approximately 3% of the N applied in the biochar plus urine treatment compared with the urine-only treatment aft er 17 d. Soil inorganic-N pools diff ered between treatments, with higher NH4 + concentrations in the presence of biochar, indicative of lower rates of nitrifi cation. Th e inorganic-N pool available for N2O-producing mechanisms was not reduced, however, by adding biochar.

Cochran, V. L., R. I. Papendick, et al. (1973). "Effectiveness of two nitrification inhibitors for anhydrous ammonia under irrigated and dryland conditions." Agronomy Journal **65**(4): 649–653.

Potassium azide (KN3) and 2-chloro-6-(trichloromethyl) pyridine (N-Serve) were evaluated as nitrification inhibitors for anhydrous NH3 field applied on irrigated and nonirrigated Ritzville silt loam and on nonirrigated Naff silt loam in eastern Washington. Formulations of KN3, N-Serve in liquid NH3, or NH3 alone were applied to fallow soil in midsummer at a rate of 90 kg N/ha. Irrigations were 15 cm of water sprinkler applied 1 day or 2 weeks after fertilizer application, and 10 to 15 cm of water each time at 4, 8, and 13 weeks after NH3 application. The NH3 retention zone was sampled for NH+4 and NO-3 periodically through December for the Naff soil and through February for the Ritzville soil. Both KN3 and N-Serve effectively inhibited nitrification of the applied NH3 on nonirrigated Ritzville soil when temperature and soil moisture were favorable for rapid nitrification. However, KN3 was completely ineffective following irrigation or, for the Naff soil, after rainwater penetrated below the retention zone 2 weeks after N application. Where irrigated 1 day or 2 weeks after fertilization application, all of the applied N had disappeared from the initial NH3 retention zone in the Ritzville soil in 8 to 13 weeks for both NH3 alone and NH3 + KN3. Results with the Naff soil for these applications were similar to results with the irrigated Ritzville soil. By contrast, N-Serve effectively suppressed nitrification under leaching and nonleaching conditions. For the Ritzville soil, total N uptake by the wheat (Triticum aestivum L.) crop for different rates of fertilizer application followed the order of NH3 + KN3 > NH3 + N-Serve > NH3 alone, but grain yields with NH3 + inhibitor were not different from yields with NH3 alone. For the Naff soil there was no N-uptake or grain-yield response to N rates, and thus no response to the inhibitors.

Coleman, M. D., J. G. Isebrands, et al. (2004). "Comparing soil carbon of short rotation poplar plantations with agricultural crops and woodlots in North Central United States." Environmental Management **33**: S299–308.

We collected soil samples from 27 study sites across North Central United States to compare the soil carbon of short rotation poplar plantations to adjacent agricultural crops and woodlots. Soil organic carbon (SOC) ranged from 20 to more than 160 Mg/ha across the sampled sites. Lowest SOC levels were found in uplands and highest levels in riparian soils. We attributed differences in bulk density and SOC among cover types to the inclusion of woodlot soils in the analysis. Paired comparison found few differences between poplar and agricultural crops. Sites with significant comparisons varied in magnitude and direction. Relatively greater SOC was often observed in poplar when native soil carbon was low, but there were important exceptions. Woodlots consistently contained greater SOC than the other crops, especially at depth. We observed little difference between paired poplar and switchgrass, both promising bioenergy crops. There was no evidence of changes in poplar SOC relative to adjacent agricultural soils when considered for stand ages up to 12 years. Highly variable native SOC levels and subtle changes over time make verification of soil carbon sequestration among land cover types difficult. In addition to soil carbon storage potential, it is therefore important to consider opportunities offered by long-term sequestration of carbon in solid wood products and carbon-offset through production of bioenergy crops. Furthermore, short rotation poplars and switchgrass offer additional carbon sequestration and other environmental benefits such as soil erosion control, runoff abatement, and wildlife habitat improvement.

Collins, H. P., P. E. Rasmussen, et al. (1992). "Crop rotation and residue management effects on soil carbon and microbial dynamics." <u>Soil Science Society of America Journal</u> **56**(3): 783–788.

> Understanding microbial dynamics is important in the development of new management strategies to reverse declining organic-matter content and fertility of agricultural soils. To determine the effects of crop rotation, crop residue management, and N fertilization, we measured changes in microbial biomass C and N and populations of several soil microbial groups in long-term (58-yr) plots under different winter wheat (Triticum aestivum L.) crop rotations. Wheat-fallow treatments included: wheat straw incorporated (5 Mg ha-1), no N fertilization; wheat straw incorporated, 90 kg N ha-1; wheat straw fall burned, no N fertilization; and wheat straw incorporated, 11 Mg barnyard manure ha-1. Annual-crop treatments were: continuous wheat, straw incorporated, 90 kg N ha-1; wheat-pea (Pisum sativum L.) rotation (25 yr), wheat and pea straw incorporated, 90 kg N ha-1 applied to wheat; and continuous grass pasture. Total soil and microbial biomass C and N contents were significantly greater in annual-crop than wheat-fallow rotations, except when manure was applied. Microbial biomass C in annual-crop and wheat-fallow rotations averaged 50 and 25%, respectively, of that in grass pasture. Residue management significantly influenced the level of microbial biomass C; for example, burning residues reduced microbial biomass to 57% of that in plots receiving barnyard manure. Microbial C represented 4.3, 2.8, and 2.2% and microbial N 5.3, 4.9, and 3.3% of total soil C and N under grass pasture, annual cropping, and wheat-fallow, respectively. Both microbial counts and microbial biomass were higher in early spring than other seasons. Annual cropping significantly reduced declines in soil organic matter and soil microbial biomass.

Conant, R. T. and K. H. Paustian (2002). "Potential soil carbon sequestration in overgrazed grassland ecosystems." <u>Global Biogeochemical Cycles</u> **16**(4): Art. No. 1143.

> Excessive grazing pressure is detrimental to plant productivity and may lead to declines in soil organic matter. Soil organic matter is an important source of plant nutrients and can enhance soil aggregation, limit soil erosion, and can also increase cation exchange and water holding capacities, and is, therefore, a key regulator of grassland ecosystem processes. Changes in grassland management which reverse the process of declining productivity can potentially lead to increased soil C. Thus, rehabilitation of areas degraded by overgrazing can potentially

sequester atmospheric C. We compiled data from the literature to evaluate the influence of grazing intensity on soil C. Based on data contained within these studies, we ascertained a positive linear relationship between potential C sequestration and mean annual precipitation which we extrapolated to estimate global C sequestration potential with rehabilitation of overgrazed grassland. The GLASOD and IGBP DISCover data sets were integrated to generate a map of overgrazed grassland area for each of four severity classes on each continent. Our regression model predicted losses of soil C with decreased grazing intensity in drier areas (precipitation less than 333 mm yr^{-1}), but substantial sequestration in wetter areas. Most (93%) C sequestration potential occurred in areas with MAP less than 1800 mm. Universal rehabilitation of overgrazed grasslands can sequester approximately 45 Tg C yr^{-1}, most of which can be achieved simply by cessation of overgrazing and implementation of moderate grazing intensity. Institutional level investments by governments may be required to sequester additional C.

Conant, R. T., K. H. Paustian, et al. (2005). "Nitrogen pools and fluxes in grassland soils sequestering carbon." Nutrient Cycling in Agroecosystems **71**(3): 239–248.

Carbon sequestration in agricultural, forest, and grassland soils has been promoted as a means by which substantial amounts of CO_2 may be removed from the atmosphere, but few studies have evaluated the associated impacts on changes in soil N or net global warming potential (GWP). The purpose of this research was to (1) review the literature to examine how changes in grassland management that affect soil C also impact soil N, (2) assess the impact of different types of grassland management on changes in soil N and rates of change, and (3) evaluate changes in N_2O fluxes from differently managed grassland ecosystems to assess net impacts on GWP. Soil C and N stocks either both increased or both decreased for most studies. Soil C and N sequestration were tightly linked, resulting in little change in C:N ratios with changes in management. Within grazing treatments N_2O made a minor contribution to GWP (0.1–4%), but increases in N_2O fluxes offset significant portions of C sequestration gains due to fertilization (10–125%) and conversion (average = 27%). Results from this work demonstrate that even when improved management practices result in considerable rates of C and N sequestration, changes in N_2O fluxes can offset a substantial portion of gains by C sequestration. Even for cases in which C sequestration rates are not entirely offset by increases in N_2O fluxes, small increases in N_2O fluxes can substantially reduce C sequestration benefits. Conversely, reduction of N_2O fluxes in grassland soils brought about by changes in management represents an opportunity to reduce the contribution of grasslands to net greenhouse gas forcing.

Conant, R. T., K. H. Paustian, et al. (2001). "Grassland management and conversion into grassland: Effects on soil carbon." Ecological Applications **11**(2): 343–355.

Grasslands are heavily relied upon for food and forage production. A key component for sustaining production in grassland ecosystems is the maintenance of soil organic matter (SOM), which can be strongly influenced by management. Many management techniques intended to increase forage production may potentially increase SOM, thus sequestering atmospheric carbon (C). Further, conversion from either cultivation or native vegetation into grassland could also sequester atmospheric carbon. We reviewed studies examining the influence of improved grassland management practices and conversion into grasslands on soil C worldwide to assess the potential for C sequestration. Results from 115 studies containing over 300 data points were

analyzed. Management improvements included fertilization (39%), improved grazing management (24%), conversion from cultivation (15%) and native vegetation (15%), sowing of legumes (4%) and grasses (2%), earthworm introduction (1%), and irrigation (1%). Soil C content and concentration increased with improved management in 74% of the studies, and mean soil C increased with all types of improvement. Carbon sequestration rates were highest during the first 40 yr after treatments began and tended to be greatest in the top 10 cm of soil. Impacts were greater in woodland and grassland biomes than in forest, desert, rain forest, or shrubland biomes. Conversion from cultivation, the introduction of earthworms, and irrigation resulted in the largest increases. Rates of C sequestration by type of improvement ranged from 0.11 to 3.04 Mg C·ha-1 yr-1, with a mean of 0.54 Mg C·ha-1·yr-1, and were highly influenced by biome type and climate. We conclude that grasslands can act as a significant carbon sink with the implementation of improved management.

Conant, R. T., J. Six, et al. (2003). "Land use effects on soil carbon fractions in the southeastern United States. I. Management-intensive versus extensive grazing." Biology and Fertility of Soils **38**(6): 386–392.

Changes in grassland management intended to increase productivity can lead to sequestration of substantial amounts of atmospheric C in soils. Management intensive grazing (MiG) can increase forage production in mesic pastures, but potential impacts on soil C have not been evaluated. We sampled four pastures (to 50 cm depth) in Virginia, USA, under MiG and neighboring pastures that were extensively grazed or hayed to evaluate impacts of grazing management on total soil organic C and N pools, and soil C fractions. Total organic soil C averaged 8.4 Mg C ha–1 (22%) greater under MiG; differences were significant at three of the four sites examined while total soil N was greater for two sites. Surface (0–10 cm) particulate organic matter (POM) C increased at two sites; POM C for the entire depth increment (0–50 cm) did not differ significantly between grazing treatments at any of the sites. Mineral-associated C was related to silt plus clay content and tended to be greater under MiG. Neither soil C:N ratios, POM C, or POM C:total C ratios were accurate indicators of differences in total soil C between grazing treatments, though differences in total soil C between treatments attributable to changes in POM C (43%) were larger than expected based on POM C as a percentage of total C (24.5%). Soil C sequestration rates, estimated by calculating total organic soil C differences between treatments assuming they arose from changing grazing management and can be achieved elsewhere) and dividing by duration of treatment, averaged 0.41 Mg C ha–1 year–1 across the four sites.

Coulter, J. A., E. D. Nafziger, et al. (2010). "Response of Bt and near-isoline corn hybrids to plant density." Agronomy Journal **102**(1): 103–111.

Transgenic Bt ( ) corn (L.) hybrids with resistance to corn rootworm (CRW; spp.) or European corn borer [ECB; (Hübner)] can have greater tolerance to water and nutrient stress, and thus may have higher optimum plant densities. Experiments were conducted following soybean [(L.) Merr.] over nine site-years in Illinois to determine whether the response to plant density for corn grain yield and net return to seed cost dif er among near-isoline hybrids with no insect resistance, Bt resistance to CRW, or Bt resistance to CRW plus ECB. Similar experiments were conducted over three site-years in Iowa following both soybean and corn for near-isoline hybrids with Bt resistance to ECB or ECB plus CRW. Larval CRW injury was low in Iowa and stalk lodging was minimal in all experiments. Across site-years in Illinois and in both crop sequences in Iowa, grain yield and net return to seed cost were not af ected by hybrid. Net return to seed cost within $2.50 ha–1 of the maximum occurred with densities of 76,300 to >98,600 plants ha–1 following soybean in Illinois, 87,100 to 93,400 plants ha–1 following soybean in Iowa, and 87,400 to 95,700 plants ha–1 following corn in Iowa. Yields within these optimum plant densities were 15.9, 16.1, and 15.4 Mg ha–1, respectively. When CRW and ECB are managed or are at low levels, optimum plant density is similar between hybrids with or without resistance to these pests.

CTIC (2008). National Crop Residue Management Survey: Conservation Tillage Data. West Lafayette, IN, Conservation Technology Information Center.

D'Haene, K., A. Van den Bossche, et al. (2008). "The effect of reduced tillage on nitrous oxide emissions of silt loam soils." Biology and Fertility of Soils **45**(2): 213–217.

The effect of reduced tillage (RT) on nitrous oxide (N2O) emissions of soils from fields with root crops under a temperate climate was studied. Three silt loam fields under RT agriculture were compared with their respective conventional tillage (CT) field with comparable crop rotation and manure application. Undisturbed soil samples taken in September 2005 and February 2006 were incubated under laboratory conditions for 10 days. The N2O emission of soils taken in September 2005 varied from 50 to 1,095 mu g N kg(-1) dry soil. The N2O emissions of soils from the RT fields taken in September 2005 were statistically (P 0.05) higher or comparable than the N2O emissions from their respective CT soil. The N2O emission of soils taken in February 2006 varied from 0 to 233 mu g N kg(-1) dry soil. The N2O emissions of soils from the RT fields taken in February 2006 tended to be higher than the N2O emissions from their respective CT soil. A positive and significant Pearson correlation of the N2O-N emissions with nitrate nitrogen (NO3--N) content in the soil was found (P 0.01). Leaving the straw on the field, a typical feature of RT, decreased NO3- -N content of the soil and reduced N2O emissions from RT soils.

Dale, P. J., B. Clarke, et al. (2002). "Potential for the environmental impact of transgenic crops." Nature Biotechnology **20**(6): 567–574.

In recent years, there has been increasing interest in how changes in agricultural practice associated with the introduction of particular genetically modified (GM) crops might indirectly impact the environment. There is also interest in any effects that might be associated with recombinant and novel combinations of DNA passing into the environment, and the possibility that they may be taken up by microorganisms or other live biological material. From the current state of knowledge, the impact of free DNA of transgenic origin is likely to be negligible compared with the large amount of total free DNA.We can find no compelling scientific arguments to demonstrate that GM crops are innately different from non-GM crops. The kinds of potential impacts of GM crops fall into classes familiar from the cultivation of non-GM crops (e.g., invasiveness, weediness, toxicity, or biodiversity). It is likely, however, that the novelty of some of the products of GM crop improvement will present new challenges and perhaps opportunities to manage particular crops in creative ways.

De Gryze, S., R. Catala, et al. (2009). Assessment of Greenhouse Gas Mitigation in California Agricultural Soils. Davis, CA, University of California, Davis. *Prepared for* Public Interest Energy Research (PIER) Program, California Energy Commission**:** 160.

Research has suggested that carbon can be captured through changes in farming practices, thereby helping California reach its greenhouse gas emission reduction goals as put forward under the California Global Warming Solutions Act of 2006, Assembly Bill 32, (Núñez, Chapter 488, Statutes of 2006). This study assessed the potential and economic feasibility of soil carbon sequestration and reduction of trace gas emissions in California agricultural soils. To accomplish this, the researchers integrated databases that include geographic data on environmental factors and land use data with ecosystem simulation models and economic analyses. The resulting assessment tool analyzes land use and management impacts on carbon stocks and associated greenhouse gas fluxes between California agricultural soils and the atmosphere. The study found that adjusting farming practices could reduce greenhouse gas emissions by about 0.5 to 3 megagrams of carbon dioxide equivalent per hectare per year. The variation in this number is mainly on the type of farming practice used. This potential increased in the following order: low nitrogen fertilizer input, reduced tillage, manure application, and winter cover cropping. Even higher potentials could be reached when these single management options are combined. However, the uncertainty around the carbon reduction potentials of a single field remains large. More research is needed to reduce this uncertainty.

De Gryze, S., M. Cullen, et al. (2010). Evaluation of the Opportunities for Generating Carbon Offsets from Soil Sequestration of Biochar. San Francisco, CA, Terra Global Capital.

Del Grosso, S. J., D. S. Ojima, et al. (2002). "Simulated effects of dryland cropping intensification on soil organic matter and greenhouse gas exchanges using the DAYCENT ecosystem model." Environmental Pollution **116**: S75–83.

We present evidence to show that DAYCENT can reliably simulate soil C levels, crop yields, and annual trace gas fluxes for various soils. DAYCENT was applied to compare the net greenhouse gas fluxes for soils under different land uses. To calculate net greenhouse gas flux we accounted for changes in soil organic C, the C equivalents of N2O emissions and CH4 uptake, and the CO2 costs of N fertilizer production. Model results and data show that dryland soils that are depleted of C due to conventional till winter wheat/fallow cropping can store C upon conversion to no till, by reducing the fallow period, or by reversion to native vegetation. However, model results suggest that dryland agricultural soils will still be net sources of greenhouse gases although the magnitude of the source can be significantly reduced and yields can be increased upon conversion to no till annual cropping.

Delgado, J. A., M. A. Dillon, et al. (2007). "A decade of advances in cover crops." Journal of Soil and Water Conservation **62**(5): 110A–117A.

Delgado, J. A. and A. R. Mosier (1996). "Mitigation alternatives to decrease nitrous oxides emissions and urea-nitrogen loss and their effect on methane flux." Journal of Environmental Quality **25**(5): 1105–1111.

Nitrous oxide (N2O) and methane (CH4) are greenhouse gases that are contributing to global warming potential. Nitrogen (N) fertilizer is one of the most important sources of anthropogenic N2O emissions. A field study was conducted to compare N-use efficiency and effect on N2O and CH4 flux, of urea, urea plus the nitrification inhibitor dicyandiamide (U + DCD), and a control release fertilizer, polyolefin coated urea (POCU) in irrigated spring barley (Hordeum vulgare L.) in northeastern Colorado. Each treatment received 90 kg urea-N ha(-1) and microplots labeled with N-15-fertilizer were established. Average N2O emissions were 4.5, 5.2, 6.9, and 8.2 g N ha(-1) d(-1) for control, U + DCD, POCU, and urea, respectively. During the initial 21 d after fertilization, N2O emissions were reduced by 82 and 71% in the U + DCD and POCU treatments, respectively, but continued release of N fertilizer from POCU maintained higher N2O emissions through the remainder of the growing season. No treatment effect on CH4 oxidation in soils was observed. Fertilizer N-15 found 50 to 110 cm below the soil surface was lower in the POCU and U + DCD treatments. At harvest, recovery of N-15-fertilizer in the plant-soil system was 98, 90, and 85% from POCU, urea, and U + DCD, respectively. Grain yield was 2.2, 2.5, and 2.7 Mg ha(-1) for POCU, urea, and U + DCD, respectively. Dicyandiamide and POCU showed the potential to be used as mitigation alternatives to decrease N2O emissions from N fertilizer and movement of N out of the root zone, but N release from POCU does need to be formulated to better match crop growth demands.

Dell, C. J., P. R. Salon, et al. (2008). "No-till and cover crops impacts on soil carbon and associated properties on Pennsylvania dairy farms." Journal of Soil and Water Conservation **63**(3): 136–142.

No-till (NT) crop production is expected to sequester soil C, but little data is available for dairy forage systems. Our objective was to quantify impacts of NT and rye (Secale cereale L.) cover crops on soil C and N pools and associated soil properties on Pennsylvania dairies. Samples were collected from seven fields following corn harvest. The NT fields had approximately 50% more C and N in particulate and mineral-associated pools in the upper 5 cm (2 in) compared to conventional tillage, but C and N accumulations below 5 cm were similar. This suggests a C sequestration rate of ~0.5 Mg ha–1 y–1 (~0.2 tn ac–1 yr –1) in the 8 to 13 years NT has been used. Soil aggregate stability and cation exchange capacity were proportional to C pool sizes. Rye cover crops had no clear impact. Findings show that expected increases in C sequestration and soil quality with NT can be achieved in dairy forage systems.

Denier van der Gon, H. A. C., M. J. Kropff, et al. (2002). "Optimizing grain yields reduces CH_4 emissions from rice paddy fields." Proceedings of the National Academy of Sciences of the United States of America **99**(19): 12021–12024.

Microbial production in anoxic wetland rice soils is a major source of atmospheric CH4, the most important non-CO2 greenhouse gas. Much higher CH4 emissions from well managed irrigated rice fields in the wet than in the dry season could not be explained by seasonal differences in temperature. We hypothesized that high CH4 emissions in the wet season are caused by low grain to biomass ratios. In a screenhouse experiment, removing spikelets to reduce the plants' capacity to store photosynthetically fixed C in grains increased CH4 emissions, presumably via extra C inputs to the soil. Unfavorable conditions for spikelet formation in the wet season may similarly explain high methane emissions. The observed relationship between reduced grain filling and CH4 emission provides opportunities to mitigate CH4 emissions by optimizing rice productivity.

DeRamus, H. A., T. C. Clement, et al. (2003). "Methane emissions of beef cattle on forages: Efficiency of grazing management systems." Journal of Environmental Quality **32**(1): 269–277.

> Fermentation in the rumen of cattle produces methane (CH4)Methane may play a role in global warming scenarios. The linking of grazing management strategies to more efficient beef production while reducing the CH4 emitted by beef cattle is important. The sulfur hexalluoride (SF6) tracer technique was used to determine the effects of best management practices (BMP) grazing compared with continuous grazing On CH4 production in several Louisiana forages during 1996-1998. Cows and heifers (Bos taurus) grazed common bermudagrass [Cynodon dactylon (L.) Pers.], babiagrass (Paspalum notatum Flugge), and ryegrass (Lolium multiflorum Lam.) pastures and were wintered on bahiagrass hay with supplements of protein molasses blocks (PMB), cottonseed meal and corn (CSMC), urea and corn (URC), or limited ryegrass grazing (LRG). Daily CH4 emissions were between 89 and 180 g d(-1) for young growing heifers and 165 to 294 g d(-1) for mature Simbrah cows. Heifers on "ad lib" ryegrass in March and April produced only one-tenth the CH4 per kg of gain as heifers on LRG of 1 h. Using BMP significantly reduced the emission of CH4 per unit of animal weight gain. Management-intensive grazing (MIG) is a BMP that offers the potential for more efficient utilization of grazed forage crops via controlled rotational grazing and more efficient conversion of forage into meat and milk. Projected CH4 annual emissions in cows reflect a 22% reduction from BMP when compared with continuous grazing in this study. With the BMP application of MIG, less methane was produced per kilogram of beef gain.

Derner, J. D., R. H. Hart, et al. (2008). "Long-term cattle gain responses to stocking rate and grazing systems in northern mixed-grass prairie." Livestock Science **117**(1): 60–69.

> The effects of stocking rate and grazing system on gains of yearling beef cattle grazing rangelands have largely been addressed in short-term (<10 years) studies, and often stocking rates are confounded within grazing systems with higher stocking rates for short-duration rotational grazing systems compared to season-long grazing. A grazing system (season-long and short-duration rotational grazing) x stocking rate (light: 16 steers/80 ha, 18.0 animal unit days/ha; moderate: 4 steers/12 ha, 30.1 animal unit days/ ha, and heavy: 4 steers/9 ha, 40.1 animal unit days/ha) study was initiated in 1982 on northern mixed-grass prairie. Here, we report on the final 16 years (1991-2006) for yearling beef cattle gains, Average daily gains (kg/head/day) across all years with season-long grazing decreased with increasing stocking rate and grazing pressure. Heavy stocking rates reduced average daily gain by 16% and 12% compared to light and moderate stocking rates, respectively. In contrast to average daily gain, beef production (kg/ha) increased with increasing stocking rate and grazing pressure. Cattle gains were reduced by 6% with short-duration rotation compared to season-long grazing over the study period, with differences between systems observed in years with average, but not dry or wet, spring (April+May+June) precipitation. Grazing season gains (kg/head) and beef production both exhibited significant increasing hyperbolic relationships with spring precipitation, with the percentage of variation explained by spring precipitation substantially higher (62-83%) for beef production compared to grazing season gains (32-45%). The influence of spring precipitation on cattle gains suggests that incorporation of these relationships into modeling efforts for strategic planning and risk assessment will assist land managers in better matching forage and animal resources for greater sustainability in this highly variable environment.

Derner, J. D. and G. E. Schuman (2007). "Carbon sequestration and rangelands: A synthesis of land management and precipitation effects." Journal of Soil and Water Conservation **62**(2): 77–85.

Management of rangelands can aid in the mitigation of rising atmospheric carbon dioxide concentrations via carbon storage in biomass and soil organic matter, a process termed carbon sequestration. Here we provide a review of current knowledge on the effects of land management practices (grazing, nitrogen inputs, and restoration) and precipitation on carbon sequestration in rangelands. Although there was no statistical relationship between change in soil carbon with longevity of the grazing management practice in native rangelands of the North American Great Plains, the general trend seems to suggest a decrease in carbon sequestration with longevity of the grazing management practice across stocking rates. The relationship of carbon sequestration to mean annual precipitation is negative for both the 0 to 10 cm (0 to 3.9 in) and 0 to 30 cm (0 to 11.8 in) soil depths across stocking rates. The threshold from positive to negative carbon change occurs at approximately 440 mm (17.3 in) of precipitation for the 0 to 10 cm soil depth and at 600 mm (23.6 in) for the 0 to 30 cm soil depth. We acknowledge that largely unexplored is the arena of management-environment interactions needed to increase our understanding of climate-plant-soil-microbial interactions as factors affecting nutrient cycling. Continued refinement of estimates of terrestrial carbon storage in rangelands will assist in the development of greenhouse gas emissions and carbon credit marketing policies, as well as potentially modifying government natural resource conservation programs to emphasize land management practices that increase carbon sequestration.

Desjardins, R. L., E. Pattey, et al. (2010). "Multiscale estimates of N_2O emissions from agricultural lands [Special Issue]." Agricultural and Forest Meteorology **150**(6): 817–824.

Nitrous oxide (N2O) emissions are a large proportion of the agriculture sector's contribution to the greenhouse gas inventory of most developed countries. The spatial and temporal variability of N2O emissions from agricultural soils has long been considered the main factor limiting our ability to estimate N2O emissions, particularly the emissions associated with the spring snowmelt period. Tower and aircraft-based flux measurement systems and a process-based model were used to quantify N2O emissions for four years (2000, 2001, 2003 and 2004) in an agricultural area of eastern Canada, near Ottawa, where a corn-soybean crop rotation dominates. A tower-based system, which relies on the flux gradient technique, provided diurnal N2O emissions at a field scale. An aircraft-based system, which relies on the relaxed eddy accumulation technique, provided N2O emissions for two similar agricultural regions and the DeNitrification and DeComposition (DNDC) model was used to estimate daily N2O emissions at a regional scale. In most cases, aircraft-based N2O emissions measurements were comparable for the two agricultural regions. Corresponding tower-based measurements which were collected over a field in the Ottawa area showed similar emission patterns to the aircraft-based measurements but in some cases the tower-based emissionswere larger, as expected. This is because the footprint of aircraft-based measurements always incorporated a significant amount of crops such as soybean and other types of vegetation which do not receive additional nitrogen fertilization as well as waterlogged areas that do not emit N2O.While in three of the four years, the tower-basedmeasurements weremade over a tile drained fieldwhere nitrogen fertilizer had been applied the previous year. The N2O emissions patterns after planting were also similar for both aircraft and tower-based systems, but again they were slightly larger for the tower-based system. Aircraft-based N2O flux measurements are also compared to the N2O emissions obtained using the most recent version of the process-based model

DNDC. Tests showed that DNDC gave comparable N2O emissions estimates for the measurement period as a whole, but was not always able to correctly predict the timing of peak emissions.

Desjardins, R. L., W. Smith, et al. (2005). "Management strategies to sequester carbon in agricultural soils and to mitigate greenhouse gas emissions." Climatic Change **70**(1): 283–297.

Carbon sequestration in agricultural soils is frequently promoted as a practical solution for slowing down the rate of increase of CO2 in the atmosphere. Consequently, there is a need to improve our understanding of how land management practices may affect the net removal of greenhouse gases (GHG) from the atmosphere. In this paper we examine the role of agriculture in influencing the GHG budget and briefly discuss the potential for carbon mitigation by agriculture. We also examine the opportunities that exist for increasing soil C sequestration using management practices such as reduced tillage, reduced frequency of summer fallowing, introduction of forage crops into crop rotations, conversion of cropland to grassland and nutrient addition via fertilization. In order to provide information on the impact of such management practices on the net GHG budget we ran simulations using CENTURY (a C model) and DNDC (a N model) for five locations across Canada, for a 30-yr time period. These simulations provide information on the potential trade-off between C sequestration and increased N2O emissions. Our model output suggests that conversion of cropland to grassland will result in the largest reduction in net GHG emissions, while nutrient additions via fertilizers will result in a small increase in GHG emissions. Simulations with the CENTURY model also indicated that favorable growing conditions during the last 15 yr could account for an increase of 6% in the soil C at a site in Lethbridge, Alberta.

Dixon, R. K., J. K. Winjum, et al. (1994). "Integrated land-use systems: Assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration." Climatic Change **27**(1): 71–92.

Degraded or sub-standard soils and marginal lands occupy a significant proportion of boreal, temperate and tropical biomes. Management of these lands with a wide range of existing, site-specific, integrated, agroforest systems represents a significant global opportunity to reduce the accumulation of greenhouse gases in the atmosphere. Establishment of extensive agricultural, agroforest, and alternative land-use systems on marginal or degraded lands could sequester 0.82-2.2 Pg carbon (C) per year, globally, over a 50-year time-frame. Moreover, slowing soil degradation by alternative grassland management and by impeding desertification could conserve up to 0.5-1.5 Pg C annually, A global analysis of biologic and economic data from 94 nations representing diverse climatic and edaphic conditions reveals a range of integrated land-use systems which could be used to establish and manage vegetation on marginal or degraded lands. Promising land-use systems and practices identified to conserve and temporarily store C include agroforestry systems, fuelwood and fiber plantations, bioreserves, intercropping systems, and shelterbelts/windbreaks. For example, successful establishment of low-intensity agroforestry systems can store up to 70 Mg C/ha in boreal, temperate and tropical ecoregions. The mean initial cost of soil rehabilitation and revegetation ranges from $500-3,000/ha for the 94 nations surveyed. Natural regeneration of woody vegetation or agro-afforestation

establishment costs were less than $1000/ha in temperate and tropical regions. The costs of C sequestration in soil and vegetation systems range from $1-69/Mg C, which compares favorably with other options to reduce greenhouse gas emissions to the atmosphere. Although agroforestry system projects were recently established to conserve and sequester C in Guatemala and Malaysia, constraints to wide-spread implementation include social conditions (demographic factors, land tenure issues, market conditions, lack of infrastructure), economic obstacles (difficulty of demonstrating benefits of alternative systems, capital requirements, lack of financial incentives) and, ecologic considerations (limited knowledge of impacts and sustainability of some systems).

Dolan, M. S., C. E. Clapp, et al. (2006). "Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management." Soil & Tillage Research **89**(2): 221–231.

Soil organic carbon (SOC) and nitrogen (N) are directly influenced by tillage, residue return and N fertilization management practices. Soil samples for SOC and N analyses, obtained from a 23-year field experiment, provided an assessment of near-equilibrium SOC and N conditions. Crops included corn (Zea mays L.) and soybean [Glycine max L. (Merrill)]. Treatments of conventional and conservation tillage, residue stover (returned or harvested) and two N fertilization rates were imposed on a Waukegan silt loam (fine-silty over skeletal, mixed, superactive, mesic Typic Hapludoll) at Rosemount, MN. The surface (0-20 cm) soils with no-tillage (NT) had greater than 30% more SOC and N than moldboard plow (MB) and chisel plow (CH) tillage treatments. The trend was reversed at 20-25 cm soil depths, where significantly more SOC and N were found in MB treatments (26 and 1.5 Mg SOC and N ha-1, respectively) than with NT (13 and 1.2 Mg SOC and N ha-1, respectively), possibly due to residues buried by inversion. The summation of soil SOC over depth to 50 cm did not vary among tillage treatments; N by summation was higher in NT than MB treatments. Returned residue plots generally stored more SOC and N than in plots where residue was harvested. Nitrogen fertilization generally did not influence SOC or N at most soil depths. These results have significant implications on how specific management practices maximize SOC storage and minimize potential N losses. Our results further suggest different sampling protocols may lead to different and confusing conclusions regarding the impact of tillage systems on C sequestration.

Donigian, A. S., A. S. Patwardhan, et al. (1995). Modeling the impacts of agricultural management practices on soil carbon in the central U.S. Soil Management and the Greenhouse Effect. R. Lal, J. Kimble, E. Levine and B. A. Stewart. Chelsea, Michigan, USA, Lewis Publishers.

Doran, J. W., E. T. Elliott, et al. (1998). "Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management." Soil & Tillage Research **49**(1–2): 3–18.

Two experiments were established in 1969 and 1970 near Sidney, NE, to determine the effect of moldboard plow (plow), sub-tillage (sub-till), and no-tillage (no-till) fallow management on soil properties, biological activities, and carbon and nitrogen cycling. One experiment was on land which had been broken from sod in 1920, seeded to crested wheatgrass [Agropyron cristatum (L.) Gaertn.] from 1957 to 1967, and cultivated for wheat again in 1967 (Previously Cultivated site). The second experiment was established on land that was in native mixed prairie sod until 1969 (Native Sod site), and compared the three tillage management practices listed above in a

winter wheat-fallow system as well as replicated plots remaining in sod. Soil sampling done 10-12 years after these experiments were initiated, indicated that the biological environment near the soil surface (0-30 cm) with no-till was often cooler and wetter than that with conventional tillage management practices, especially moldboard plowing. Biological activity and organic C and N reserves were concentrated nearer the soil surface (0-7.6 cm) with no-tillage, resulting in greater potential for tie-up of plant available N in organic forms. However, regardless of tillage practice with wheat-fallow management at either site, long-term (22-27 years) losses of soil organic C from surface soil (0-30 cm) ranged from 12 to 32% (320-530 kg C ha(-1) year(-1)), respectively, for no-till and plowing. These soil C losses were closely approximated by losses measured to a depth of 122 cm, indicating that under the cropping, tillage, and climatic conditions of this study, soil C changes were adequately monitored by sampling to a depth of 30 cm within which most C loss occurs. No-till management maintains a protective surface cover of residue and partially decomposed materials near the soil surface. However, the decline in soil organic matter, and associated degradation in soil quality, will likely only be slowed by increasing C inputs to soil through use of a more intensive cropping system which increases the time of cropping and reduces the time in fallow.

Drury, C. F., W. D. Reynolds, et al. (2006). "Emissions of nitrous oxide and carbon dioxide: Influence of tillage type and nitrogen placement depth." Soil Science Society of America Journal **70**(2): 570–581.

Innovative management practices are required to increase the efficiency of N fertilizer usage and to reduce nitrous oxide (N2O) and carbon dioxide (CO2) emissions from agricultural soils. The objectives of this study were to evaluate the feasibility of using conservation tillage and N fertilizer placement depth to reduce N2O and CO2 emissions associated with corn (Zea mays L.) production on clay loam soils in Eastern Canada. A 3-yr field study was established on a wheat (Triticum aestivum L.)-corn-soybean [Glycine max (L.) Merr.] rotation with each phase of the rotation present every year. Investigations were focused on the corn phase of the rotation. The tillage treatments following winter wheat included fall moldboard plow tillage (15 cm depth), fall zone-tillage (21 cm width, 15 cm depth), and no-tillage. The N placement treatments were "shallow" placement of sidedress N (2-cm depth) and "deep" placement of sidedress N (10-cm depth). Nitrous oxide emissions were measured 53 times and CO2 emissions were measured 43 times over three growing seasons using field-based sampling chambers. There was a significant tillage and N placement interaction on N2O emissions. Averaged over all three tillage systems and site-years, N2O emissions from shallow N placement (2.83 kg N ha-1 yr-1) were 26% lower than deep N placement (3.83 kg N ha-1 yr-1). The N2O emissions were similar among the tillage treatments when N was placed in the soil at a shallow depth. However, when N was placed deeper in the soil (10 cm), the 3-yr average N2O emissions from zone-tillage (2.98 kg N ha-1 yr-1) were 20% lower than from no-tillage (3.71 kg N ha-1 yr-1) and 38% lower than those from moldboard plow tillage (4.81 kg N ha-1 yr-1). Tillage type and N placement depth did not affect CO2 emissions (overall average = 5.80 Mg C ha-1 yr-1). Hence, zone-tillage and shallow N placement depth reduced N2O emissions without affecting CO2 emissions.

Duvick, D. N. (2005). "The contribution of breeding to yield advances in maize (*Zea mays* L.)." Advances in Agronomy **86**: 83–145.

Maize (Zea mays L.) yields have risen continually wherever hybrid maize has been adopted, starting in the U.S. corn belt in the early 1930s. Plant breeding and improved management practices have produced this gain jointly. On average, about 50% of the increase is due to management and 50% to breeding. The two tools interact so closely that neither of them could have produced such progress alone. However, genetic gains may have to bear a larger share of the load in future years. Hybrid traits have changed over the years. Trait changes that increase resistance to a wide variety of biotic and abiotic stresses (e.g., drought tolerance) are the most numerous, but morphological and physiological changes that promote efficiency in growth, development, and partitioning (e.g., smaller tassels) are also recorded. Some traits have not changed over the years because breeders have intended to hold them constant (e.g., grain maturity date in U.S. corn belt). In other instances, they have not changed, despite breeders' intention to change them (e.g., harvest index). Although breeders have always selected for high yield, the need to Select Simultaneously for overall dependability has been a driving force in the selection of hybrids with increasingly greater stress tolerance over the years. Newer hybrids yield more than their predecessors in unfavorable as well as favorable growing conditions. Improvement in the ability of the maize plant to overcome both large and small stress bottlenecks, rather than improvement in primary productivity, has been the primary driving force of higher yielding ability of newer hybrid.

Eagle, A. J., J. A. Bird, et al. (2000). "Rice yield and nitrogen utilization efficiency under alternative straw management practices." Agronomy Journal **92**(6): 1096–1103.

Nitrogen fertility is an important component of rice (Oryza sativa L.) cultivation systems, especially where air and soil quality issues have prompted a search for alternatives to rice straw burning. This study examined the effects of different rice straw management practices and winter flooding on yield, N uptake, and N use efficiency. The experiment, established on two sites in California, was initiated in 1993 on a Sodic Endoaquert near Maxwell and in 1994 on a Xeric Duraquert near Biggs. Main plot treatments were winter flooding and no winter flooding, and four straw management practices-straw burned, incorporated, relied, and baled/removed-were subplot treatments. Zero N fertilizer microplots were established yearly in each plot. At currently recommended N fertilization levels, where other nutrients were sufficient, grain yield was unaffected by alternative straw management or winter flooding. However, in the third year after experiment initiation, the grain yield in zero N fertilizer plots was greater where straw was retained, i.e., incorporated and rolled. In Years 3 through 5 at Maxwell, straw retention increased N uptake by rice by an average of 19 kg N ha(-1) where no N fertilizer was applied and by It kg N ha(-1) at recommended rate of N fertilizer application. Winter flooding further increased crop N uptake when straw was retained. The additional available soil N from straw led to increased N uptake without corresponding increased grain yield, which decreased N use efficiency and necessitates the re-evaluation of N fertilizer application rates.

Edgerton, M. D. (2009). "Increasing crop productivity to meet global needs for feed, food, and fuel." Plant physiology **149**(1): 7–13.

from text...In the United States, breeders, agronomists, and farmers have a documented history of increasing yield. U.S. average corn yields have increased from approximately 1.6 tonnes/ha in the first third of the 20th century to today’s approximately 9.5 tonnes/ha. This dramatic yield improvement is due to the development and widespread use of new farming technologies such as hybrid corn, synthetic fertilizers, and farm machinery. The introduction of biotechnology traits and development of new breeding methodology using DNA-based markers are further

improving yields. Outside the United States, similar farming practices have been adopted in some agricultural nations, but in many major grain producing countries, yields still lag well behind world averages. By continuing to develop new farming technologies and deploying of them on a global basis, demand for feed, fuel, and food can be met without the commitment of large land areas to new production.

Elder, J. W. and R. Lal (2008). "Tillage effects on gaseous emissions from an intensively farmed organic soil in North Central Ohio." Soil & Tillage Research **98**(1): 45–55.

As in other drained, intensively cultivated Histosols of the world, soil subsidence is a growing concern of vegetable farmers in the muck crops region of North Central, Ohio. Subsidence in organic soils is caused primarily by aerobic degradation of soil organic matter (SOM), which in turn makes available large quantities of once bound C and N. Upon drainage and cultivation, soil C and N dynamics shift drastically. Organic soils transition from CO2 and organic N sinks, to persistent sources, whereas CH4 uptake capacity increases. Therefore, this study was conducted to assess the short-term (within the first year) impact of conversion of intensively tilled organic soils to no-till management. The specific objectives of this study were to: (i) compare soil moisture content, soil temperature, and greenhouse gas (GHG) emission rates from moldboard/disking (MB), no-till (NT), and bare (B) treatments in cultivated organic soils, and (ii) estimate the rate of subsidence associated with these tillage practices. Over the year, soil moisture content (SMC) was significantly higher in MB (0.90 kg kg-1) than B (0.84 kg kg-1) treatments; however NT (0.87 kg kg-1) was not significantly different from either MB or B treatments. Mean annual temperatures at 5 cm depth were significantly higher in B (16.9 °C) compared to MB (16.2 °C) and NT (15.9 °C) treatments The CO2 emissions were not significantly different among treatments, while N2O emissions were significantly higher from MB (96.9 kg N2O-N ha-1 yr-1) than NT (35.8 kg N2O-N ha-1 yr-1) plots. Both CH4 uptake and CH4 emission exhibited low annual flux in all treatments.

Entry, J. A., R. E. Sojka, et al. (2002). "Management of irrigated agriculture to increase organic carbon storage in soils." Soil Science Society of America Journal **66**(6): 1957–1964.

Increasing the amount of C in soils may be one method to reduce the concentration of CO2 in the atmosphere. We measured organic C stored in southern Idaho soild having long term cropping histories that supported native sagebrush vegetation (NSB), irrigated mold-board plowed crops (IMP), irrigated conservation-chisel-tilled crops (ICT), and irrigated pasture systems (IP). The CO2 emitted as a result of fertilizer production, farm operations, and CO2 lost via dissolved carbonate in irrigation water, over a 30-yr period was included. Net organic C in ecosystems decreased in the order IP>ICT>NSB>IMP. In this study if NSB were converted to IMP, 0.15 g C m-2 would be emitted to the atmosphere, but if convered to IP 3.56 g C m-2 could be sequestered. If IMP land were converted to ICT, 0.95 g C m-2 could be sequestered in soil and if converted to IP 3.71 g C m-2 could be sequestered. There are 2.6 x 10 ^8 ha of land worldwide presently irrigated. If irrigated ariculture were expanded 10% and the same amount of rainfed land were converted back to native grassland, an increase of 3.4 x 10^9 Mg C (5.9% of the total C emitted in the next 30 yr) could potentially be sequestered. The total projected release of CO2 is 5.7x 10^10 Mg C worldwide during the next 30 yr/ Converting rainfed agriculture back to native vegetation while modestly increasing areas in irrigated agriculture could have a significant impact on CO_2 atmospheric concentrations while maintaining or increasing food production.

Euliss, N. H., Jr., R. A. Gleason, et al. (2006). "North American prairie wetlands are important nonforested land-based carbon storage sites." Science of the Total Environment **361**(1–3): 179–188.

We evaluated the potential of prairie wetlands in North America as carbon sinks. Agricultural conversion has resulted in the average loss of 10.1 Mg ha(-1) of soil organic carbon on over 16 million ha of wetlands in this region. Wetland restoration has potential to sequester 378 Tg of organic carbon over a 10-year period. Wetlands can sequester over twice the organic carbon as no-till cropland on only about 17% of the total land area in the region. We estimate that wetland restoration has potential to offset 2.4% of the annual fossil CO_2 emission reported for North America in 1990.

Ewers, R. M., J. P. W. Scharlemann, et al. (2009). "Do increases in agricultural yield spare land for nature?" Global Change Biology **15**(7): 1716–1726.

Feeding a rapidly expanding human population will require a large increase in the supply of agricultural products during the coming decades. This may lead to the transformation of many landscapes from natural vegetation cover to agricultural land use, unless increases in crop yields reduce the need for new farmland. Here, we assess the evidence that past increases in agricultural yield have spared land for wild nature.We investigated the relationship between the change in the combined energy yield of the 23 most energetically important food crops over the period 1979–1999 and the change in per capita cropland area for 124 countries over the same period. Per capita area of the 23 staple crops tended to decrease in developing countries where large yield increases occurred. However, this was counteracted by a tendency for the area used to grow crops other than staples to increase in the countries where staple crop yields increased. There

remained a weak tendency in developing countries for the per capita area of all cropland to decline as staple crop yield increased, a pattern that was most evident in developing countries with the highest per capita food supplies. In developed countries, there was no evidence that higher staple crop yields were associated with decreases in per capita cropland area. This may be because high agricultural subsidies in developed countries override any land-sparing pattern that might otherwise occur. Declines in the area of natural forest were smaller in countries where the yield of staple crops increased most, when the negative effects of human population increases on forest area were controlled for. Our results show that land-sparing is a weak process that occurs under a limited set of circumstances, but that it can have positive outcomes for the conservation of wild nature.

Falloon, P., D. S. Powlson, et al. (2004). "Managing field margins for biodiversity and carbon sequestration: a Great Britain case study." Soil Use and Management **20**: 240–247.

Field margins are a valuable resource in the farmed landscape, providing numerous environmental benefits. We present a preliminary analysis of the carbon mitigation potential of different field margin management options for Great Britain, calculated using data from long-term experiments and literature estimates. The carbon sequestration potential of the individual options investigated here varies from 0.1 to 2.4% of 1990 UK CO2-C emissions, or 0.7±20% of the Quantified Emission Limitation Reduction Commitment (QELRC). The scenarios investigated covered three possible margin widths and options for the management of margins at each width (viz. grass strips, hedgerows and tree strips). Scenarios involving margin widths of 2, 6 or 20m would require approximately 2.3, 6.7 or 21.3% of the total arable area of Great Britain, respectively. Scenarios including tree strips offered the greatest potential for carbon sequestration, since large amounts would be accumulated in above-ground biomass in addition to that in soil. We also accounted for the possible impacts of changed land management on trace gas fluxes, which indicated that any scenario involving a change from arable to grass strip, hedgerow or tree strip would significantly reduce N_2O emissions, and thus further increase carbon mitigation potential. There would also be considerable potential for including the scenarios investigated here with other strategies for the alternative management of UK arable land to identify optimal combinations. We assumed that it would take 50±100 years for soil carbon to reach a new equilibrium following a land use change. More detailed analyses need to be conducted to include environmental benefits, socioeconomic factors and the full system carbon balance.

FAO (2006). World Agriculture: towards 2030/2050 – Prospects for food, nutrition, agriculture and major commodity groups. Rome, Food and Agriculture Organization of the United Nations.

from intro: This is an updated version, with extension of projections to 2050, of two of the key chapters (Chapters 2 and 3) of the study World Agriculture: Towards 2015/30 completed in 2002 and published in 2003 (Bruinsma, 2003). Chapter 2 presents prospective developments in food demand and consumption and possible implications for nutrition and undernourishment. Chapter 3 deals with production, consumption and trade, in terms of the main commodity sectors and aggregate agriculture.

Farahbakhshazad, N., D. L. Dinnes, et al. (2008). "Modeling biogeochemical impacts of alternative management practices for a row-crop field in Iowa." Agriculture, Ecosystems & Environment **123**: 30–48.

The management of contemporary agriculture is rapidly shifting from single-goal to multi-goal strategies. The bottleneck of implementing the strategies is the capacity of predicting the simultaneous impacts of change in management practices on agricultural production, soil and water resources and environmental safety. Process-based models provide an opportunity to quantify the impacts of farm management options on various pools and fluxes of carbon (C) and nitrogen (N) in agroecosystems. The denitrification–decomposition or DNDC model was recently modified for simulating N cycling for the U.S. Midwestern agricultural systems. This paper reports a continuous effort on applying the model for estimating the impacts of alternative management practices (e.g., no-till, cover crop, change in fertilizer rate or timing) on agroecosystems in the Midwestern U.S. A typical row-crop field in Iowa was selected for the sensitivity tests. The modeled results were assessed with a focus on four major indicators of agro-ecosystems, namely crop yield, soil organic carbon (SOC) sequestration, nitrate–N leaching loss and nitrous oxide (N2O) emissions. The results indicated that no-till practice significantly increased SOC storage and reduced nitrate–N leaching rate, but slightly decreased crop yield and increased N2O emissions. By modifying the methods of fertilizer application in conjunction with the no-till practice, the disadvantages of no-till could be overcome. For example, increasing the fertilizing depth and using a nitrification inhibitor could substantially reduce N2O emissions and increase crop yield under the no-till conditions. This study revealed the complexity of impacts of the alternative farming management practices across different climate conditions, soil properties and management regimes. Process-based models can play an important role in quantifying the comprehensive effects of management alternatives on agricultural production and the environment.

Farooq, M., N. Kobayashi, et al. (2009). "Strategies for producing more rice with less water." Advances in Agronomy **101**: 351–388.

Fisher, M. J., I. M. Rao, et al. (1994). "Carbon storage by introduced deep-rooted grasses in the South American savannas." Nature **371**(6494): 236–238.

ESTIMATES of the global carbon dioxide balance have identified a substantial 'missing sink' of 0.4-4.3 Gt per year(1). It has been suggested that much of this may reside in the terrestrial biosphere(2). Here we present an analysis of the carbon stored by pastures based on deep-rooted grasses which have been introduced in the South American savannas. Although the deep-rooted grasses were chosen principally for agricultural reasons(3), we find that they also sequester significant amounts of organic carbon deep in the soil. If our study sites are representative of similar pastures throughout South America, this process could account for the sequestration of 100-507 Mt carbon per year-a substantial part of the 'missing sink'. Thus, although some land-use changes(4) (such as burning tropical rainforests) contribute to the atmospheric CO2 burden, we conclude that the introduced pastures studied here help to offset the effect of anthropogenic CO2 emissions.

Fitzgerald, G. J., K. M. Scow, et al. (2000). "Fallow season straw and water management effects on methane emissions in California rice." Global Biogeochemical Cycles **14**(3): 767–776.

In response to legislative mandate to reduce postharvest straw burning and environmental concerns to restore wetland habitat for Pacific fly-way waterfowl, California rice growers are incorporating straw into soil and flooding rice fields in winter. These changes were hypothesized to alter soil carbon cycling pathways across the region. The principal objective of this study was to determine how various winter fallowed straw and water management changes would affect year-round methane emissions. Main plots were winter flood and nonflood, and subplots had straw treatments: burned, soil incorporated, or rolled (partially soil incorporated). Results showed the principal factor controlling methane emissions was the interaction of flooding and straw amendments. The presence of either water or straw alone led to low emissions. Winter emissions accounted for 50% of annual totals in straw-amended treatments despite lower temperatures and the presence of plants in summer. Summer emissions were significantly influenced by winter straw amendments but not by winter flood. Postdrain peaks after winter drain accounted for 10-13% of annual emissions in treatments with amended straw. Although rolled and incorporated treatments had similar straw inputs, methane fluxes from rolled treatments were higher than from incorporated treatments. Measurements of methane should be conducted year-round to capture fallow and postdrain fluxes and improve global emission estimates. Regional emission estimates showed that 2.6 times more methane was emitted after flooding plus incorporation was implemented than before the legislative mandate was enacted.

Flint-Garcia, S. A., L. L. Darrah, et al. (2003). "Phenotypic versus marker-assisted selection for stalk strength and second-generation European corn borer resistance in maize." Theoretical and Applied Genetics **107**(7): 1331–1336.

> Maize (Zea mays L.) stalk lodging is breakage of the stalk at or below the ear, which may result in loss of the ear at harvest. Stalk lodging is often intensified by the stalk tunneling action of the second-generation of the European corn borer (2-ECB) [Ostrinia nubilalis (Hübner)]. Rind penetrometer resistance (RPR) has been used to measure stalk strength and improve stalk lodging resistance, and quantitative trait loci (QTL) have been identified for both RPR and 2-ECB damage. Phenotypic recurrent selection (PS) increases the frequency of favorable alleles over cycles of selection. Several studies have indicated that marker-assisted selection (MAS) is also a potentially valuable selection tool. The objective of this study was to compare the efficiency of PS versus MAS for RPR and 2-ECB. Marker-assisted selection for high and low RPR was effective in the three populations studied. Phenotypic selection for both high and low RPR was more effective than MAS in two of the populations. However, in a third population, MAS for high RPR using QTL effects from the same population was more effective than PS, and using QTL effects from a separate population was just as effective as PS. Marker-assisted selection for resistance and susceptibility to 2-ECB using QTL effects from the same population was effective in increasing susceptibility, but not in increasing resistance. Marker-assisted selection using QTL effects from a separate population was effective in both directions of selection. Thus, MAS was effective in selecting for both resistance and susceptibility to 2-ECB. These results demonstrated that MAS can be an effective selection tool for both RPR and 2-ECB resistance. These results also validate the locations and effects of QTL for RPR and 2-ECB resistance identified in earlier studies.

Follett, R. F. (2001). Organic Carbon Pools in Grazing Land Soils. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Boca Raton, FL, CRC Press.

Follett, R. F. (2001). "Soil management concepts and carbon sequestration in cropland soils." Soil & Tillage Research **61**(1–2): 77–92.

> One of the most important terrestrial pools for carbon (C) storage and exchange with atmospheric CO2 is soil organic carbon (SOC). Following the advent of large-scale cultivation, this long-term balance was disrupted and increased amounts of SOC were exposed to oxidation and loss as atmospheric CO2. The result was a dramatic decrease in SOC. If amounts of C entering the soil exceed that lost to the atmosphere by oxidation, SOC increases. Such an increase can result from practices that include improved: (1) tillage management and cropping systems, (2) management to increase amount of land cover, and (3) efficient use of production inputs, e.g. nutrients and water. Among the most important contributors is conservation tillage (i.e., no-till, ridge-till, and mulch-tillage) whereby higher levels of residue cover are maintained than for conventional-tillage. Gains in amount of land area under conservation tillage between 1989 and 1998 are encouraging because of their contributions to soil and water conservation and for their potential to sequester SOC. Other important contributors are crop residue and biomass management and fallow reduction. Collectively, tillage management and cropping systems in the US are estimated to have the potential to sequester 30-105 million metric tons of carbon (MMTC) yr-1. Two important examples of management strategies whereby land cover is

increased include crop rotations with winter cover crops and the conservation reserve program (CRP). Such practices enhance SOC sequestration by increasing the amount and time during which the land is covered by growing plants. Crop rotations, winter cover crops, and the CRP combined have the potential to sequester 14-29 MMTC yr-1. Biomass production is increased by efficient use of production inputs. Optimum fertility levels and water availability in soils can directly affect quantity of crop residues produced for return to the soil and for SOC sequestration. Nutrient inputs and supplemental irrigation are estimated to have the potential to sequester 11-30 MMTC yr-1. In the future, it is important to acquire an improved understanding of SOC sequestration processes, the ability to make quantitative estimates of rates of SOC sequestration, and technology to enhance these rates in an energy- and input-efficient manner. Adoption of improved tillage practices and cropping systems, increased land cover, and efficient use of nutrient and water inputs are examples where such information is necessary.

Follett, R. F., J. M. Kimble, et al. (2001). The potential of U.S. grazing lands to sequester soil carbon. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R. F. Follett, J. M. Kimble and R. Lal. Boca Raton, FL, CRC Press**:** 401–430.

Follett, R. F. and D. A. Reed (2010). "Soil carbon sequestration in grazing lands: Societal benefits and policy implications." Rangeland Ecology & Management **63**(1): 4–15.

This forum manuscript examines the importance of grazing lands for sequestering soil organic carbon (SOC), providing societal benefits, and potential influences on them of emerging policies and legislation. Global estimates are that grazing lands occupy similar to 3.6 billion ha and account for about one-fourth of potential carbon (C) sequestration in world soils. They remove the equivalent of similar to 20% of the carbon dioxide (CO2) released annually into the earth's atmosphere from global deforestation and land-use changes. Atmospheric CO2 enters grazing lands soils through photosynthetic assimilation by green plants, subsequent cycling, and sequestration of some of that C as SOC to in turn contribute to the ability of grazing lands to provide societal (environmental and economic) benefits in every country where they exist. Environmental benefits provided include maintenance and well-being of immediate and surrounding soil and water resources, air quality, human and wildlife habitat, and esthetics. Grazing lands contribute to the economic well-being of those living on the land, to trade, and to exchange of goods and services derived from them at local, regional, or national levels. Rates of SOC sequestration vary with climate, soil, and management; examples and conditions selected from US literature illustrate the SOC sequestration that might be achieved. Public efforts, policy considerations, and research in the United States illustrate possible alternatives that impact grazing lands. Discussion of US policy issues related to SOC sequestration and global climate change reflect the importance attached to these topics and of pending legislative initiatives in the United States. Addressing primarily US policy does not lessen the importance of such issues in other countries, but allows an in-depth analysis of legislation, US Department of Agriculture program efforts, soil C credits in greenhouse gas markets, and research needs.

Foltz, J. and G. Lang (2005). "The adoption and impact of management intensive rotational grazing (MIRG) on Connecticut dairy farms." Renewable Agriculture and Food Systems **20**(4): 261–266.

Management intensive rotational grazing (MIRG) has garnered a great deal of interest in recent years as a method for returning profitability to Northeastern dairy farms. This work uses a random sample of Connecticut dairy farmers to estimate a binary choice adoption model and then cost, productivity, and profit functions that control for the adoption choice. MIRG adopters are shown to be more educated and have less rented agricultural land (a proxy for lack of access to land within a short distance of the barn). MIRG adoption had no significant effects on costs and productivity, nor did it lower profits, per cow. Evidence was found, however, to suggest that full adopters of the technology had more profitable farms than partial adopters. These results also show the importance of controlling for the different characteristics of adopters when evaluating the returns to animal grazing.

Fowles, M. (2007). "Black carbon sequestration as an alternative to bioenergy." Biomass & Bioenergy **31**(6): 426–432.

Most policy and much research concerning the application of biomass to reduce global warming gas emissions has concentrated either on increasing the Earth's reservoir of biomass or on substituting biomass for fossil fuels, with or without CO2 sequestration. Suggested approaches entail varied risks of impermanence, delay, high costs, and unknowable side-effects. An under-researched alternative approach is to extract from biomass black (elemental) carbon, which can be permanently sequestered as mineral geomass and may be relatively advantageous in terms of those risks. This paper reviews salient features of black carbon sequestration and uses a high-level quantitative model to compare the approach with the alternative use of biomass to displace fossil fuels. Black carbon has been demonstrated to produce significant benefits when sequestered in agricultural soil, apparently without bad side-effects. Black carbon sequestration appears to be more efficient in general than energy generation, in terms of atmospheric carbon saved per unit of biomass; an exception is where biomass can efficiently displace coal-fired generation. Black carbon sequestration can reasonably be expected to be relatively quick and cheap to apply due to its short value chain and known technology. However, the model is sensitive to several input variables, whose values depend heavily on local conditions. Because characteristics of black carbon sequestration are only known from limited geographical contexts, its worldwide potential will not be known without multiple streams of research, replicated in other contexts.

Frank, A. B. (2004). "Six years of CO_2 flux measurements for a moderately grazed mixed-grass prairie." Environmental Management **33**(Suppl. 1): S426–431.

The large area occupied by temperate grassland ecosystems makes it important to determine their strength as a carbon sink. The Bowen ratio/energy balance (BREB) technique was used to determine CO 2 fluxes over a moderately grazed mixed-grass prairie at Mandan, North Dakota, USA, over a 6-year period from 1996 to 2001. Above-ground biomass and leaf area index (LAI) were measured about every 21 days throughout the growing period. Root biomass was determined to 1.1 m depth in mid-July each year. Peak above-ground biomass typically occurred between mid-July to early August and ranged from 782 kg/ha in 1998 to 2173 kg/ha in 1999. Maximum LAI ranged from 0.4 in 1998 to 0.9 in 1999. Root biomass ranged from 11.8 Mg/ha in 1997 to 17.4 Mg/ha in 1996. Maximum daily CO 2 fluxes generally coincided with periods of maximum LAI and above-ground green biomass. The average time period for CO 2 uptake was 5 May to 3 October. Annual CO 2 fluxes ranged from a low of 13 g CO 2/m 2 in 1998 to a high of

247 g CO_2/m 2 in 2001, nearly a 20-fold difference, and averaged 108 g CO_2/m 2. The cumulative annual flux over all 6 years was 646 g CO_2/m 2 or 176 g CO_2-C/m 2. These results indicate that the strength of the carbon sink for this moderately grazed prairie site is about 30 g CO_2-C/m 2/yr, which is quite small, but considering that the site was grazed and still remains a sink for carbon, it is significant.

Franzluebbers, A. J. (2005). "Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA." Soil & Tillage Research **83**(1): 120–147.

Agriculture in the southeastern USA can be highly productive (i.e., high photosynthetic fixation of atmospheric CO_2) due to warm-moist climatic conditions. However, its impacts on greenhouse gas emissions and mitigation potential have not been thoroughly characterized. This paper is a review and synthesis of literature pertaining to soil organic C (SOC) sequestration and greenhouse gas emissions from agricultural activities in the southeastern USA. Conservation tillage is an effective strategy to regain some of the SOC lost following decades, and in some areas centuries, of intensive soil tillage and erosion. With conventional tillage (CT) as a baseline, SOC sequestration with no tillage (NT) was 0.42 ± 0.46 Mg ha-1 year-1 (10 ± 5 years). Combining cover cropping with NT enhanced SOC sequestration (0.53 ± 0.45 Mg ha-1 year-1) compared with NT and no cover cropping (0.28 ± 0.44 Mg ha-1 year-1). By increasing cropping system complexity, SOC could be increased by 0.22 Mg ha-1 year-1, irrespective of tillage management. Taking into account an average C cost of producing and transporting N fertilizer, SOC sequestration could be optimized at 0.24 Mg ha-1 year-1 with application of 107 kg N ha-1 year-1 on N-responsive crops, irrespective of tillage management. In longer-term studies (5-21 years), poultry litter application led to SOC sequestration of 0.72 ± 0.67 Mg ha-1 year-1 (17 ± 15% of C applied). Land that was previously cropped and converted to forages sequestered SOC at a rate of 1.03 ± 0.90 Mg ha-1 year-1 (15 ± 17 years). Limited data suggest animal grazing increases SOC sequestration on upland pastures. By expanding research on SOC sequestration into more diverse pasture and manure application systems and gathering much needed data on methane and nitrous oxide fluxes under almost any agricultural operation in the region, a more complete analysis of greenhouse gas emissions and potential mitigation from agricultural management systems would be possible. This information will be necessary for developing appropriate technological and political solutions to increase agricultural sustainability and combat environmental degradation in the southeastern USA.

Franzluebbers, A. J. (2010). "Achieving soil organic carbon sequestration with conservation agricultural systems in the southeastern United States." Soil Science Society of America Journal **74**(2): 347–357.

Conservation management of degraded land has the potential to build soil fertility, restore soil functions, and mitigate greenhouse gas emissions as a consequence of surface soil organic matter accumulation. Literature from the southeastern United States was reviewed and synthesized to: (i) quantitatively evaluate the magnitude and rate of soil organic C (SOC) sequestration with conservation agricultural management; (ii) evaluate how conservation management affects surface SOC accumulation and its implications on ecosystem services; and (iii) recommend practical soil sampling strategies based on spatial and temporal issues to improve the detection of statistically significant SOC sequestration. Soil organic C sequestration was 0.45 ± 0.04 Mg C ha−1 yr−1 (mean ± standard error, n = 147, 20 ± 1 cm depth, 11 ± 1 yr) with conservation tillage compared with conventional tillage cropland. Establishment of perennial pastures sequestered 0.84 ± 0.11 Mg C ha−1 yr−1 (n = 35, 25 ± 2 cm depth, 17 ± 1 yr). Stratification of SOC with depth was common under conservation agricultural management and appears to be integrally linked to abatement of soil erosion, improvement in water quality, and SOC sequestration. Sampling of conservation management systems should ideally occur repeatedly with time in controlled and replicated experiments, but there is also an urgent need for chronosequence and paired-field surveys of SOC on working farms in the region to validate and expand the scope of inference of experimental results. Landowners in the southeastern United States have great potential to restore soil fertility and mitigate greenhouse gas emissions with the adoption of and improvement in conservation agricultural systems (e.g., continuous no-till, high-residue crop rotations, high organic matter inputs).

Franzluebbers, A. J. and R. F. Follett (2005). "Greenhouse gas contributions and mitigation potential in agricultural regions of North America: Introduction." Soil & Tillage Research **83**(1): 1–8.

Franzluebbers, A. J., F. M. Hons, et al. (1998). "In situ and potential CO_2 evolution from a Fluventic Ustochrept in southcentral Texas as affected by tillage and cropping intensity." Soil & Tillage Research **47**(3–4): 303–308.

Quality of agricultural soils is largely a function of soil organic matter. Tillage and crop management impact soil organic matter dynamics by modification of the soil environment and quantity and quality of C input. We investigated changes in pools and fluxes of soil organic C (SOC) during the ninth and tenth year of cropping with various intensities under conventional disk-and-bed tillage (CT) and no tillage (NT). Soil organic C to a depth of 0.2 m increased with cropping intensity as a result of greater C input and was 10% to 30% greater under NT than under CT. Sequestration of crop-derived C input into SOC was 22+-2% under NT and 9+-4% under CT (mean of cropping intensities +- standard deviation of cropping systems). Greater sequestration of SOC under NT was due to a lower rate of in situ soil CO2 evolution than under CT (0.22+-0.03 vs.0.27+-0.06 g CO2-C g-1 SOC yr-1). Despite a similar labile pool of SOC under NT than under CT (1.1+-0.1 vs. 1.0+-0.1 g mineralizable C kg-1 SOC d-1), the ratio of in situ to potential CO2 evolution was less under NT (0.56+-0.03) than under CT (0.73+-0.08), suggesting strong environmental controls on SOC turnover, such as temperature, moisture, and residue placement. Both increased C sequestration and a greater labile SOC pool were achieved in this low-SOC soil using NT and high-intensity cropping.

Franzluebbers, A. J. and J. L. Steiner (2002). Climatic influences on soil organic carbon storage with no tillage. Agricultural Practices and Policies for Carbon Sequestration in Soil. J. M. Kimble, R. Lal and R. F. Follett. Boca Raton, FL, CRC Press**:** 71–86.

No-tillage crop production has become an accepted practice throughout the U.S. The Kyoto Protocol on climate change has prompted great interest in conservation tillage as a management strategy to help sequester CO2 from the atmosphere into soil organic matter. Numerous reports published in recent years indicate a large variation in the amount of potential soil organic carbon (SOC) storage with no tillage (NT) compared with conventional tillage (CT). Environmental controls (i.e., macroclimatic variables of temperature and precipitation) may limit the potential of NT to store SOC. We synthesized available data on SOC storage with NT compared with CT from published reports representing 111 comparisons from 39 locations in 19 states and provinces across the U.S. and Canada. These sites provided a climatic continuum of mean annual temperature and precipitation, which was used to identify potential SOC storage limitations with NT. Soil organic C storage potential under NT was greatest (~0.050 kg · m –2· yr–1) in subhumid regions of North America with mean annual precipitation-to-potential evapotranspiration ratios of 1.1 to 1.4 mm · mm–1. Although NT is important for water conservation, aggregation, and protection of the soil surface from wind and water erosion in all climates, potential SOC storage with NT compared with CT was lowest in cold and dry climates, perhaps due to prevailing cropping systems that relied on low-intensity cropping, which limited C fixation. Published data indicate that increasing cropping intensity to utilize a greater fraction of available water in cold and dry climates can increase potential SOC storage with NT. These analyses indicate greatest potential SOC storage with NT would be most likely in the relatively mild climatic regions rather than extreme environments.

Franzluebbers, A. J. and J. A. Stuedemann (2009). "Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA." Agriculture, Ecosystems & Environment **129**(1–3): 28–36.

Soil organic C (SOC) and total soil N (TSN) sequestration estimates are needed to improve our understanding of management influences on soil fertility and terrestrial C cycling related to greenhouse gas emission. We evaluated the factorial combination of nutrient source (inorganic, mixed inorganic and organic, and organic as broiler litter) and forage utilization (unharvested, low and high cattle grazing pressure, and hayed monthly) on soil-profile distribution (0-150 cm) of SOC and TSN during 12 years of pasture management on a Typic Kanhapludult (Acrisol) in Georgia, USA. Nutrient source rarely affected SOC and TSN in the soil profile, despite addition of 73.6 Mg ha-1 (dry weight) of broiler litter during 12 years of treatment. At the end of 12 years, contents of SOC and TSN at a depth of 0-90 cm under haying were only 82 ± 5% (mean ± S.D. among treatments) of those under grazed management. Within grazed pastures, contents of SOC and TSN at a depth of 0-90 cm were greatest within 5 m of shade and water sources and only 83 ± 7% of maximum at a distance of 30 m and 92 ± 14% of maximum at a distance of 80 m, suggesting a zone of enrichment within pastures due to animal behavior. During 12 years, the annual rate of change in SOC (0-90 cm) followed the order: low grazing pressure (1.17 Mg C ha-1 year-1) > unharvested (0.64 Mg C ha-1 year-1) = high grazing pressure (0.51 Mg C ha-1 year-1) > hayed (-0.22 Mg C ha-1 year-1). This study demonstrated that surface accumulation of SOC and TSN occurred, but that increased variability and loss of SOC with depth reduced the significance of surface effects.

Franzluebbers, A. J., J. A. Stuedemann, et al. (2000). "Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA." Soil Biology & Biochemistry **32**(4): 469–478.

Soil organic matter pools under contrasting long-term management systems provide insight into potentials for sequestering oil C, sustaining soil fertility and functioning of the soil±atmospheric interface. We compared soil C and N pools (total, articulate and microbial) under pastures (1) varying due to harvest technique (grazing or haying), species composition (cool- or arm-season), stand age and previous land use and (2) in comparison with other land uses. Grazed tall fescue-common ermudagrass pasture (20 yr old) had greater soil organic C (31%), total N (34%), particulate organic C (66%), articulate organic N (2.4 fold) and soil microbial biomass C (28%) at a depth of 0±200 mm than adjacent land in conservation-tillage cropland (24 yr old). Soil organic

C and total N at a depth of 0±200 mm averaged 3800 and 294 g m-2 , respectively, under grazed bermudagrass and 3112 and 219 g m-2, respectively, under hayed bermudagrass. A chronosequence of grazed tall fescue suggested soil organic N sequestration rates of 7.3, 4.4 and 0.6 g m-2 yr-1 to a depth of 200 mm during 0±10, 10±30 and 30±50 yr, respectively. Soil C storage under long-term grazed tall fescue was 85 to 88% of that under forest, whereas soil N storage was 77 to 90% greater under grazed tall fescue than under forest. Properly grazed pastures in the Southern Piedmont USA have great potential to restore natural soil fertility, sequester soil organic C and N and increase soil biological activity.

Franzluebbers, A. J., J. A. Stuedemann, et al. (2001). "Bermudagrass management in the Southern Piedmont USA: I. Soil and surface residue carbon and sulfur." Soil Science Society of America Journal **65**(3): 834–841.

Improved forage management impacts on soil organic C and S depth distribution and surface residue accumulation could be large, but detailed temporal data are not available. We evaluated the factorial combination of three levels of N fertilization [inorganic, crimson clover (Trifolium incarnatum L.) cover crop plus inorganic, and broiler litter] and four levels of harvest strategy (unharvested, low grazing pressure, high grazing pressure, and hayed monthly) on soil bulk density, soil organic C, and total S, and surface residue C and S during the first 5 yr of 'Coastal' bermudagrass [Cynodon dactylon (L.) Pers.] management. Soil bulk density of the 0- to 6-cm depth responded very little to management, but across treatments it decreased 0.06 Mg m23 yr21 due to increasing soil organic matter with time. Soil organic C did not respond significantly to fertilization strategy during the 5 yr, but total S of the 0- to 6-cm depth was greater under broiler litter than under other fertilization strategies at the end of 3, 4, and 5 yr. Low and high grazing pressure were similar in their effect on soil organic C accumulation, averaging 140 g m22 yr21. Most of the net change in soil organic C occurred in the 0- to 2-cm depth. Soil under unharvested and hayed management accumulated organic C at rates less than one-half of those observed under cattle grazing. Cattle grazing shunted C more directly from forage to the soil, which contributed to greater sequestration of soil organic C than with haying or unharvested management.

Franzluebbers, A. J., S. R. Wilkinson, et al. (2004). "Bermudagrass management in the southern piedmont USA: X. Coastal productivity and persistence in response to fertilization and defoliation regimes." Agronomy Journal **96**(5): 1400–1411.

Forage utilization could affect soil nutrient dynamics and depth distribution, potentially changing long-term productivity and environmental quality. The effect of forage utilization on nutrient cycling might also be altered depending upon the source and quantity of nutrients applied. We evaluated changes in soil pH and extractable-soil nutrient cations during the first 5 yr of bermudagrass [Cynodon dactylon (L.) Pers.] management varying in fertilization (three different sources targeted to supply 200 kg N ha−1 yr−1) and forage utilization (four levels). Chicken (Gallus gallus) broiler litter (5.4 Mg ha−1 yr−1) was a significant source of nutrient cations in addition to N and P and therefore, at the end of 5 yr, resulted in extractable-soil concentrations (0- to 15-cm depth) that were 1.5 ± 0.1 times greater for K, 1.6 ± 0.2 times greater for Mn, 4.3 ± 2.2 times greater for Zn, and 7.5 ± 0.8 times greater for Cu than under inorganic and clover (Trifolium incarnatum L.) + inorganic fertilization regimes. The increases in extractable-soil K, Zn, Mn, and Cu concentrations with broiler litter, however, were only 13 ±

42% of nutrients applied. Removal of forage as hay resulted in significant declines in extractable-soil K and Mg under all fertilization regimes and in extractable-soil Ca and Mn with inorganic and clover + inorganic fertilization. Cattle (Bos taurus) grazing resulted in greater nutrient cycling within the paddock domain, and the more diverse and higher quantity of several nutrient cations applied with broiler litter either prevented a decline or contributed to an increase in concentrations with time.

Frate, C. A., B. H. Marsh, et al. (2008). Sample Costs to Produce Grain Corn (Field Corn), San Joaquin Valley - South. Davis, CA, University of California Cooperative Extension.

Freeman, M. W., M. A. Viveros, et al. (2008). Sample Costs to Establish an Almond Orchard and Produce Almonds, San Joaquin Valley South, Micro-Sprinkler Irrigation. Davis, CA, University of California Cooperative Extension.

Freeze, B. S. and T. G. Sommerfeldt (1985). "Breakeven hauling distances for beef feedlot manure in southern Alberta." Canadian Journal of Soil Science **65**(4): 687–693.

Freibauer, A., M. D. A. Rounsevell, et al. (2004). "Carbon sequestration in the agricultural soils of Europe." Geoderma **122**(1): 1–23.

In this review, technical and economically viable potentials for carbon sequestration in the agricultural soils of Europe by 2008-2012 are analysed against a business-as-usual scenario. We provide a quantitative estimation of the carbon absorption potential per hectare and the surface of agricultural land that is available and suitable for the implementation of those measures, their environmental effects as well as the effects on farm income. Realistically, agricultural soils in EU-15 can sequester up to 16-19 Mt C year^{-1} during the first Kyoto commitment period (2008-2012), which is less than one fifth of the theoretical potential and equivalent to 2% of European anthropogenic emissions. We identified as most promising measures: the promotion of organic inputs on arable land instead of grassland, the introduction of perennials (grasses, trees) on arable set-aside land for conservation or biofuel purposes, to promote organic farming, to raise the water table in farmed peatland, and--with restrictions--zero tillage or conservation tillage. Many options have environmental benefits but some risk of increasing N_2O emissions. For most measures it is impossible to determine the overall impact on farm profitability. Efficient carbon sequestration in agricultural soils demands a permanent management change and implementation concepts adjusted to local soil, climate and management features in order to allow selection of areas with high carbon sequestering potential. Some of the present agricultural policy schemes have probably helped to maintain carbon stocks in agricultural soils.

Fronning, B. E., K. D. Thelen, et al. (2008). "Use of manure, compost, and cover crops to supplant crop residue carbon in corn stover removed cropping systems." Agronomy Journal **100**(6): 1703–1710.

The emerging cellulosic-based ethanol industry will likely use corn (Zea mays L.) stover as a feedstock source. Growers wishing to maintain, or increase soil C levels for agronomic and environmental benei t will need to use C amendments such as manure, compost, or cover crops, to replace C removed with the corn stover. h e objective of this research was to determine the ef ect of cover crops, manure, and compost on short-term C sequestration rates and net global warming potential (GWP) in a corn–soy-bean [Glycine max (L.) Merr.] rotation with complete corn stover removal. Field experiments consisting of a corn–soybean–corn rotation with whole-plant corn harvest, were conducted near East Lansing, MI over a 3-yr period beginning in the fall of 2001. Carbon amendments were: compost, manure, and a winter cereal rye (Secale cereale L.) cover crop. Compost and manure amendments raised soil C levels in the 0 to 5 and 0 to 25 cm soil proi le but not in the 5 to 25 cm soil proi le over the relatively short-term duration of the study. Total soil organic C (SOC) (kg ha–1) in the 0 to 25 cm proi le increased by 41 and 25% for the compost and manure treatments, respectively, and decreased by 3% for the untreated check. Compost and manure soil amendments resulted in a net GWP of –1811 and –1060 g CO2 m–2 yr–1, respectively, compared to 12 g CO2 m–2 yr–1 for untreated.

Frye, W. W. (1984). Energy requirement in no tillage. No Tillage Agriculture, Principles and Practices. B. E. Phillips and S. F. Phillips. New York, NY, Van Nostrand Reinhold**:** 127–151.

Chapter in a book

Fuhlendorf, S. D., H. Zhang, et al. (2002). "Effects of grazing on restoration of southern mixed prairie soils." Restoration Ecology **10**(2): 401–407.

A comparative analysis of soils and vegetation from cultivated areas reseeded to native grasses and native prairies that have not been cultivated was conducted to evaluate restoration of southern mixed prairie of the Great Plains over the past 30 to 50 years. Restored sites were within large tracts of native prairie and part of long-term grazing intensity treatments (heavy, moderate, and ungrazed), allowing evaluation of the effects of grazing intensity on prairie restoration. Our objective was to evaluate restored and native sites subjected to heavy and moderate grazing regimes to determine if soil nutrients from reseeded cultivated land recovered after 30 years of management similar to the surrounding prairie and to identify the interactive influence of different levels of grazing and history of cultivation on plant functional group composition and soils in mixed prairies. For this mixed prairie, soil nitrogen and soil carbon on previously cultivated sites was 30 to 40% lower than in uncultivated native prairies, indicating that soils from restored sites have not recovered over the past 30 to 50 years. In addition, it appears that grazing alters the extent of recovery of these grassland soils as indicated by the significant interaction between grazing intensity and cultivation history for soil nitrogen and soil carbon. Management of livestock grazing is likely a critical factor in determining the potential restoration of mixed prairies. Heavy grazing on restored prairies reduces the rate of soil nutrient and organic matter accumulation. These effects are largely due to changes in composition (reduced tallgrasses), reduced litter accumulation, and high cover of bare ground in heavily grazed restored prairies. However, it is evident from this study that regardless of grazing intensity, restoration of native prairie soils requires many decades and possibly external inputs to adequately restore organic matter, soil carbon, and soil nitrogen.

Gaunt, J. L. and K. Driver (2010). Bringing biochar projects into the carbon marketplace: An introduction to biochar science, feedstocks and technology, Carbon Consulting and Blue Source.

Gaunt, J. L. and J. Lehmann (2008). "Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production." Environmental Science & Technology **42**(11): 4152–4158.

> The implications for greenhouse gas emissions of optimizing a slow pyrolysis-based bioenergy system for biochar and energy production rather than solely for energy production were assessed. Scenarios for feedstock production were examined using a life-cycle approach. We considered both purpose grown bioenergy crops (BEC) and the use of crop wastes (CW) as feedstocks. The BEC scenarios involved a change from growing winterwheat to purpose grown miscanthus, switchgrass, and corn as bioenergy crops. The CW scenarios consider both corn stover and winter wheat straw as feedstocks. Our findings show that the avoided emissions are between 2 and 5 times greater when biochar is applied to agricultural land (2–19 Mg CO_2 ha^{-1} y^{-1}) than used solely for fossil energy offsets. 41–64% of these emission reductions are related to the retention of C in biochar, the rest to offsetting fossil fuel use for energy, fertilizer savings, and avoided soil emissions other than CO_2. Despite a reduction in energy output of approximately 30% where the slow pyrolysis technology is optimized to produce biochar for land application, the energy produced per unit energy input at 2–7 MJ/MJ is greater than that of comparable technologies such as ethanol from corn. The C emissions per MWh of electricity production range from 91–360 kg CO_2 MWh^{-1}, before accounting for C offset due to the use of biochar are considerably below the lifecycle emissions associated with fossil fuel use for electricity generation (600–900 kg CO_2 MWh^{-1}). Low-temperature slow pyrolysis offers an energetically efficient strategy for bioenergy production, and the land application of biochar reduces greenhouse emissions to a greater extent than when the biochar is used to offset fossil fuel emissions.

Gebbers, R. and V. I. Adamchuk (2010). "Precision agriculture and food security." Science **327**(5967): 828–831.

> Precision agriculture comprises a set of technologies that combines sensors, information systems, enhanced machinery, and informed management to optimize production by accounting for variability and uncertainties within agricultural systems. Adapting production inputs site-specifically within a field and individually for each animal allows better use of resources to maintain the quality of the environment while improving the sustainability of the food supply. Precision agriculture provides a means to monitor the food production chain and manage both the quantity and quality of agricultural produce.

Gilley, J. E. and L. M. Risse (2000). "Runoff and soil loss as affected by the application of manure." Transactions of the ASAE **43**(6): 1583–1588.

> Manure has been used effectively to improve crop production and soil properties because it contains nutrients and organic matter. While it is generally accepted that the improved soil properties associated with manure application lead to changes in runoff and soil erosion, few studies have quantified these impacts. Water quality models used to assess watershed management and estimate total maximum daily load must accurately predict loading rates from fields where manure has been applied. This study was conducted to assemble and summarize information quantifying the effects of manure application on runoff and soil loss resulting from natural precipitation events, and to develop regression equations relating runoff and soil loss to annual manure application rates. For selected locations at which manure was added annually,

runoff was reduced from 2 to 62%, and soil loss decreased from 15 to 65% compared to non-manured sites. Measured runoff and soil loss values were reduced substantially as manure application rates increased. Regression equations were developed relating runoff and soil loss to manure application for rates ranging from 11 to 45 Mg ha–1, and slope lengths varying from 21 to 24 m. The equations can be used in estimating environmental impacts or to account for manure applications in water quality modeling efforts.

Glaser, B., L. Haumaier, et al. (2001). "The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics." Naturwissenschaften **88**(1): 37–41.

Many soils of the lowland humid tropics are thought to be too infertile to support sustainable agriculture. However, there is strong evidence that permanent or semi-permanent agriculture can itself create sustainably fertile soils known as 'Terra Preta' soils. These soils not only contain higher concentrations of nutrients such as nitrogen, phosphorus, potassium and calcium, but also greater amounts of stable soil organic matter. Frequent findings of charcoal and highly aromatic humic substances suggest that residues of incomplete combustion of organic material (black carbon) are a key factor in the persistence of soil organic matter in these soils. Our investigations showed that 'Terra Preta' soils contained up to 70 times more black carbon than the surrounding soils. Due to its polycyclic aromatic structure, black carbon is chemically and microbially stable and persists in the environment over centuries. Oxidation during this time produces carboxylic groups on the edges of the aromatic backbone, which increases its nutrient-holding capacity. We conclude that black carbon can act as a significant carbon sink and is a key factor for sustainable and fertile soils, especially in the humid tropics.

Gleason, R. A., B. A. Tangen, et al. (2009). "Greenhouse gas flux from cropland and restored wetlands in the Prairie Pothole Region." Soil Biology & Biochemistry **41**: 2501–2507.

It has been well documented that restored wetlands in the Prairie Pothole Region of North America do store carbon. However, the net benefit of carbon sequestration in wetlands in terms of a reduction in global warming forcing has often been questioned because of potentially greater emissions of greenhouse gases (GHGs) such as nitrous oxide (N_2O) and methane (CH_4). We compared gas emissions (N_2O, CH_4, carbon dioxide [CO_2]) and soil moisture and temperature from eight cropland and eight restored grassland wetlands in the Prairie Pothole Region from May to October, 2003, to better understand the atmospheric carbon mitigation potential of restored wetlands. Results show that carbon dioxide contributed the most (90%) to net-GHG flux, followed by CH_4 (9%) and N_2O (1%). Fluxes of N_2O, CH_4, CO_2, and their combined global warming potential (CO_2 equivalents) did not significantly differ between cropland and grassland wetlands. The seasonal pattern in flux was similar in cropland and grassland wetlands with peak emissions of N_2O and CH_4 occurring when soil water-filled pore space (WFPS) was 40–60% and >60%, respectively; negative CH_4 fluxes were observed when WFPS approached 40%. Negative CH_4 fluxes from grassland wetlands occurred earlier in the season and were more pronounced than those from cropland sites because WFPS declined more rapidly in grassland wetlands; this decline was likely due to higher infiltration and evapotranspiration rates associated with grasslands. Our results suggest that restoring cropland wetlands does not result in greater emissions of N_2O and CH_4, and therefore would not offset potential soil carbon sequestration. These findings, however, are limited to a small sample of seasonal wetlands with relatively short hydroperiods. A more comprehensive assessment of the GHG mitigation

potential of restored wetlands should include a diversity of wetland types and land-use practices and consider the impact of variable climatic cycles that affect wetland hydrology.

Gollehon, N., M. Caswell, et al. (2001). Confined Animal Production and Manure Nutrients. Agriculture Information Bulletin No. 771. Washington, DC, USDA Economic Research Service, Resource Economics Division**:** 40.

Census of agriculture data were used to estimate manure nutrient production and the capacity of cropland and pastureland to assimilate nutrients. Most farms (78 percent for nitrogen and 69 percent for phosphorus) have adequate land on which it is physically feasible to apply the manure produced onfarm at agronomic rates. (The costs of applying manure at these rates have not been assessed). Even so, manure that is produced on operations that cannot fully apply it to their own land at agronomic rates accounts for 60 percent of the Nation’s manure nitrogen and 70 percent of the manure phosphorus. In these cases, most counties with farms that produce “excess” nutrients have adequate crop acres not associated with animal operations, but within the county, on which it is feasible to spread the manure at agronomic rates. However, barriers to moving manure to other farms need to be studied. About 20 percent of the Nation’s onfarm excess manure nitrogen is produced in counties that have insufficient cropland for its application at agronomic rates (23 percent for phosphorus). For areas without adequate land, alternatives to local land application—such as energy production—will need to be developed.

Grace, P. R., G. P. Robertson, et al. (2010). "The contribution of maize cropping in the Midwest USA to global warming: A regional estimate." Agricultural Systems **In press**.

Graham, R. L., L. L. Wright, et al. (1992). "The potential for short-rotation woody crops to reduce U.S. CO_2 emissions." Climatic Change **22**(3): 223–238.

Short-rotation woody crops (SRWC) could potentially displace fossil fuels and thus mitigate CO 2 buildup in the atmosphere. To determine how much fossil fuel SRWC might displace in the United States and what the associated fossil carbon savings might be, a series of assumptions must be made. These assumptions concern the net SRWC biomass yields per hectare (after losses); the amount of suitable land dedicated to SRWC production; wood conversion efficiencies to electricity or liquid fuels; the energy substitution properties of various fuels; and the amount of fossil fuel used in growing, harvesting, transporting, and converting SRWC biomass. Assuming the current climate, present production, and conversion technologies and considering a conservative estimate of the U.S. land base available for SRWC (14 x 106 ha), we calculate that SRWC energy could displace 33.2 to 73.1 x 106 Mg of fossil carbon releases, 3-6% of the current annual U.S. emissions. The carbon mitigation potential per unit of land is larger with the substitution of SRWC for coal-based electricity production than for the substitution of SRWC-derived ethanol for gasoline. Assuming current climate, predicted conversion technology advancements, an optimistic estimate of the U.S. land base available for SRWC (28 x 106 ha), and an optimistic average estimate of net SRWC yields (22.4 dry Mg/ha), we calculate that SRWC energy could displace 148 to 242 x 106 Mg of annual fossil fuel carbon releases. Under this scenario, the carbon mitigation potential of SRWC-based electricity production would be equivalent to about 4.4% of current global fossil fuel emissions and 20% of current U.S. fossil fuel emissions.

Grandy, A. S., T. D. Loecke, et al. (2006). "Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems." Journal of Environmental Quality **35**(4): 1487–1495.

No-till cropping can increase soil C stocks and aggregation but patterns of long-term changes in N2O emissions, soil N availability, and crop yields still need to be resolved. We measured soil C accumulation, aggregation, soil water, N2O emissions, soil inorganic N, and crop yields in till and no-till corn-soybean-wheat rotations between 1989 and 2002 in southwestern Michigan and investigated whether tillage effects varied over time or by crop. Mean annual NO3- concentrations in no-till were significantly less than in conventional till in three of six corn years and during one year of wheat production. Yields were similar in each system for all 14 years but three, during which yields were higher in no-till, indicating that lower soil NO3- concentrations did not result in lower yields. Carbon accumulated in no-till soils at a rate of 26 g C m-2 yr-1 over 12 years at the 0- to 5-cm soil depth. Average nitrous oxide emissions were similar in till (3.27 {+/-} 0.52 g N ha d-1) and no-till (3.63 {+/-} 0.53 g N ha d-1) systems and were sufficient to offset 56 to 61% of the reduction in CO2 equivalents associated with no-till C sequestration. After controlling for rotation and environmental effects by normalizing treatment differences between till and no-till systems we found no significant trends in soil N, N2O emissions, or yields through time. In our sandy loam soils, no-till cropping enhances C storage, aggregation, and associated environmental processes with no significant ecological or yield tradeoffs.

Grant, B., W. N. Smith, et al. (2004). "Estimated N_2O and CO_2 emissions as influenced by agricultural practices in Canada." Climatic Change **65**(3): 315–332.

The Denitrification-Decompostion (DNDC) model was used to estimate the impact of change in management practices on N2O emissions in seven major soil regions in Canada, for the period 1970 to 2029. Conversion of cultivated land to permanent grassland would result in the greatest reduction in N2O emissions, particularly in eastern Canada wherethe model estimated about 60% less N2O emissions for thisconversion. About 33% less N2O emissions were predicted for a changefrom conventional tillage to no-tillage in western Canada, however, a slight increase in N2O emissions was predicted for eastern Canada. GreaterN2O emissions in eastern Canada associated with the adoption of no-tillage were attributed to higher soil moisture causing denitrification, whereas the lower emissions in western Canada were attributed to less decomposition of soil organic matter in no-till versus conventional tilled soil. Elimination of summer fallow in a crop rotation resulted in a 9% decrease in N2O emissions, with substantial emissions occurringduring the wetter fallow years when N had accumulated. Increasing N-fertilizer application rates by 50% increased average emissions by 32%,while a 50% decrease of N-fertilizer application decreased emissions by16%. In general, a small increase in N2O emissions was predicted when N-fertilizer was applied in the fall rather than in the spring. Previous research on CO2 emissions with the CENTURY model (Smith et al.,2001) allowed the quantification of the combined change in N2O andCO2 emissions in CO2 equivalents for a wide range of managementpractices in the seven major soil regions in Canada. The management practices that have the greatest potential to reduce the combined N2O andCO2 emissions are conversion from conventional tillage to permanent grassland, reduced tillage, and reduction of summer fallow. The estimated net greenhouse gas (GHG) emission reduction when changing from cultivated land to permanent grassland ranged from 0.97 (Brown Chernozem) to 4.24 MgCO2 equiv. ha-1 y-1 (BlackChernozem) for the seven soil regions examined. When changing from conventional tillage to no-tillage the net GHG emission reduction ranged from 0.33 (Brown

Chernozem) to 0.80 Mg CO2 equiv. ha-1 y-1 (Dark GrayLuvisol). Elimination of fallow in the crop rotation lead to an estimated net GHG emission reduction of 0.43 (Brown Chernozem) to 0.80 Mg CO2 equiv.ha-1 y-1 (Dark Brown Chernozem). The addition of 50% more or 50% less N-fertilizer both resulted in slight increases in combined CO2 and N2O emissions. There was a tradeoff in GHG flux with greaterN2O emissions and a comparable increase in carbon storage when 50% more N-fertilizer was added. The results from this work indicate that conversion of cultivated land to grassland, the conversion from conventional tillage to no-tillage, and the reduction of summerallow in crop rotations could substantially increase C sequestration and decrease net GHG emissions. Based on these results a simple scaling-up scenario to derive the possible impacts on Canada's Kyoto commitment has been calculated.

Grant, R. F., E. Pattey, et al. (2006). "Modeling the effects of fertilizer application rate on nitrous oxide emissions." Soil Science Society of America Journal **70**(1): 235–248.

The attribution of N_2O emission factors to N inputs from chemical fertilizers requires an understanding of how those inputs affect the biological processes from which these emissions are generated. We propose a detailed model of soil N transformations as part of the ecosystem model *ecosys* for use in attributing N_2O emission factors to fertilizer use. In this model, the key biological processes--mineralization, immobilization, nitrification, denitrification, root, and mycorrhizal uptake--controlling the generation of N_2O were coupled with the key physical processes--convection, diffusion, volatilization, dissolution--controlling the transport of the gaseous reactants and products of these biological processes. Physical processes controlling gaseous transport and solubility caused large temporal variation in the generation and emission of N_2O in the model. This variation limited the suitability of discontinuous surface flux chambers measurements used to test modeled N_2O emissions. Continuous flux measurements using micrometeorological techniques were better suited to the temporal scales at which variation in N_2O emission occurred and at which model testing needed to be conducted. In a temperate, humid climate, modeled N_2O emissions rose nonlinearly with fertilizer application rate once this rate exceeded the crop and soil uptake capacities for added N. These capacities were partly determined by history of fertilizer use, so that the relationship between N_2O emissions and current N inputs depended on earlier N inputs. A scheme is proposed in which N_2O emission factors rise nonlinearly with fertilizer N inputs that exceed crop plus soil N uptake capacities.

Green, M. B. (1987). Energy in pesticide manufacture, distribution and use. Energy in Plant Nutrition and Pest Control (Energy in World Agriculture). Z. R. Helsel. New York, NY, Elsevier Publications**:** 165–177.

Green, R. E., S. J. Cornell, et al. (2005). "Farming and the fate of wild nature." Science **307**(5709): 550–555.

World food demand is expected to more than double by 2050. Decisions about how to meet this challenge will have profound effects on wild species and habitats. We show that farming is already the greatest extinction threat to birds (the best known taxon), and its adverse impacts look set to increase, especially in developing countries. Two competing solutions have been proposed: wildlife-friendly farming (which boosts densities of wild populations on farmland but may decrease agricultural yields) and land sparing (which minimizes demand for farmland by increasing yield). We present a model that identifies how to resolve the trade-off between these

approaches. This shows that the best type of farming for species persistence depends on the demand for agricultural products and on how the population densities of different species on farmland change with agricultural yield. Empirical data on such density-yield functions are sparse, but evidence from a range of taxa in developing countries suggests that high-yield farming may allow more species to persist.

Gregorich, E. G., C. F. Drury, et al. (2001). "Changes in soil carbon under long-term maize in monoculture and legume-based rotation." Canadian Journal of Soil Science **81**(1): 21–31.

Legume-based cropping systems could help to increase crop productivity and soil organic matter levels, thereby enhancing soil quality, as well as having the additional benefit of sequestering atmospheric C. To evaluate the effects of 35 yr of maize monoculture and legume-based cropping on soil C levels and residue retention, we measured organic C and 13C natural abundance in soils under: fertilized and unfertilized maize (Zea mays L.), both in monoculture and legume-based [maize–oat (Avena sativa L.)–alfalfa (Medicago sativa L.)–alfalfa] rotations; fertilized and unfertilized systems of continuous grass (Poa pratensis L.); and under forest. Solid state 13C nuclear magnetic resonance (NMR) was used to chemically characterize the organic matter in plant residues and soils. Soils (70-cm depth) under maize cropping had about 30–40% less C, and those under continuous grass had about 16% less C, than those under adjacent forest. Qualitative differences in crop residues were important in these systems, because quantitative differences in net primary productivity and C inputs in the different agroecosystems did not account for observed differences in total soil C. Cropping sequence (i.e., rotation or monoculture) had a greater effect on soil C levels than application of fertilizer. The difference in soil C levels between rotation and monoculture maize systems was about 20 Mg C ha–1. The effects of fertilization on soil C were small (~6 Mg C ha–1), and differences were observed only in the monoculture system. The NMR results suggest that the chemical composition of organic matter was little affected by the nature of crop residues returned to the soil. The total quantity of maize-derived soil C was different in each system, because the quantity of maize residue returned to the soil was different; hence the maize-derived soil C ranged from 23 Mg ha–1 in the fertilized and 14 Mg ha–1 in the unfertilized monoculture soils (i.e., after 35 maize crops) to 6–7 Mg ha–1 in both the fertilized and unfertilized legume-based rotation soils (i.e., after eight maize crops). The proportion of maize residue C returned to the soil and retained as soil organic C (i.e., Mg maize-derived soil C/Mg maize residue) was about 14% for all maize cropping systems. The quantity of C3-C below the plow layer in legume-based rotation was 40% greater than that in monoculture and about the same as that under either continuous grass or forest. The soil organic matter below the plow layer in soil under the legume-based rotation appeared to be in a more biologically resistant form (i.e., higher aromatic C content) compared with that under monoculture. The retention of maize residue C as soil organic matter was four to five times greater below the plow layer than that within the plow layer. We conclude that residue quality plays a key role in increasing the retention of soil C in agroecosystems and that soils under legumebased rotation tend to be more “preservative” of residue C inputs, particularly from root inputs, than soils under monoculture.

Gregorich, E. G., K. J. Greer, et al. (1998). "Carbon distribution and losses: erosion and deposition effects." Soil & Tillage Research **47**(3–4): 291–302.

Because of concerns about the eventual impact of atmospheric CO_2 accumulations, there is growing interest in reducing net CO_2 emissions from soil and increasing C storage in soil. This review presents a framework to assess soil erosion and deposition processes on the distribution and loss of C in soils. The physical processes of erosion and deposition affect soil C distribution in two main ways and should be considered when evaluating the impact of agriculture on C storage. First, these processes redistribute considerable amounts of soil C, within a toposequence or a field, or to a distant site. Accurate estimates of soil redistribution in the landscape or field are needed to quantify the relative magnitude of soil lost by erosion and accumulated by deposition. Secondly, erosion and deposition drastically alter the biological process of C mineralization in soil landscapes. Whereas erosion and deposition only redistribute soil and organic C, mineralization results in a net loss of C from the soil system to the atmosphere. Little is known about the magnitude of organic C losses by mineralization and those due to erosion, but the limited data available suggest that mineralization predominates in the first years after the initial cultivation of the soil, and that erosion becomes a major factor in later years. Soils in depositional sites usually contain a larger proportion of the total organic C in labile fractions of soil C because this material can be easily transported. If the accumulation of soil in depositional areas is extensive, the net result of the burial (and subsequent reduction in decomposition) of this active soil organic matter would be increased C storage. Soil erosion is the most widespread form of soil degradation. At regional or global levels its greatest impact on C storage may be in affecting soil productivity. Erosion usually results in decreased primary productivity, which in turn adversely affects C storage in soil because of the reduced quantity of organic C returned to the soil as plant residues. Thus the use of management practices that prevent or reduce soil erosion may be the best strategy to maintain, or possibly increase, the worlds soil C storage.

Gregorich, E. G., P. Rochette, et al. (2005). "Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada." Soil & Tillage Research **83**(1): 53–72.

Agricultural soils can constitute either a net source or sink of the three principal greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). We compiled the most up-to-date information available on the contribution of agricultural soils to atmospheric levels of these gases and evaluated the mitigation potential of various management practices in eastern Canada and northeastern USA. Conversion of native ecosystems to arable cropping resulted in a loss of ~22% of the original soil organic carbon (C)--a release of about 123 Tg C to the atmosphere; drainage and cultivation of organic soils resulted in an additional release of about 15 Tg C. Management practices that enhance C storage in soil include fertilization and legume- and forage-based rotations. Adopting no-till did not always increase soil C. This apparent absence of no-till effects on C storage was attributed to the type and depth of tillage, soil climatic conditions, the quantity and quality of residue C inputs, and soil fauna. Emission of N_2O from soil increased linearly with the amount of mineral nitrogen (N) fertilizer applied (0.0119 kg N_2O-N kg N^{-1}). Application of solid manure resulted in substantially lower N_2O emission (0.99 kg N_2O-N ha^{-1} $year^{-1}$) than application of liquid manure (2.83 kg N_2O-N ha^{-1} $year^{-1}$) or mineral fertilizer (2.82 kg N_2O-N ha^{-1} $year^{-1}$). Systems containing legumes produced lower annual N_2O emission than fertilized annual crops, suggesting that alfalfa (Medicago sativa L.) and other legume forage crops be considered different from other crops when deriving national inventories of greenhouse gases from agricultural systems. Plowing manure or crop stubble into the soil in the autumn led to higher levels of N_2O production

(2.41 kg N2O-N ha-1 year-1) than if residues were left on the soil surface (1.19 kg N2O-N ha-1 year-1). Elevated N2O emission during freeze/thaw periods in winter and spring, suggests that annual N2O emission based only on growing-season measurements would be underestimated. Although measurements of CH4 fluxes are scant, it appears that agricultural soils in eastern Canada are a weak sink of CH4, and that this sink may be diminished through manuring. Although the influence of agricultural management on soil C storage and emission of greenhouse gases is significant, management practices often appear to involve offsets or tradeoffs, e.g., a particular practice may increase soil C storage but also increase emission of N2O. In addition, because of high variability, adequate spatial and temporal sampling are needed for accurate estimates of greenhouse gas flux and soil C stock. Therefore a full accounting of greenhouse gas contributions of agricultural soils is imperative for determining the true mitigation potential of management practices.

Grigal, D. F. and W. E. Berguson (1998). "Soil carbon changes associated with short-rotation systems." Biomass & Bioenergy **14**(4): 371–377.

The effect of all land management practices on carbon (C) balances are under scrutiny, including the management of short-rotation woody biomass crops. Studies of invasion of old fields by forests, and limited information from short-rotation plantations, lead to a hypothesis that such plantations will increase soil C by 10-25 Mg ha-1 over a 10- to 15-year rotation. Soil C under other land uses, such as row crops or pasture, has usually been reduced from native, undisturbed levels. Highly productive woody crops will add substantial C to soil, both above- and below-ground. In addition, within 2-3 years after plantation establishment, mulching by leaf litter and lack of cultivation will slow decomposition and further help retain C. We collected data from five hybrid poplar plantations in Minnesota, from 6 to 15 years old, and found no differences in soil C compared to adjacent row crops or hayland. A simple analysis of C balance indicated an initial decline and then an increase in soil C, consistent with literature reports. The analysis also indicated that structural roots are very importantin plantation soil-C balance. Before definitive statements can be made about the C balance of short-rotation plantations, selected plantations must be followed through one or more rotations using standard protocols to facilitate intercomparisons.

Gurian-Sherman, D. (2009). Failure to Yield. Cambridge, MA, Union of Concerned Scientists**:** 51.

from exec summary: "This report is the first to evaluate in detail the overall, or aggregate, yield effect of GE after more than 20 years of research and 13 years of commercialization in the United States. Based on that record, we conclude that GE has done little to increase overall crop yields....Genetic engineering has not increased intrinsic yield...Genetic engineering has delivered only minimal gains in operational yield...Most yield gains are attributable to non-genetic engineering approaches...Experimental high-yield genetically engineered crops have not succeeded...

Gurian-Sherman, D. and N. Gurwick (2009). No Sure Fix: Prospects for Reducing Nitrogen Fertilizer Pollution through Genetic Engineering. Cambridge, MA, Union of Concerned Scientists**:** 51.

from exec summary: "At this point, the prospects for GE contributing substantially to improved NUE are uncertain...At this point, the prospects for GE contributing substantially to improved NUE are uncertain..."

Haan, M. M., J. R. Russell, et al. (2007). "Effects of forage management on pasture productivity and phosphorus content." Rangeland Ecology & Management **60**(3): 311–318.

The objectives of the current study were to determine the amounts of above- and below-ground plant biomass production, P uptake by forage, and P concentration of cool-season grass forage as influenced by management and season. Five forage management treatments were evaluated over 3 years in smooth bromegrass (Bromus inermis Leyss) pastures. Management practices were: ungrazed (U), hay harvest/fall stockpile grazing (HS), rotational stocking to residual sward heights of 10 (10R) or 5 (5R) cm, and continuous stocking to maintain sward height at 5 cm (5C). Forage samples were hand-clipped within and outside grazing exclosures monthly from April through November of each year and analyzed for mass and P concentration. Root samples were collected at the initiation and completion of the study for determination of root length density (RLD) and root surface area density (RSAD). Phosphorus concentrations of forage outside the grazing exclosures did not differ among 5C, 5R, and IOR treatments, which were greater than U paddocks in April and August and less than HS paddocks in June. Mean annual forage productivity was greater in HS, 10R, 5R, and 5C paddocks (6 744 +/- 62 kg center dot ha(-1) mean +/- SE) than in the U paddocks (1 872 +/- 255 kg center dot ha(-1)). Mean P concentration of forage outside exclosures was greatest during the spring (0.21 +/- 0.01%), and lowest during the fall (0.13 +/- 0.01%). Mean annual P uptake by forage followed the same trend as forage production, being greater in the HS, 10R, 5R, and 5C paddocks (13.9 +/- 2.0 kg center dot ha(-1)) than in the U paddocks (3.7 +/- 0.5 kg center dot ha(-1)). After 3 years, RLD decreased in the ungrazed paddocks, but was unchanged in the HS, 10R, 5R, and 5C paddocks. Forage production and P uptake by forage is stimulated by forage harvest, either by grazing or hay harvest in smooth bromegrass pastures.

Haas, H. J., W. O. Willis, et al. (1974). Summer fallow in the western United States. Washington, DC, U.S. Department of Agriculture, Agricultural Research Service**:** 35.

Halvorson, A. D., M. E. Bartolo, et al. (2008). "Nitrogen effects on onion yield under drip and furrow irrigation." Agronomy Journal **100**(4): 1062–1069.

Onion (Allium cepa L.) is a high cash value crop with a very shallow root system that is frequently irrigated and fertilized with high N rates to maximize yield. Converting from furrow-irrigated to drip-irrigatcd onion production may reduce N fertilizer needs, water inputs, and NO3-N leaching potential. Onion growth and N uptake, fresh yield, and residual soil NO3-N were determined under drip and furrow irrigation on a clay loam soil with N fertilizer rates from 0 to 224 kg N ha(-1). Onions were sampled bi-weekly from 25 May to 30 August in 2005 and 2006 from each treatment. In 2005, 72% less water was applied with the drip system compared with furrow system, and 57% less in 2006. Onion yields were significantly greater with the drip system. Total marketable fresh onion yield increasedwith increasing N rate in 2005 only.The drip system had more colossal andjumbo sized onions and less medium sized onions than the furrow system. Biomass production and N accumulation accelerated in mid-June each year with an

average total N accumulation (leaves + bulbs) of 121 kg N ha(-1) at final harvest. Irrigation water use efficiency (IWUE) and N use efficiency (NUE) were higher with the drip system than with the furrow system. Residual soil NO3-N levels were greater in the drip-irrigated treatments after onion harvest in 2005 than in the furrow-irrigated treatments, but soil NO3-N levels were similar after harvest in 2006. Adjusted gross economic returns (less the cost ofN, water, and drip system) were greater with drip irrigation than with furrow irrigation. This study demonstrates that fresh onion yields, potential economic returns, IWUE, and NUE can be improved in Colorado by using drip irrigation for onion production rather than furrow irrigation.

Halvorson, A. D., S. J. Del Grosso, et al. (2010). "Tillage and inorganic nitrogen source effects on nitrous oxide emissions from irrigated cropping systems." Soil Science Society of America Journal **74**(2): 436–445.

Nitrogen fertilization is essential for optimizing crop yields; however, it increases N2O emissions. The study objective was to compare N2O emissions resulting from application of commercially available enhanced-efficiency N fertilizers with emissions from conventional dry granular urea in irrigated cropping systems. Nitrous oxide emissions were monitored from corn (Zea mays L.) based rotations receiving fertilizer rates of 246 kg N ha-1 when in corn, 56 kg N ha-1 when in dry bean (Phaseolus vulgaris L.), and 157 kg N ha-1 when in barley (Hordeum vulgare L. ssp. vulgare). Cropping systems included conventional-till continuous corn (CT-CC), no-till continuous corn (NT-CC), no-till corn-dry bean (NT-CDb), and no-till corn-barley (NT-CB). In the NT-CC and CT-CC systems, a controlled-release, polymer-coated urea (ESN) and dry granular urea were compared. In the NT-CDb and NT-CB rotations, a stabilized urea source (SuperU) was compared with urea. Nitrous oxide fluxes were measured during two growing seasons using static, vented chambers and a gas chromatograph analyzer. Cumulative growing season N2O emissions from urea and ESN application were not different under CT-CC, but ESN reduced N2O emissions 49% compared with urea under NT-CC. Compared with urea, SuperU reduced N2O emissions by 27% in dry bean and 54% in corn in the NT-CDb rotation and by 19% in barley and 51% in corn in the NT-CB rotation. This work shows that the use of no-till and enhanced-efficiency N fertilizers can potentially reduce N2O emissions from irrigated systems.

Halvorson, A. D., S. J. Del Grosso, et al. (2008). "Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems." Journal of Environmental Quality **37**(4): 1337–1344.

We evaluated the effects of irrigated crop management practices on nitrous oxide (N2O) emissions from soil. Emissions were monitored from several irrigated cropping systems receiving N fertilizer rates ranging from 0 to 246 kg N ha-1 during the 2005 and 2006 growing seasons. Cropping systems included conventional-till (CT) continuous corn (Zea mays L.), no-till (NT) continuous corn, NT corn-dry bean (Phaseolus vulgaris L.) (NT-CDb), and NT corn-barley (Hordeum distichon L.) (NT-CB). In 2005, half the N was subsurface band applied as urea-ammonium nitrate (UAN) at planting to all corn plots, with the rest of the N applied surface broadcast as a polymer-coated urea (PCU) in mid-June. The entire N rate was applied as UAN at barley and dry bean planting in the NT-CB and NT-CDb plots in 2005. All plots were in corn in 2006, with PCU being applied at half the N rate at corn emergence and a second N application as dry urea in mid-June followed by irrigation, both banded on the soil surface in the corn row. Nitrous oxide fluxes were measured during the growing season using static, vented chambers (1-3 times wk-1) and a gas chromatograph analyzer. Linear increases in N2O emissions were observed with increasing N-fertilizer rate, but emission amounts varied with growing season. Growing season N2O emissions were greater from the NT-CDb system during the corn phase of the rotation than from the other cropping systems. Crop rotation and N rate had more effect than tillage system on N2O emissions. Nitrous oxide emissions from N application ranged from 0.30 to 0.75% of N applied. Spikes in N2O emissions after N fertilizer application were greater with UAN and urea than with PCU fertilizer. The PCU showed potential for reducing N2O emissions from irrigated cropping systems.

Halvorson, A. D., G. A. Peterson, et al. (2002). "Tillage system and crop rotation effects on dryland crop yields and soil carbon in the central Great Plains." Agronomy Journal **94**(6): 1429–1436.

Winter wheat (Triticum aestivum L.)-fallow (WF) using conventional stubble mulch tillage (CT) is the predominant production practice in the central Great Plains and has resulted in high erosion potential and decreased soil organic C (SOC) contents. This study, conducted from 1990 through 1994 on a Weld silt loam (Aridic Argiustoll) near Akron, CO, evaluated the effect of WF tillage system with varying degrees of soil disturbance [no-till (NT), reduced till (RT), CT, and bare fallow (BF)] and crop rotation [WF, NT wheat-corn (Zea mays L.)-fallow (WCF), and NT continuous corn (CC)] on winter wheat and corn yields, aboveground residue additions to the soil at harvest, surface residue amounts at planting, and SOC. Neither tillage nor crop rotation affected winter wheat yields, which averaged 2930 kg ha-1. Corn grain yields for the CC (NT) and WCF (NT) rotations averaged 1980 and 3520 kg ha-1, respectively. The WCF (NT) rotation returned 8870 kg ha-1 residue to the soil in each 3-yr cycle, which is 2960 kg ha-1 on an annualized basis. Annualized residue return in WF averaged 2520 kg ha-1, which was 15% less than WCF (NT). Annualized corn residue returned to the soil was 3190 kg ha-1 for the CC (NT) rotation. At wheat planting, surface crop residues varied with year, tillage, and rotation, averaging WCF (NT) (5120 kg ha-1) > WF (NT) (3380 kg ha-1) > WF (RT) (2140 kg ha-1) > WF (CT) (1420 kg ha-1) > WF (BF) (50 kg ha-1). Soil erosion potential was lessened with WCF (NT), CC (NT), and WF (NT) systems because of the large amounts of residue cover. Levels of SOC in descending order in 1994 were CC (NT) [>=] WCF (NT) [>=] WF (NT) = WF (RT) = WF (CT) > WF (BF). Although not statistically significant, the CC (NT) treatment appeared to be accumulating more SOC than any of the rotations that included a fallow period, even more rapidly than WCF (NT), which had a similar amount of annualized C addition. Reduced tillage and intensified cropping increased SOC and reduced soil erosion potential.

Halvorson, A. D., B. J. Wienhold, et al. (2002). "Tillage, nitrogen, and cropping system effects on soil carbon sequestration." Soil Science Society of America Journal **66**(3): 906–912.

Soil C sequestration can improve soil quality and reduce agriculture's contribution to CO2 emissions. The long-term (12 yr) effects of tillage system and N fertilization on crop residue production and soil organic C (SOC) sequestration in two dryland cropping systems in North Dakota on a loam soil were evaluated. An annual cropping (AC) rotation [spring wheat (SW) (Triticum aestivum L.)-winter wheat (WW)-sunflower (SF) (Helianthus annuus L.)] and a spring wheat-fallow (SW-F) rotation were studied. Tillage systems included conventional-till (CT), minimum-till (MT), and no-till (NT). Nitrogen rates were 34, 67, and 101 kg N ha-1 for the AC system and 0, 22, and 45 kg N ha-1 for the SW-F system. Total crop residue returned to the soil was greater with AC than with SW-F. As tillage intensity decreased, SOC sequestration increased (NT > MT > CT) in the AC system but not in the SW-F system. Fertilizer N increased crop residue quantity returned to the soil, but generally did not increase SOC sequestration in either cropping system. Soil bulk density decreased with increasing tillage intensity in both systems. The results suggest that continued use of a crop-fallow farming system, even with NT, may result in loss of SOC. With NT, an estimated 233 kg C ha-1 was sequestered each year in AC system, compared with 25 kg C ha-1 with MT and a loss of 141 kg C ha-1 with CT. Conversion from crop-fallow to more intensive cropping systems utilizing NT will be needed to have a positive impact on reducing CO2 loss from croplands in the northern Great Plains.

Hansen, E. A. (1993). "Soil carbon sequestration beneath hybrid poplar plantations in the North Central United States " Biomass & Bioenergy **5**(6): 431–436.

Hybrid poplar plantations grown on tilled agricultural lands previously in prairie, sequester significant quantities of soil carbon. Comparisons are made between hybrid poplar plantations and adjacent row crops or mowed grass. Establishing and tending plantations often results in early soil carbon loss, but soil carbon is significantly related (positive) to tree age. Increasing tree age eventually results in a net addition of soil carbon from plantations older than about 6 to 12 years of age. Soil carbon loss under trees occurred most frequently from the surface 30 cm early in the plantation history-evidence that the loss was due to mineralization. Soil carbon gain was most significant in the 30 50 cm layer and was attributed to tree root growth. Soil carbon accretion rate beneath 12- to 18-year-old poplar plantations exceeded that of adjacent agricultural crops by 1.63 +/- 0.16 Mg ha-1 yr-1. There was a significant crop x soil depth interaction for bulk density with bulk density lower beneath trees in the 0 30 cm layer and higher in the 30-50 cm layer. There was little evidence of carbon trapping of wind-blown organic detritus by tree plantations in the prairie environment

Hao, X., C. Chang, et al. (2001). "Nitrous oxide emissions from an irrigated soil as affected by fertilizer and straw management." Nutrient Cycling in Agroecosystems **60**(1): 1–8.

Nitrous oxide (N2O) emission from farmland is a concern for both environmental quality and agricultural productivity. Field experiments were conducted in 1996–1997 to assess soil N2O emissions as affected by timing of N fertilizer application and straw/tillage practices for crop production under irrigation in southern Alberta. The crops were soft wheat (Triticum aestivum L.) in 1996 and canola (Brassica napus L.) in 1997. Nitrous oxide flux from soil was measured using a vented chamber technique and calculated from the increase in concentration with time. Nitrous oxide fluxes for all treatments varied greatly during the year, with the greatest fluxes occurring in association with freeze-thaw events during March and April. Emissions were greater when N fertilizer (100 kg N ha−1) was applied in the fall compared to spring application. Straw removal at harvest in the fall increased N2O emissions when N fertilizer was applied in the fall, but decreased emissions when no fertilizer was applied. Fall plowing also increased N2O emissions compared to spring plowing or direct seeding. The study showed that N2O emissions may be minimized by applying N fertilizer in spring, retaining straw, and incorporating it in spring. The estimates of regional N2O emissions based on a fixed proportion of applied N may be tenuous since N2O emission varied widely depending on straw and fertilizer management practices.

Hargrove, W. L., Ed. (1991). Cover crops for clean water. Ankeny, IA, Soil and Water Conservation Society.

Hausenbuiller, R. L. (1985). Soil Science – Principles and Practice. Dubuque, IA, William C. Brown Publishers.

Heath, L. S., J. Kimble, et al. (2003). The potential of U.S. forest soils to sequester carbon. The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. J. Kimble, L. S. Heath, R. Birdsey and R. Lal. Boca Raton, FL, CRC Press.

> from intro "The purpose of this chapter is to synthesize key information from the present volume for easy reference. The main topics are the characteristics of forests and forest soils and how to measure and monitor them; C dynamics and soils processes, including the activity of soil organisms; forest management activities and their impacts on soils; and discussions of specific forest ecosystems with unique soil C dynamics or management needs. The typical managed forest in the conterminous United States is a productive, closed-canopy, temperate deciduous or coniferous forest. The soil C in boreal regions, high elevations, the arid West, wetlands, and subtropical areas, as well as urban areas and areas of agroforestry, may have distinct features, and so forests in these areas are treated separately. Finally, quantitative estimates of the potential of forest soils to sequester C are provided."

Heffer, P. (2009). Assessment of Fertilizer Use by Crop at the Global Level - 2006/07–2007/08. Paris, France, International Fertilizer Industry Association**:** 12.

> According to the latest data for 2006-2006/0, fertilizer applications to cereals would amount to 81.0 million metric tonnes (Mt) nutrients, i.e. half (50.2%) of world fertilizer uses. This level is considerably lower than the “conventionally agreed” figure of 60%. This can be explained by the high contribution of fruits and vegetables, which is estimated at 27.4 Mt, or 17.0% of world fertilizer consumption. Fertilizer applications to the three main cereals are of similar magnitude: 15.9% for maize, 15.2% for wheat and 14.6% for rice. Fertilizer use on the other cereals represents 4.6% of the world total. Oil crops account together for 9.3% of world fertilizer consumption (15.0 Mt), with market shares of 3.4% for soybean, 1.5% for oil palm and 4.4% for the other oilseeds. Cotton receives some 3.6% of the fertilizer applied worldwide. Use on the other fibre crops is negligible. Sugar cane and sugar beet together account for some 4.3% of world fertilizer uses. The other crops receive the remaining 15.5%.

Hefting, M. M., R. Bobbink, et al. (2003). "Nitrous oxide emission and denitrification in chronically nitrate-loaded riparian buffer zones." Journal of Environmental Quality **32**(4): 1194–1203.

> Riparian buffer zones are known to reduce diffuse N pollution of streams by removing and modifying N from agricultural runoff. Denitrification, often identified as the key N removal process, is also considered as a major source of the greenhouse gas nitrous oxide (N2O). The risks of high N2O emissions during nitrate mitigation and the environmental controls of emissions have been examined in relatively few riparian zones and the interactions between controls and emissions are still poorly understood. Our objectives were to assess the rates of N2O emission from riparian buffer zones that receive large loads of nitrate, and to evaluate

various factors that are purported to control N emissions. Denitrification, nitrification, and N2O emissions were measured seasonally in grassland and forested buffer zones along first-order streams in the Netherlands. Lateral nitrate loading rates were high, up to 470 g N m-2 yr-1. Nitrogen process rates were determined using flux chamber measurements and incubation experiments. Nitrous oxide emissions were found to be significantly higher in the forested (20 kg N ha-1 yr-1) compared with the grassland buffer zone (2-4 kg N ha-1 yr-1), whereas denitrification rates were not significantly different. Higher rates of N2O emissions in the forested buffer zone were associated with higher nitrate concentrations in the ground water. We conclude that N transformation by nitrate-loaded buffer zones results in a significant increase of greenhouse gas emission. Considerable N2O fluxes measured in this study indicate that Intergovernmental Panel on Climate Change methodologies for quantifying indirect N2O emissions have to distinguish between agricultural uplands and riparian buffer zones in landscapes receiving large N inputs.

Heller, M. C., G. A. Keoleian, et al. (2003). "Life cycle assessment of a willow bioenergy cropping system." Biomass & Bioenergy **25**(2): 147–165.

The environmental performance of willow biomass crop production systems in New York (NY) is analyzed using life cycle assessment (LCA) methodology. The base-case, which represents current practices in NY, produces 55 units of biomass energy per unit of fossil energy consumed over the biomass crop's 23-year lifetime. Inorganic nitrogen fertilizer inputs have a strong influence on overall system performance, accounting for 37% of the non-renewable fossil energy input into the system. Net energy ratio varies from 58 to below 40 as a function of fertilizer application rate, but application rate also has implications on the system nutrient balance. Substituting inorganic N fertilizer with sewage sludge biosolids increases the net energy ratio of the willow biomass crop production system by more than 40%. While CO2 emitted in combusting dedicated biomass is balanced by CO2 adsorbed in the growing biomass, production processes contribute to the system's net global warming potential. Taking into account direct and indirect fuel use, N2O emissions from applied fertilizer and leaf litter, and carbon sequestration in below ground biomass and soil carbon, the net greenhouse gas emissions total 0.68 g CO2 eq. MJ(biomass produced)(-1). Site specific parameters such as soil carbon sequestration could easily offset these emissions resulting in a net reduction of greenhouse gases. Assuming reasonable biomass transportation distance and energy conversion efficiencies, this study implies that generating electricity from willow biomass crops could produce 11 units of electricity per unit of fossil energy consumed. Results from the LCA support the assertion that willow biomass crops are sustainable from an energy balance perspective and contribute additional environmental benefits.

Helsel, Z. R. (1992). Energy and alternatives for fertilizer and pesticide use. Energy in farm production. R. C. Fluck. New York, NY, Elsevier Science Publishers.

Helsel, Z. R. (2007). Energy in pesticide production and use. Encyclopedia of Pest Management. D. Pimentel. Boca Raton, FL, CRC Press. **2:** 157–160.

Hepperly, P., D. Lotter, et al. (2009). "Compost, manure and synthetic fertilizer influences crop yields, soil properties, nitrate leaching and crop nutrient content." Compost Science & Utilization **17**(2): 117–126.

From 1993 to 2001, a maize-vegetable-wheat rotation was compared using either 1) composts, 2) manure, or 3) synthetic fertilizer for nitrogen nutrient input. From 1993 to 1998, red clover (Trifolium pratense L.) and crimson clover (Trifolium incarnatum L.) were used as an annual winter legume cover crop prior to maize production. From 1999 to 2001, hairy vetch (Vicia villosa Roth.) served as the legume green manure nitrogen (N) source for maize. In this rotation, wheat depended entirely on residual N that remained in the soil after maize and vegetable (pepper and potato) production. Vegetables received either compost, manure, or fertilizer N inputs. Raw dairy manure stimulated the highest overall maize yields of 7,395 kg/ha (approximately 140 bushels per acre). This exceeded the Berks County mean yield of about 107 bushels per acre from 1994 to 2001. When hairy vetch replaced clover as the winter green manure cover crop, maize yields rose in three of the four treatments (approximately 500-1,300 kg/ha, or 10-24 bu/a). Hairy vetch cover cropping also resulted in a 9-25% increase in wheat yields in the compost treatments compared to clover cover cropping. Hairy vetch cover crops increased both maize and wheat grain protein contents about 16 to 20% compared to the clover cover crop. Compost was superior to conventional synthetic fertilizer and raw dairy manure in 1) building soil nutrient levels, 2) providing residual nutrient support to wheat production, and 3) reducing nutrient losses to ground and surface waters. After 9 years, soil carbon (C) and soil N remained unchanged or declined slightly in the synthetic fertilizer treatment, but increased with use of compost amendments by 16-27% for C and by 13-16%. for N. However, with hairy vetch cover crops, N leaching increased 4 times when compared to clover cover crops. September was the highest month for nitrate leaching, combining high rainfall with a lack of active cash crop or cover crop growth to use residual N. Broiler litter leaf compost (BLLC) showed the lowest nitrate leaching of all the nutrient amendments tested (P= 0.05).

Hoben, J. P., R. J. Gehl, et al. (2010). "Non-linear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the U.S. Midwest." Global Change Biology **In press**.

Horner, G. M. (1960). "Effect of cropping systems on runoff, erosion, and wheat yields." Agronomy Journal **52**(6): 342–344.

Crop rotations that include legume-grass sod crops are more effective for runoff and erosion control, soil organic matter maintenance, and high wheat yields than the unfertilized pea-wheat and fallow-wheat systems. Summer fallowing causes the largest erosion losses and the most rapid depletion of organic matter.

Houlbrooke, D. J., R. P. Littlejohn, et al. (2008). "Effect of irrigation and grazing animals on soil quality measurements in the North Otago Rolling Downlands of New Zealand." Soil Use and Management **24**(4): 416–423.

The North Otago Rolling Downlands (NORD) of New Zealand is currently undergoing a large change in land use with subsequent intensification as a result of a new large community irrigation scheme. To assess the effect of this change, a 4-year monitoring survey was established on two common Pallic soil types of the area to determine the influence of irrigation term (short, < 5 years vs. long, > 5 years) and grazing animal (cattle vs. sheep) on a range of physical and organic matter soil quality parameters. This 4-year survey also included the historical land use of dryland sheep farming in the absence of irrigation water. Irrigation term had no significant ($P > 0.05$) effect on soil physical parameters (percentage macroporosity and bulk density) for 3 of 4 years and no significant effect ($P > 0.05$) on topsoil total carbon or nitrogen contents. However, irrigation term had a significant ($P < 0.01$) but biologically small effect on the ratio of carbon to nitrogen with narrowing of the range under longer term irrigation. A significant difference between the dryland and irrigated surveys was found for macroporosity (dryland sheep 17.3% v/v vs. irrigated sheep 13.4% v/v; $P < 0.001$) and for the C:N ratio (dryland sheep 10.7 vs. irrigated sheep 10.2; $P < 0.05$). The change in macroporosity under irrigation is likely to take effect within 1 or 2 years of land-use change as little discernable differences in soil physical properties were evident from land under short- or long-term irrigation.

Huang, Y., R. L. Sass, et al. (1998). "A semi-empirical model of methane emission from flooded rice paddy soils." Global Change Biology **4**(3): 247–268.

Reliable regional or global estimates of methane emissions from flooded rice paddy soils depend on an examination of methodologies by which the current high variability in the estimates might be reduced. One potential way to do this is the development of predictive models. With an understanding of the processes of methane production, oxidation and emission, a semi-empirical model, focused on the contributions of rice plants to the processes and also the influence of environmental factors, was developed to predict methane emission from flooded rice fields. A simplified version of the model was also derived to predict methane emission in a more practical manner. In this study, it was hypothesized that methanogenic substrates are primarily derived from rice plants and added organic matter. Rates of methane production in flooded rice soils are determined by the availability of methanogenic substrates and the influence of environmental factors. Rice growth and development control the fraction of methane emitted. The amount of methane transported from the soil to the atmosphere is determined by the rates of production and the emitted fraction. Model validation against observations from single rice growing seasons in Texas, USA demonstrated that the seasonal variation of methane emission is regulated by rice growth and development. A further validation of the model against measurements from irrigated rice paddy soils in various regions of the world, including Italy, China, Indonesia, Philippines and the United States, suggests that methane emission can be predicted from rice net productivity, cultivar character, soil texture and temperature, and organic matter amendments.

Huang, Y., W. J. Sun, et al. (2010). "Marshland conversion to cropland in northeast China from 1950 to 2000 reduced the greenhouse effect." Global Change Biology **16**(2): 680–695.

It has been well recognized that converting wetlands to cropland results in loss of soil organic carbon (SOC), while less attention was paid to concomitant changes in methane (CH4) and nitrous oxide (N2O) emissions. Using datasets from the literature and field measurements, we investigated loss of SOC and emissions of CH4 and N2O due to marshland conversion in northeast China. Analysis of the documented crop cultivation area indicated that 2.91 Mha of marshland were converted to cropland over the period 1950-2000. Marshland conversion resulted in SOC loss of similar to 240 Tg and introduced similar to 1.4 Tg CH4 and similar to 138 Gg N2O emissions in the cropland, while CH4 emissions reduced greatly in the marshland, cumulatively similar to 28 Tg over the 50 years. Taking into account the loss of SOC and emissions of CH4 and N2O, the global warming potential (GWP) at a 20-year time horizon was estimated to be similar to 180 Tg CO2_eq. yr-1 in the 1950s and similar to 120 Tg CO2_eq. yr-1 in the 1990s, with a similar to 33% reduction. When calculated at 100-year time horizon, the GWP was similar to 73 Tg CO2 _eq. yr-1 in the 1950s and similar to 58 Tg CO2_eq. yr-1 in the 1990s, with a similar to 21% reduction. It was concluded that marshland conversion to cropland in northeast China reduced the greenhouse effect as far as GWP is concerned. This reduction was attributed to a substantial decrease in CH4 emissions from the marshland. An extended inference is that the declining growth rate of atmospheric CH4 since the 1980s might be related to global loss of wetlands, but this connection needs to be confirmed.

Hultgreen, G. and P. Leduc (2003). The effect of nitrogen fertilizer placement, formulation, timing, and rate on greenhouse gas emissions and agronomic performance. Swift Current, SK, Agriculture and Agr-Food Canada & Prairie Agricultural Machinery Institute.

Hutchinson, J. J., C. A. Campbell, et al. (2007). "Some perspectives on carbon sequestration in agriculture." Agricultural and Forest Meteorology **142**(2–4): 288–302.

One of the main options for greenhouse gas (GHG) mitigation identified by the IPCC is the sequestration of carbon in soils. Since the breaking of agricultural land in most regions, the carbon stocks have been depleted to such an extent, that they now represent a potential sink for CO, removal from the atmosphere. Improved management will however, be required to increase the inputs of organic matter in the top soil and/or decrease decomposition rates. In this paper we use data from selected regions to explore the global potential for carbon sequestration in arable soils. While realising that C sequestration is not limited to the selected regions, we have, however, focussed our review on two regions: (i) Canadian Prairies and (ii) The Tropics. In temperate regions, management changes for an increase in C involve increase in cropping frequency (reducing bare fallow), increasing use of forages in crop rotations, reducing tillage intensity and frequency, better crop residue management, and adopting agroforestry. In the tropics, agroforestry remains the primary method by which sequestration rates may be significantly increased. Increases in soil C may be achieved through improved fertility of cropland/pasture; on extensive systems with shifting cultivation cropped fallows and cover crops may be beneficial, and adopting agro forestry or foresting marginal cropland is also an alternative. In addition, in the tropics it is imperative to reduce the clearing of forests for conversion to cropland. Some regional analyses of soil C sequestration and sequestration potential have been performed, mainly for temperate industrialized North America where the majority of research pertaining to C sequestration has been carried out. More research is needed, especially for the Tropics, to more accurately capture the impact of region-specific interactions between climate, soil, and management of resources on C sequestration, which are lost in global level assessments. By itself, C sequestration in agricultural soils can make only modest contributions (3-6% of fossil fuel contributions) to mitigation of overall greenhouse gas emissions. However, effective mitigation policies will not be based on any single 'magic bullet' solutions, but rather on many modest reductions which are economically efficient and which confer additional benefits to society. In this context, soil C sequestration is a significant mitigation option.

Hyatt, C. R., R. T. Venterea, et al. (2010). "Polymer-coated urea maintains potato yields and reduces nitrous oxide emissions in a Minnesota loamy sand." Soil Science Society of America Journal **74**(2): 419–428.

> Irrigated potato (Solanum tuberosum L.) production requires large inputs of N, and therefore has high potential for N loss including emissions of N2O. Two strategies for reducing N loss include split applications of conventional fertilizers, and single applications of polymer-coated urea (PCU), both of which aim to better match the timing of N availability with plant demand. The objective of this 3-yr study was to compare N2O emissions and potato yields following a conventional split application (CSA) using multiple additions of soluble fertilizers with single preplant applications of two different PCUs (PCU-1 and PCU-2) in a loamy sand in Minnesota. Each treatment received 270 kg of fertilizer N ha-1 per season. An unfertilized control treatment was included in 2 of 3 yr. Tuber yields did not vary among fertilizer treatments, but N2O emissions were significantly higher with CSA than PCU-1. During 3 consecutive yr, mean growing season emissions were 1.36, 0.83, and 1.13 kg N2O-N ha-1 with CSA, PCU-1, and PCU-2, respectively, compared with emissions of 0.79 and 0.42 kg N2O-N ha-1 in the control. The PCU-1 released N more slowly during in situ incubation than PCU-2, although differences in N2O emitted by the two PCUs were not generally significant. Fertilizer-induced emissions were relatively low, ranging from 0.10 to 0.15% of applied N with PCU-1 up to 0.25 to 0.49% with CSA. These results show that N application strategies utilizing PCUs can maintain yields, reduce costs associated with split applications, and also reduce N2O emissions.

Indraratne, S. P., X. Y. Hao, et al. (2009). "Rate of soil recovery following termination of long-term cattle manure applications." Geoderma **150**(3–4): 415–423.

> Livestock manure application increases soil nutrient levels, enhancing their bioavailability, but potentially increasing environmental concerns. This study investigates the residual effects of long-term cattle feedlot manure applications to continuously cropped fields under semi-arid conditions on soil properties, crop yields and rate of soil recovery after manure application ceases. Solid cattle feedlot manure was applied to a Dark Brown Chemozemic clay loam at 0, 30, 60 and 90 Mg ha(-1) yr(-1) under rain-fed and 0, 60,120 and 180 Mg ha(-1) yr(-1) under irrigated conditions annually for 14 years (1973-1986) followed by 16 years with no further manure application (1987-2003). Soil samples to 1.5 m were taken and analyzed. Soil organic matter (OM), total nitrogen (TN), NOT, total P (TP), soil test P (STP), and electrical conductivity (EC) levels remained significantly higher in previously manured treatments than in the Control 16 years after manure application ceased. The average grain yields were similar to the Control while straw yields in irrigated treatments were higher than values for the Control over the 16 years following the last manure application. Based on a three-parameter exponential decay (y=y(s) + a (*) e(-bx)) model, the estimated recovery time for soil to return to the pre-manure treatment state increased with the previous manure application rate and was shorter under irrigation. For soil TN, TP and STP, estimated recovery time ranged from 17 to 99 years for surface soil and 0 to 157 years for the 15 to 30 cm depth, while soil NO3- and EC in the soil profile (0 to 150 cm) requires 182 to 297 years under rain-fed and 24 to 52 years under irrigated conditions. Thus, long lasting N and P enrichment, from excessive long-term cattle manure applications could pose environmental threats long after application ceases.

IPCC (2000). Land Use, Land-Use Change, and Forestry. Cambridge, UK, Cambridge University Press, for the Intergovernmenatl Panel on Climate Change.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 4. Agriculture, Forestry and Other Land Use, Prepared by the National Greenhouse Gas Inventories Programme. Japan, IGES.

Izaurralde, R. C., W. B. McGill, et al. (1998). Scientific challenges in developing a plan to predict and verify carbon storage in Canadian Prairie soils. Management of Carbon Sequestration in Soil. R. Lal, J. M. Kimble, R. F. Follett and B. A. Stewart. Boca Raton, FL, CRC Press**:** 433–446.

Jacinthe, P.-A. and W. A. Dick (1997). "Soil management and nitrous oxide emissions from cultivated fields in southern Ohio." Soil & Tillage Research **41**(3–4): 221–235.

> Nitrous oxide (N2O) is an important atmospheric trace gas due to its involvement in the postulated global warming phenomenon and in the depletion of the ozone layer. Widespread concern has been triggered by recent reports of increased atmospheric N2O concentration. Since agriculture has been implicated as one contributor to that increase, a monitoring program was undertaken during the 1993 and 1994 cropping season (May-October) to evaluate the effect of several soil management practices on N2O emission from soil. Our results show that rates of N2O emission were generally near baseline levels during most sampling occasions. Major, but short-lived, fluxes of N2O were observed after rainfall events and during the days immediately following fertilizer application. It was during these times that most of the seasonal N2O loss occurred. An excellent relationship was found between seasonal N2O loss (y) and the maximum daily flux of N2O (x) during a season (y = -0.4x2 + 43.1x + 338, r2 = 0.89, P < 0.0001). The N2O emission data were log normally distributed for both years. Average daily emissions of N2O were 6.9 ± 6.3 g (range, 0.3 - 74.7 g) N2O---N ha-1 day-1 and 17.6 ± 10.5 g (range, 0.1-326 g) N2O---N ha-1 day-1 during the 1993 and 1994 seasons, respectively. Seasonal N2O---N losses were, in general, highest in the continuous corn (CC) (Zea mays L.) plots and lowest in the soybean (Glycine max L.) plots of the corn/soybean/wheat (Triticum aestivum L.)-hairy vetch (Vicia villosa Roth) rotation (CSW-V). Average N loss as N2O during a cropping season was between 0.6 kg (for the soybean crop of the CSWV rotation and ridge till treatment) and 3.7 kg N2O---N ha-1 year-1, (for the CC rotation and the chisel till treatment). Approximately 0.5-3% of the inorganic N fertilizer added was lost as N2O. Our data show that seasonal N2O---N loss from chisel-till plots were generally significantly higher than from no-till or ridge till plots.

Jacobo, E. J., A. M. Rodriguez, et al. (2006). "Rotational grazing effects on rangeland vegetation at a farm scale." Rangeland Ecology & Management **59**(3): 249–257.

> We evaluated the adequacy of rotational grazing to improve rangeland condition in the Flooding Pampa region, eastern Argentina, comparing the floristic composition dynamic of the 2 main plant communities under rotational and continuous grazing over a study period of 4 years (1993-1996). The experiment was conducted in commercial farms located in 4 sites of the Flooding Pampa region. In each site, a couple of farms, one managed under rotational grazing (implemented in 1989) and an adjacent one managed under continuous grazing at a similar stocking rate (1 AU(.)ha(-1)), constituted the replications of the experiment. Basal cover of

species, litter, and bare soil were monitored in midslope and lowland grassland communities on each farm. Total plant basal cover in midslope and in lowland communities remained unchanged over the whole experimental period under both grazing methods. Under rotational grazing, litter cover was higher in both communities while the amount of bare soil showed a significant reduction in lowlands and a tendency to be lower in midslope. Basal cover of legumes, C-3 annual and C-3 perennial grasses was higher, while cover of C-4 prostrate grasses was lower under rotational grazing in the midslope community. In the lowland community, rotational grazing effects were evident only in the drier years, when higher cover of hydrophytic grasses and legumes and lower cover of forbs occurred. Plant species diversity did not change in response to grazing. In conclusion, rotational grazing promoted functional groups composed of high forage value species and reduced bare soil through the accumulation of litter. These changes indicate an improvement in rangeland condition and in carrying capacity. As the stocking rate was approximately 60% higher than the average stocking rate of the Flooding Pampa region, we believe that productivity and sustainability may be compatible by replacing continuous with rotational grazing.

Janzen, H. H. (2001). "Soil science on the Canadian prairies – Peering into the future from a century ago." Canadian Journal of Soil Science **81**(3): 489–503.

Janzen, H. H., C. A. Campbell, et al. (1998). "Management effects on soil C storage on the Canadian prairies." Soil & Tillage Research **47**(3–4): 181–195.

The Canadian prairie, which accounts for about 80% of Canada's farmland, has large reserves of soil organic carbon (SOC). Changes in the size of the SOC pool have implications for soil productivity and for atmospheric concentrations of CO2, an important [`]greenhouse gas'. We reviewed recent findings from long-term research sites to determine the impact of cropping practices on SOC reserves in the region. From this overview, we suggest that: (1) the loss of SOC upon conversion of soils to arable agriculture has abated; (2) significant gains in SOC (typically about 3 Mg C ha-1 or less within a decade) can be achieved in some soils by adoption of improved practices, like intensification of cropping systems, reduction in tillage intensity, improved crop nutrition, organic amendments, and reversion to perennial vegetation; (3) changes in SOC occur predominantly in [`]young' or labile fractions; (4) the change in SOC, either gain or loss, is of finite duration and magnitude; (5) estimates of SOC change from individual studies are subject to limitations and are best viewed as part of a multi-site network; and (6) the energy inputs into agroecosystems need to be included in the calculation of the net C balance. The long-term sites indicate that Canadian prairie soils can be a net sink for CO2, though perhaps only in the short term. These sites need to be maintained to measure the effects of continued agronomic evolution and predicted global changes.

Johnson, J. M.-F., A. J. Franzluebbers, et al. (2007). "Agricultural opportunities to mitigate greenhouse gas emissions." Environmental Pollution **150**(1): 107–124.

Agriculture is a source for three primary greenhouse gases (GHGs): CO2, CH4, and N2O- It can also be a sink for CO2 through C sequestration into biomass products and soil organic matter. We summarized the literature on GHG emissions and C sequestration, providing a perspective on how agriculture can reduce its GHG burden and how it can help to mitigate GHG emissions through conservation measures. Impacts of agricultural practices and systems on GHG emission are reviewed and potential trade-offs among potential mitigation options are discussed. Conservation practices that help prevent soil erosion, may also sequester soil C and enhance CH4 consumption. Managing N to match crop needs can reduce N2O emission and avoid adverse impacts on water quality. Manipulating animal diet and manure management can reduce CH4 and N2O emission from animal agriculture. All segments of agriculture have management options that can reduce agriculture's environmental footprint.

Johnson, J. M.-F., D. C. Reicosky, et al. (2005). "Greenhouse gas contributions and mitigation potential of agriculture in the central USA." Soil & Tillage Research **83**(1): 73–94.

The central USA contains some of the most productive agricultural land of the world. Due to the high proportion of land area committed to crops and pasture in this region, the carbon (C) stored and greenhouse gas (GHG) emission due to agriculture represent a large percentage of the total for the USA. Our objective was to summarize potential soil organic C (SOC) sequestration and GHG emission from this region and identify how tillage and cropping system interact to modify these processes. Conservation tillage (CST), including no-tillage (NT), has become more widespread in the region abating erosion and loss of organic rich topsoil and sequestering SOC. The rate of SOC storage in NT compared to conventional tillage (CT) has been significant, but variable, averaging 0.40 ± 0.61 Mg C ha-1 year-1 (44 treatment pairs). Conversion of previous cropland to grass with the conservation reserve program increased SOC sequestration by 0.56 ± 0.60 Mg C ha-1 year-1 (five treatment pairs). The relatively few data on GHG emission from cropland and managed grazing land in the central USA suggests a need for more research to better understand the interactions of tillage, cropping system and fertilization on SOC sequestration and GHG emission.

Johnson, J. M. F., D. W. Archer, et al. (2010). "Greenhouse gas emission from contrasting management scenarios in the northern Corn Belt." Soil Science Society of America Journal **74**(2): 396–406.

The agricultural sector is a small but significant contributor to the overall anthropogenic greenhouse gas (GHG) emission and a major contributor of N2O emission in the United States. Land management practices or systems that reduce GHG emission would aid in slowing climate change. We measured the emission of CO2, CH4, and N2O from three management scenarios: business as usual (BAU), maximum C sequestration (MAXC), and optimum greenhouse gas benefits (OGGB). The BAU scenario was chisel or moldboard plowed, fertilized, in a 2-yr rotation (corn [Zea mays L.]-soybean [Glycine max (L.) Merr]). The MAXC and OGGB scenarios were strip tilled in a 4-yr rotation (corn-soybean-wheat [Triticum aestivum L.]/alfalfa [Medicago sativa L.]-alfalfa). The MAXC received fertilizer inputs but the OGGB scenario was not fertilized. Nitrous oxide, CO2, and CH4 emissions were collected using vented static chambers. Carbon dioxide flux increased briefly following tillage, but the impact of tillage was negligible when CO2 flux was integrated across an entire year. The sod tended to be neutral to a slight CH4 sink under these managements scenarios. The N2O flux during spring thaw accounted for up to 65% of its annual emission, compared with 6% or less due to application of N fertilizer. Annual cumulative emissions of CO2, CH4, and N2O did not vary significantly among these three management scenarios. Reducing tillage and increasing the length of the crop rotation did not appreciably change GHG emissions, Strategies that reduce N2O flux during spring thaw could reduce annual N2O emission.

Kallenbach, C. M., D. E. Rolston, et al. (2010). "Cover cropping affects soil N_2O and CO_2 emissions differently depending on type of irrigation." Agriculture, Ecosystems & Environment **137**(3–4): 251–260.

Agricultural management practices such as subsurface drip irrigation (SDI) and winter legume cover cropping (WLCC) influence soil water dynamics as well as carbon and nitrogen cycling, potentially changing emission rates of soil CO2 and N2O, principal greenhouse gases. A split plot tomato field trial in California's Central Valley was used to evaluate the use of SDI and WLCC on event-based CO2 and N2O emissions. SDI and WLCC were compared to the region's more conventional practices: furrow irrigation (FI) and no cover crop (NCC). Our results indicate that SDI offers the potential to manage cover crops without the significant increases in greenhouse gas production during the growing season as seen under FI cover-cropped systems. The highest N2O emissions occurred during the beginning of the rainy season in November in the FI–WLCC treatment (5mg m−2 h−1) and the lowest in August in the SDI–NCC treatments (4.87ug m−2 h−1). CO2 emissions ranged from 200mg m−2 h−1 during the rainy season (winter) and >500m−2 h−1 during the growing season. Though no differences were detected in CO2 emissions between irrigation practices, mean CO2 emissions under WLCC were 40% and 15% greater compared to NCC under FI and SDI, respectively. The treatment with the greatest effect on CO2 and N2O emissions was WLCC, which increased average growing season N2O and CO2 emissions under FI by 60ugN2O m−2 h−1 and 425mg CO2 m−2 h−1 compared to NCC. In SDI there was no effect of a cover crop on growing season CO2 and N2O emissions. In the rainy season, however, SDI N2O and CO2 emissions were not different from FI. In the rainy season, the cover crop increased N2O emissions in SDI only and increased CO2 emissions only under FI. Subsurface drip shows promise in reducing overall N2O emissions in crop rotations with legume cover crops.

Kang, G., Z. Cai, et al. (2002). "Importance of water regime during the non-rice growing period in winter in regional variation of CH_4 emissions from rice fields during following rice growing period in China." Nutrient Cycling in Agroecosystems **64**: 95–100.

Rice fields are either continuously flooded or drained in China in the winter (non-rice growth season). Due to great spatial variation of precipitation and temperature, there is a spatial variation of soil moisture in the fields under drained conditions during the winter season. The effect of water regime in winter on CH4 emissions during the following rice growing period and their regional variation were investigated. Soil moisture in the winter was simulated by DNDC model with daily precipitation and temperature as model inputs. Under the same management during the rice growing period, CH4 emissions was higher from rice fields flooded, compared to those from fields drained during winter. CH4 emission from rice fields correlated significantly with simulated soil moisture and with mean precipitation of the preceding winter season. Spatial variation of precipitation in winter and corresponding variations of soil moisture regimes control the regional and annual variation of CH4 emissions from rice fields in China. Keeping soils drained as much as possible during winter seems to be a feasible option to reduce CH4 emissions during the following rice growing seasons.

Kaspar, T. C., T. B. Parkin, et al. (2006). "Examining changes in soil organic carbon with oat and rye cover crops using terrain covariates." Soil Science Society of America Journal **70**: 1168–1177.

Winter cover crops have the potential to increase soil organic C in the corn (Zea mays L.)–soybean [Glycine max (L.) Merr.] rotation in the upper Midwest. Management effects on soil C, however, are often difficult to measure because of the spatial variation of soil C across the landscape. The objective of this study was to determine the effect of oat (Avena sativa L.), rye (Secale cereale L.), and a mixture of oat and rye used as winter cover crops following soybean on soil C levels over 3 yr and both phases of a corn–soybean rotation using terrain attributes as covariates to account for the spatial variability in soil C. A field experiment was initiated in 1996 with cover crop treatments, both phases of a corn–soybean rotation, and a controlled-traffic no-till system. Oat, rye, and oat–rye mixture cover crop treatments were overseeded into the soybean phase of the rotation in late August each year. Cover crop treatments were not planted into or after the corn phase of the rotation. Soil C concentration was measured on 450 samples taken across both rotation phases in a 7.62-m grid pattern in the late spring of 2000, 2001, and 2002. Slope, relative elevation, and wetness index (WI) were used as covariates in the analysis of variance to remove 77% of the variation of soil C caused by landscape driven patterns of soil C. Soil C concentrations were 0.0023 g C g soil -1 higher in 2001 and 0.0016 g C g soil-1 higher in 2002 than in 2000. The main effects of cover crops were not significant, but the interaction of cover crops and rotation phase was significant. The rye cover crop treatment had 0.0010 g C g soil-1 higher soil C concentration than the no-cover- crop control in the soybean phase of the rotation, which included cover crops, but had 0.0016 g C g soil -1 lower C concentrations than the control in the corn phase of the rotation, which did not have cover crops. Using terrain covariates allowed us to remove most of the spatial variability of soil C, but oat and rye cover crops planted every other year after soybean did not increase soil C concentrations averaged over years and rotation phases.

Khan, S. A., R. L. Mulvaney, et al. (2007). "The myth of nitrogen fertilization for soil carbon sequestration." Journal of Environmental Quality **36**(6): 1821–1832.

Intensive use of N fertilizers in modern agriculture is motivated by the economic value of high grain yields and is generally perceived to sequester soil organic C by increasing the input of crop residues. This perception is at odds with a century of soil organic C data reported herein for Morrow Plots, the world's oldest experimental site under continuous corn (Zea mays L.). After 40 to 50 yr of synthetic fertilization that exceeded grain N removal by 60 to 190%, a net decline occurred in soil C despite increasingly massive residue C incorporation, the decline being more extensive for a corn-soybean (Glycine max L. Merr.) or corn-oats (Avena sativa L.)-hay rotation than for continuous corn and of greater intensity for the profile (0-46 cm) than the surface soil. These findings implicate fertilizer N in promoting the decomposition of crop residues and soil organic matter and are consistent with data from numerous cropping experiments involving synthetic N fertilization in the USA Corn Belt and elsewhere, although not with the interpretation usually provided. These are important implications for soil C sequestration because the yield-based input of fertilizer N has commonly exceeded grain N removal for corn production on fertile soils since the 1960s. To mitigate the ongoing consequences of soil deterioration, atmospheric CO_2 enrichment, and NO_3^- pollution of ground and surface waters, N fertilization should be managed by site-specific assessment of soil N availability. Current fertilizer N managment practices, if combined with corn stover removal for bioenergy production; exacerbate soil C loss.

Kijne, J. W., T. P. Tuong, et al. (2002). Ensuring food security via improvement in crop water productivity. Challenge Program on Water and Food. Rome, Consultative Group on International Agricultural Research**:** 196.

Kim, D. G., T. M. Isenhart, et al. (2010). "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of Environmental Quality **39**(1): 97–105.

While water quality functions of conservation buffers established adjacent to cropped Fields have been widely documented, the relative contribution of these re-established perennial plant systems to greenhouse gases has not been completely documented. In the case of methane (CH4), these systems have the potential to serve as sinks of CH4 or may provide favorable conditions for CH4 production. This study quantifies CH4 flux from soils of riparian buffer systems comprised of three vegetation types and compares these fluxes with those of adjacent crop fields. We measured soil properties and diel and seasonal variations of CH4 flux in 7 to 17 yr-old re-established riparian forest buffers, warm-season and cool-season grass filters, and an adjacent crop field located in the Bear Creek watershed in central Iowa. Forest buffer and grass filter soils had significantly lower bulk density ($P < 0.01$); and higher pH ($P < 0.01$), total carbon (TC) ($P < 0.01$), and total nitrogen (TN) ($P < 0.01$) than crop field soils. There was no significant relationship between CH4 flux mid soil moisture or soil temperature among sites within the range of conditions observed. Cumulative CH4 flux was -0.80 kg CH4-C ha(-1) yr(-1) in the cropped field, -0.416 kg CH4-C ha(-1) yr(-1) within the forest buffers, and 0.04 kg CH4-C ha(-1) yr(-1) within grass filters, but difference among vegetation covers was not significant. Results Suggest that CH4 flux was not changed after establishment of perennial vegetation on cropped soils, despite significant changes in soil properties.

Kingery, W. L., C. W. Wood, et al. (1994). "Impact of long-term land application of broiler litter on environmentally related soil properties." Journal of Environmental Quality **23**(1): 139–147.

The largest portion of Alabama’s rapidly growing poultry industry is geographically concentrated in the Sand Mountainr egion of northern Alabama. The result is that large amounts of waste are applied to relatively small areas of agricultural soils. A study was conducted to determine the effects of long-term broiler waste (litter) application on environmentally related soil conditions in the region. The region has an average annual rainfall of 1325 mm, which is evenly distributed

throughout the year, a thermic temperature regime, and soils in the region are of the UItisol order. In each of four major broiler producing counties, three pairs of sites consisting of long-term (15-28 yr) littered and nonlittered fields on matching soil series and maintained under perennial tall fescue (Festuca arundinacea Schreb.) were sampled. Soil cores were taken to 3 m or lithic contact and depth-incremented samples (0-15, 15-30, and each subsequent 30-cm interval) were analyzed for organic C, total N, NO3-N, pH, electrical conductivity, and acid-extractable P, K, Ca, Mg, Cu, and Zn. Litter application increased organic C and total N to depths of 15 and 30 cm, respectively, as comparedw ith nonlittered soils, whereas pHw as 0.5 units higher to a depth of 60 cm under littered soils. Significant accumulation of NO3-Nw as found in littered soils to or near bedrock. Extractable P concentrations in littered soils were more than six times greater than in nonlittered soils to a depth of 60 cm. Elevated levels of extractable K, Ca, and Mg to depths greater than 60 cm also were found as a result of long-term litter use. Extractable Cu and Zn had accumulated in littered soils to a depth of 45 cmo These findings indicate that long-term land application of broiler litter, at present rates, has altered soil chemical conditions and has created a potential for adverse environmental impacts in the Sand Mountain region of Alabama.

Kong, A. Y. Y., S. J. Fonte, et al. (2009). "Transitioning from standard to minimum tillage: Trade-offs between soil organic matter stabilization, nitrous oxide emissions, and N availability in irrigated cropping systems." Soil & Tillage Research **104**(2): 256–262.

Few studies address nutrient cycling during the transition period (e.g., 1-4 years following conversion) from standard to some form of conservation tillage. This study compares the influence of minimum versus standard tillage on changes in soil nitrogen (N) stabilization, nitrous oxide (N2O) emissions, short-term N cycling, and crop N use efficiency 1 year after tillage conversion in conventional (i.e., synthetic fertilizer-N only), low-input (i.e., alternating annual synthetic fertilizer- and cover crop-N), and organic (i.e., manure- and cover crop-N) irrigated, maize-tomato systems in California. To understand the mechanisms governing N cycling in these systems, we traced N-15-labeled fertilizer/cover crop into the maize grain, whole soil, and three soil fractions: macroaggregates (>250 mu m), microaggregates (53-250 mu m) and silt-and-clay (<53 mu m). We found a cropping system effect on soil N-new (i.e., N derived from N-15-fertilizer or - N-15-cover crop), with 173 kg N-new ha(-1) in the conventional system compared to 71.6 and 69.2 kg N-new ha(-1) in the low-input and organic systems, respectively. In the conventional system, more N-new was found in the microaggregate and silt-and-clay fractions, whereas, the N-new of the organic and low-input systems resided mainly in the macroaggregates. Even though no effect of tillage was found on soil aggregation, the minimum tillage systems showed greater soil fraction-N-new than the standard tillage systems, suggesting greater potential for N stabilization under minimum tillage. Grain-N-new was also higher in the minimum versus standard tillage systems. Nevertheless, minimum tillage led to the greatest N2O emissions (39.5 g (NO)-O-2-N ha(-1) day(-1)) from the conventional cropping system, where N turnover was already the fastest among the cropping systems. In contrast, minimum tillage combined with the low-input system (which received the least N ha(-1)) produced intermediate N2O emissions, soil N stabilization, and crop N use efficiency. Although total soil N did not change after 1 year of conversion from standard to minimum tillage, our use of stable isotopes permitted the early detection of interactive effects between tillage regimes and cropping systems that determine the trade-offs among N stabilization, N2O emissions, and N availability.

Kyveryga, P. M., A. M. Blackmer, et al. (2004). "Soil pH effects on nitrification of fall-applied anhydrous ammonia." Soil Science Society of America Journal **68**(2): 545–551.

Soil temperature at the time of application has been the primary factor used to predict rates of nitrification and assess the risks associated with losses of N applied in the fall as anhydrous ammonia in the Corn Belt. We report studies assessing the importance of soil pH as a factor affecting nitrification rates and losses of this N before corn (Zea Mays L.) begins rapid growth in June. Data were collected in a series of field studies conducted during 4 yr. Anhydrous ammonia was applied in the fall after soils had cooled to <8degreesC, and soils were sampled before corn plants emerged in the spring. Soil pH ranged from <6.0 to >7.5. Significant relationships between soil pH and percentage nitrification were observed each year. Means of measurements made in mid-April (when planting begins) indicated 89% nitrification of fertilizer N in soils having pH > 7.5 and 39% nitrification of this N in soils having pH < 6.0. The finding that soil pH influenced when nitrification occurred helps to explain why the effects of nitrification inhibitors have been

variable in this region. Significant relationships between soil pH and recovery of fertilizer N as exchangeable NH4+ and NO3- were observed in years with above-average rainfall before samples were collected in April. The effects of soil pH on nitrification, therefore, influenced the amounts of NO3- lost by denitrification or leaching during spring rainfall. The observed effects of pH on nitrification rates suggest that economic and environmental benefits of delaying application of fertilizer N may be greater in higher-pH soils than in lower-pH soils.

Laird, D. A. (2008). "The charcoal vision: a win win win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality." Agronomy Journal **100**(1): 178–181.

Processing biomass through a distributed network of fast pyrolyzers may be a sustainable platform for producing energy from biomass. Fast pyrolyzers thermally transform biomass into bio-oil, syngas, and charcoal. The syngas could provide the energy needs of the pyrolyzer. Bio-oil is an energy raw material ([~]17 MJ kg-1) that can be burned to generate heat or shipped to a refinery for processing into transportation fuels. Charcoal could also be used to generate energy; however, application of the charcoal co-product to soils may be key to sustainability. Application of charcoal to soils is hypothesized to increase bioavailable water, build soil organic matter, enhance nutrient cycling, lower bulk density, act as a liming agent, and reduce leaching of pesticides and nutrients to surface and ground water. The half-life of C in soil charcoal is in excess of 1000 yr. Hence, soil-applied charcoal will make both a lasting contribution to soil quality and C in the charcoal will be removed from the atmosphere and sequestered for millennia. Assuming the United States can annually produce 1.1 x 109 Mg of biomass from harvestable forest and crop lands, national implementation of The Charcoal Vision would generate enough bio-oil to displace 1.91 billion barrels of fossil fuel oil per year or about 25% of the current U.S. annual oil consumption. The combined C credit for fossil fuel displacement and permanent sequestration, 363 Tg per year, is 10% of the average annual U.S. emissions of CO2-C.

Lal, R. (2001). The physical quality of soils on grazing lands and its effects on sequestering carbon. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R. F. Follett, J. M. Kimble and R. Lal. Boca Raton, FL, CRC Press: 249–266.

Lal, R. (2003). "Global potential of soil carbon sequestration to mitigate the greenhouse effect." Critical Reviews in Plant Sciences **22**(2): 151–184.

An increase in atmospheric concentration of CO2 from 280 ppmv in 1750 to 367 ppmv in 1999 is attributed to emissions from fossil fuel combustion estimated at 270 +/- 30 Pg C and land use change at 136 +/- 55 Pg. Of the emissions from land use change, 78 +/- 12 Pg is estimated from depletion of soil organic carbon (SOC) pool. Most agricultural soils have lost 50 to 70% of their original SOC pool, and the depletion is exacerbated by further soil degradation and desertification. The restoration of degraded soils, conversion of agriculturally marginal lands to appropriate land use, and the adoption of recommended management practices on agricultural soils can reverse degradative trends and lead to SOC sequestration. Technological options for SOC sequestration on agricultural soils include adoption of conservation tillage, use of manures, and compost as per integrated nutrient management and precision fanning strategies,

conversion of monoculture to complex diverse cropping systems, meadow-based rotations and winter cover crops, and establishing perennial vegetation on contours and steep slopes. The global potential of SOC sequestration and restoration of degraded/desertified soils is estimated at 0.6 to 1.2 Pg C/y for about 50 years with a cumulative sink capacity of 30 to 60 Pg. The SOC sequestration is a cost-effective strategy of mitigating the climate change during the first 2 to 3 decades of the 21(st) century. While improving soil quality, biomass productivity and enhanced environment quality, the strategy of SOC sequestration also buys us time during which the non-carbon fuel alternatives can take effect.

Lal, R. (2004). "Soil carbon sequestration impacts on global climate change and food security." Science **304**(5677): 1623–1627.

The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66% of the historic carbon loss of 42 to 78 gigatons of carbon. The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossilfuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions.

Lal, R. (2005). "World crop residues production and implications of its use as a biofuel." Environment International **31**(4): 575–584.

Reducing and off-setting anthropogenic emissions of CO, and other greenhouse gases (GHGs) are important strategies of mitigating the greenhouse effect. Thus, the need for developing carbon (C) neutral and renewable sources of energy is more than ever before. Use of crop residue as a possible source of feedstock for bioenergy production must be critically and objectively assessed because of its positive impact on soil C sequestration.. soil quality maintenance and ecosystem functions. The amount of crop residue produced in the US is estimated at 367x10(6) Mg/year for 9 cereal crops, 450x10(6) Mg/year for 14 cereals and legumes, and 488x10(6) Mg/year for 21 crops. The amount of crop residue produced in the world is estimated at 2802x10(6) Mg/year for cereal crops, 3107x10(6) Mg/year for 17 cereals and legumes, and 3758x10(6) Mg/year for 27 food crops. The fuel value of the total annual residue produced is estimated at 1.5x10(15) kcal, about I billion barrels (bbl) of diesel equivalent, or about 8 quads for the US; and 11.3x10(15) kcal, about 7.5 billion bbl of diesel or 60 quads for the world. However, even a partial removal (30-40%) of crop residue from land can exacerbate soil erosion hazard, deplete the SOC pool, accentuate emission of CO, and other GHGs from soil to the atmosphere, and exacerbate the risks of global climate change. Therefore, establishing bioenergy plantations of site-specific species with potential of producing 10-15 Mg biomass/year is an option that needs to be considered. This option will require 40-60 million hectares of land in the US and about 250 million hectares worldwide to establish bioenergy plantations.

Lal, R., R. F. Follett, et al. (2003). "Achieving soil carbon sequestration in the United States: A challenge to the policy makers." Soil Science **168**(12): 827–845.

> Carbon (C) sequestration in soil implies enhancing the concentrations/pools of soil organic matter and secondary carbonates. It is achieved through adoption of recommended management practices (RMPs) on soils of agricultural, grazing, and forestry ecosystems, and conversion of degraded soils and drastically disturbed lands to restorative land use. Of the 916 million hectares (Mha) comprising the total land area in the continental United States and Alaska, 157 Mha (17.1%) are under cropland, 336 Mha (36.7%) under grazing land, 236 Mha (25.8%) under forest, 14 Mha (1.5%) under Conservation Reserve Programs (CRP), and 20 Mha (2.2%) are under urban land use. Land areas affected by different soil degradative processes include 52 Mha affected by water erosion, 48 Mha by wind erosion, 0.2 Mha by secondary salinization, and more than 4 Mha affected by mining. Adoption of RMPs can lead to sequestration of soil organic carbon (SOC) at an annual rate of 45 to 98 Tg (teragram = 1 X 10(12) g = 1 million metric tons or MMT) in cropland, 13 to 70 Tg in grazing land, and 25 to 102 Tg in forestlands. In addition, there is an annual soil C sequestration potential of 21 to 77 Tg by land conversion, 25 to 60 Tg by land restoration, and 15 to 25 Tg by management of other land uses. Thus, the total potential of C sequestration in soils of the United States is 144 to 432 Tg/y or an average of 288 Tg C/y. With the implementation of suitable policy initiatives, this potential is realizable for up to 30 years or when the soil C sink capacity is filled. In comparison, emission by agricultural activities is estimated at: 43 Tg C/y, and the current rate of SOC sequestration is reported as 17 Tg C/y. The challenge the policy makers face is to be able to develop and implement policies that are conducive to realization of this potential.

Lal, R., R. F. Follett, et al. (2007). "Soil carbon sequestration to mitigate climate change and advance food security " Soil Science **172**(12): 943–956.

> World soils have been a source of atmospheric carbon dioxide since the dawn of settled agriculture, which began about 10 millennia ago. Most agricultural soils have lost 30% to 75% of their antecedent soil organic carbon (SOC) pool or 30 to 40 t C ha-1. The magnitude of loss is often more in soils prone to accelerated erosion and other degradative processes. On a global scale, CO_2-C emissions since 1850 are estimated at 270 +/- 30 giga ton (billion ton or Gt) from fossil fuel combustion compared with 78 +/- 12 Gt from soils. Consequently, the SOC pool in agricultural soils is much lower than their potential capacity. Furthermore, depletion of the SOC pool also leads to degradation in soil quality and declining agronomic/biomass productivity. Therefore, conversion to restorative land uses (e.g., afforestation, improved pastures) and adoption of recommended management practices (RMP) can enhance SOC and improve soil quality. Important RMP for enhancing SOC include conservation tillage, mulch farming, cover crops, integrated nutrient management including use of manure and compost, and agroforestry. Restoration of degraded/desertified soils and ecosystems is an important strategy. The rate of SOC sequestration, ranging from 100 to 1000 kg ha-1 year-1, depends on climate, soil type, and site-specific management. Total potential of SOC sequestration in the United States of 144 to 432 Mt year-1 (288 Mt year-1) comprises 45 to 98 Mt in cropland, 13 to 70 Mt in grazing land, and 25 to 102 Mt in forestland. The global potential of SOC sequestration is estimated at 0.6 to 1.2 Gt C year-1, comprising 0.4 to 0.8 Gt C year-1 through adoption of RMP on cropland (1350 Mha), and 0.01 to 0.03 Gt C year-1 on irrigated soils (275 Mha), and 0.01 to 0.3 Gt C year-1 through improvements of rangelands and grasslands (3700 Mha). In addition, there is a large

potential of C sequestration in biomass in forest plantations, short rotation woody perennials, and so on. The attendant improvement in soil quality with increase in SOC pool size has a strong positive impact on agronomic productivity and world food security. An increase in the SOC pool within the root zone by 1 t C ha-1 year-1 can enhance food production in developing countries by 30 to 50 Mt year-1 including 24 to 40 Mt year-1 of cereal and legumes, and 6 to 10 Mt year-1 of roots and tubers. Despite the enormous challenge of SOC sequestration, especially in regions of warm and arid climates and predominantly resource-poor farmers, it is a truly a win-win strategy. While improving ecosystem services and ensuring sustainable use of soil resources, SOC sequestration also mitigates global warming by offsetting fossil fuel emissions and improving water quality by reducing nonpoint source pollution.

Lal, R., J. M. Kimble, et al. (1999). The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Boca Raton, FL, CRC Press.

from exec. summary: "This report...assesses the potential of U.S. cropland to sequester carbon (C). It concludes that properly applied soil restorative processes and best management practices (BMPs) can mitigate the greenhouse effect both by decreasing the emissions of greenhouse gases (GHGs) from U.S. agricultural activities and by making U.S. cropland a major sink for C sequestration. Worldwide soil restoration and adoption of BMPs has a potential to mitigate effectively a large proportion ofthe annual increase in atmostpheric concentration of CO_2."

Lal, R., A. A. Mahboubi, et al. (1994). "Long-term tillage and rotation effects on properties of a central Ohio soil." Soil Science Society of America Journal **58**(2): 517–522.

Sustainable use of soil resources can be assessed from management-induced changes in soil properties from long-term experiments. Such data are scanty, especially with regard to changes in soil physical properties. Therefore, soil physical and chemical analyses were performed 28 yr after initiating a crop rotation-tillage experiment on a well-drained Wooster silt loam soil (fine-loamy, mixed, mesic Typic Fragiudalf) at Wooster, OH. All combinations of three rotations (continuous corn [CC; Zea mays L.]; corn and soybean [Glycine mar (L.) Merr.] in a 2-yr rotation [CS]; and corn, oat [Avena sativa L.], and meadow in a 3-yr rotation [COM]) and of three tillage treatments (no-tillage [NT]; chisel plow [CP]; and moldboard plow [MP]) were maintained on the same plots for the entire length of study. All crops were grown every year. Soil properties studied for the 0- to 15-cm layer were: structural stability of aggregates, bulk density, total porosity, penetration resistance, organic C, pH, cation-exchange capacity (CEC), and exchangeable K, Ca and Mg. Mean bulk densities measured prior to tillage treatments and planting were 1.18, 1.24, and 1.28 Mg m-3 for CC, CS, and COM rotations, respectively. The lowest bulk density was observed for the CC-NT combination. Total aggregation in CS was 26.9% greater than CC and 111.2% greater than COM. With tillage treatments, aggregation was in the order of NT>CP>MP. Rotation treatments had no effect on aggregate size. In accord with bulk density, the relative magnitude of organic C content was 100, 85, and 63 for CC, CS, and COM rotations, respectively.

Lamm, F. R., H. L. Manges, et al. (1995). "Water requirement of subsurface drip-irrigated corn in northwest Kansas." Transactions of the ASAE **38**(2): 441–448.

Irrigation development during the last 50 years has led to overdraft in many areas of the large Ogallala aquifer in the central United States. Faced with the decline in irrigated acres, irrigators and wafer resource personnel are examining many new techniques to conserve this valuable resource. A three-year study (1989 to 1991) was conducted on a Keith silt loam soil (Aridic Argiustoll) in northwest Kansas to determine the water requirement of corn (*Zea mays* L.) grown using a subsurface drip irrigation (SDI) system. A dryland control and five irrigation treatments, designed to meet from 25 to 125% of calculated evapotranspiration (ET) needs of the crop were examined. Although cumulative evapotranspiration and precipitation were near normal for the three growing seasons, irrigation requirements were higher than normal due to the timing of precipitation and high evapotranspiration periods. Analysis of the seasonal progression of soil water revealed the well-watered treatments (75 to 125% of ET treatments) maintained stable soil water levels above approximately 55 to 60% of field capacity for the 2.4-m soil profile; while the deficit-irrigated treatments (no irrigation to 50% of ET treatments) mined the soil water. Corn yields were highly linearly related to calculated crop water use, producing 0.048 Mg/ha of grain for each millimeter of water used above a threshold of 328 mm. Analysis of the calculated water balance components indicated that careful management of SDI systems can reduce net irrigation needs by nearly 25%, while still maintaining top yields of 12.5 Mg/ha. Most of these water savings can be attributable to minimizing nonbeneficial water balance components such as soil evaporation and long-term drainage. The SDI system is one technology that can make significant improvements in water use efficiency by better managing the water balance components.

LaSalle, T. J. and P. Hepperly (2008). Regenerative Organic Farming: A Solution to Global Warming. Kutztown, PA, Rodale Institute.

Laub, C. A. and J. M. Luna (1992). "Winter cover crop suppression practices and natural enemies of armyworm (Lepidoptera: *Noctuidae*) in no-till corn." Environmental Entomology **21**: 41–49.

Rye, *Secale cereale* L., used as a winter cover crop was killed by the herbicide paraquat or by mowing with a rotary mower. In subsequent no-ill corn, *Glyptapanteles militaris* (Walsh) (Hymenoptera: Braconidae) and *Periscepsia laevigata* (Wulp) (Diptera: Tachinidae) were the most abundant of twelve species of parasitoids that emerged from field-collected larvae of the armyworm, *Pseudaletia unipuncta* (Haworth). No effects of cover crop suppression practices were detected for parasitism rates for any individual species or for total armyworm parasitism. Seasonal parasitism rates ranged from 32 to 45%. HIgher numbers of *Pterostichus* spp. and *Scarites* spp. (Coleoptera: Carabidae), and wolf spiders (Araneae: Lycosidae) occurred early in the corn season in the mowed cover crop treatment compared with the herbicide killed cover crop treatment. Subsequent reduction oflarval densities of armyworm in mowed plots following higher predator densities suggests the role of these generalist predators in biological control of armyworm.

LeCain, D. R., J. A. Morgan, et al. (2000). "Carbon exchange rates in grazed and ungrazed pastures of Wyoming." Journal of Range Management **53**(2): 199–206.

The influence of cattle grazing on carbon cycling in the mixed grass prairie was investigated by measuring the CO2 exchange rate in pastures with a 13 year history of heavy or light grazing and an ungrazed exclosure at the High Plains Grasslands Research Station near Cheyenne, Wyo. In 1995, 1996 and 1997 a closed system chamber, which covered 1 m(2) of ground, was used every 3 weeks from April to October to measure midday CO2 exchange rate. Green vegetation index (similar to leaf area index), soil respiration rate, species composition, soil mater content, soil temperature, and air temperature were also measured to relate to CO2 exchange rates of the 3 grazing treatments. Treatment differences varied among gears, but overall early season (mid April to mid June) CO2 exchange rates in the grazed pastures were higher (up to 2.5 X) than in the exclosure. Higher early season CO2 exchange rates were associated with earlier spring green-up in grazed pastures, measured as higher green vegetation index. As the growing season progressed, green vegetation index increased in all pastures, but more so in the ungrazed exclosure, resulting in occasionally higher (up to 2 X) CO2 exchange rate compared with grazed pastures late in the season. Seasonal treatment differences mere not associated with soil temperature, soil respiration rate, or air temperature, nor was there a substantial change in species composition due to grazing. We hypothesize that early spring green-up and higher early season CO2 exchange rate in grazed pastures may be due to better light penetration and a warmer microclimate near the soil surface because of less litter and standing dead compared to the ungrazed pastures. When all the measurements mere averaged over the entire season, there mas no difference in CO2 exchange rate between heavily grazed, lightly prated and ungrazed pastures in this ecosystem.

Lee, J. J., D. L. Phillips, et al. (1993). "The effect of trends in tillage practices on erosion and carbon content of soils in the U.S. corn belt." Water, Air, and Soil Pollution **70**(1): 389–401.

The EPIC model was used to simulate soil erosion and soil C content at 100 randomly selected sites in the US corn belt. Four management scenarios were run for 100 years: (1) current mix of tillage practices maintained; (2) current trend of conversion to mulch-till and no-till maintained; (3) trend to increased no-till; (4) trend to increased no-till with addition of winter wheat cover crop. As expected, the three alternative scenarios resulted in substantial decreases in soil erosion compared to the current mix of tillage practices. C content of the top 15 cm of soil increased for the alternative scenarios, while remaining approximately constant for the current tillage mix. However, total soil C to a depth of 1 m from the original surface decreased for all scenarios except for the no-till plus winter wheat cover crop scenario. Extrapolated to the entire US corn belt, the model results suggest that, under the current mix of tillage practices, soils used for corn and/or soybean production will lose 3.2 × 106 tons of C per year for the next 100 years. About 21% of this loss will be C transported off-site by soil erosion; an unknown fraction of this C will be released to the atmosphere. For the base trend and increased no-till trend, these soils are projected to lose 2.2 × 106 t-C yr-1 and 1.0 × 106 t-C yr-1, respectively. Under the increased no-till plus cover crop scenario, these soils become a small sink of 0.1 × 106 t-C yr-1. Thus, a shift from current tillage practices to widespread use of no-till plus winter cover could conserve and sequester a total of 3.3 × 106 t-C yr-1 in the soil for the next 100 years.

Lehmann, J. (2007). "A handful of carbon." Nature **447**(7141): 143–144.

Lehmann, J., J. L. Gaunt, et al. (2006). "Bio-char sequestration in terrestrial ecosystems – A review." Mitigation and Adaptation Strategies for Global Change **11**: 403–427.

The application of bio-char (charcoal or biomass-derived black carbon (C)) to soil is proposed as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Apart from positive effects in both reducing emissions and increasing the sequestration of greenhouse gases, the production of bio-char and its application to soil will deliver immediate benefits through improved soil fertility and increased crop production. Conversion of biomass C to bio-char C leads to sequestration of about 50% of the initial C compared to the low amounts retained after burning (3%) and biological decomposition (<10–20% after 5–10 years), therefore yielding more stable soil C than burning or direct land application of biomass. This efficiency of C conversion of biomass to bio-char is highly dependent on the type of feedstock, but is not significantly affected by the pyrolysis temperature (within 350–500 ?C common for pyrolysis). Existing slash-andburn systems cause significant degradation of soil and release of greenhouse gases and opportunies may exist to enhance this system by conversion to slash-and-char systems. Our global analysis revealed that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash-and-burn is replaced by slash-and-char. Agricultural and forestry wastes such as forest residues, mill residues, field crop residues, or urban wastes add a conservatively estimated 0.16 PgCyr-1. Biofuel production using modern biomass can produce a bio-char by-product through pyrolysis which results in 30.6 kgC sequestration for each GJ of energy produced. Using published projections of the use of renewable fuels in the year 2100, bio-char sequestration could amount to 5.5–9.5 PgCyr-1 if this demand for energy was met through pyrolysis, which would exceed current emissions from fossil fuels (5.4 PgC yr-1). Bio-char soil management systems can deliver tradable C emissions reduction, and C sequestered is easily accountable, and verifiable.

Lehmann, J., D. C. Kern, et al. (2004). Soil fertility and production potential. Amazonian Dark Earths: Origin, Properties, Management. J. Lehmann, D. C. Kern, B. Glaser and W. I. Woods. Dordrecht, Springer Netherlands**:** 105–124.

Lehmann, J., J. Skjemstad, et al. (2008). "Australian climate-carbon cycle feedback reduced by soil black carbon." Nature Geoscience **1**(12): 832–835.

Annual emissions of carbon dioxide from soil organic carbon are an order of magnitude greater than all anthropogenic carbon dioxide emissions taken together(1). Global warming is likely to increase the decomposition of soil organic carbon, and thus the release of carbon dioxide from soils(2-5), creating a positive feedback(6-9). Current models of global climate change that recognize this soil carbon feedback are inaccurate if a larger fraction of soil organic carbon than postulated has a very slow decomposition rate. Here we show that by including realistic stocks of black carbon in prediction models, carbon dioxide emissions are reduced by 18.3 and 24.4% in two Australian savannah regions in response to a warming of 3 degrees C over 100 years(1). This reduction in temperature sensitivity, and thus the magnitude of the positive feedback, results from the long mean residence time of black carbon, which we estimate to be approximately 1,300 and 2,600 years, respectively. The inclusion of black carbon in climate models is likely to require spatially explicit information about its distribution, given that the black carbon content of soils ranged from 0 to 82% of soil organic carbon in a continental-scale analysis of Australia. We conclude that accurate information about the distribution of black carbon in soils is important for projections of future climate change.

Leifeld, J., R. Reiser, et al. (2009). "Consequences of conventional versus organic farming on soil carbon: Results from a 27-year field experiment." Agronomy Journal **101**(5): 1204–1218.

Organic farming practices are regarded as being beneficial for the environment by promoting soil quality and sequestering soil organic carbon (SOC). We studied SOC dynamics in the long-term field experiment DOK in Switzerland. The experiment compares three organically fertilized treatments under conventional (CONFYM), bioorganic (BIOORG), and biodynamic (BIO-DYN) management, and two systems with (CONMIN) or without (NOFERT) mineral fertilizer. We analyzed measured SOC time series from 1977 to 2004 and applied soil fractionation, radiocarbon dating, and modeling with the carbon model RothC. The SOC declined significantly in most parcels, but was not systematically different between systems. Initial SOC contents correlated with soil texture and were identified as being important with respect to the change rate. The SOC loss was at the expense of mineral-associated carbon whereas the more labile fractions increased. The overall decline was explained by reduced carbon inputs since commencement of the experiment and was most pronounced in NOFERT and CONMIN. The model satisfactorily simulated the dynamics of most of the treatments for both initialization with equilibrium runs or measured SOC fractions. Carbon loss in CONFYM was not fully captured by the model. Composition of organic fertilizers depended on the particular management, and a model adjustment of their relative stability improved the match between model and measurements. Model runs without management effects indicated that the observed increase in temperatures at the experimental site does not induce a change in SOC. Overall, the study does not support a benefit of organic farming on SOC contents compared with conventional systems with manure.

Lemke, R. L., H. Wang, et al. (2003). The effect of nitrogen fertilizer placement, formulation, timing and rate on greenhouse gas emissions and agronomic performance. Swift Current, SK, Agriculture & Agri-Food Canada.

This 3-year project compared agronomic performance, energy use and nitrous oxide (N2O) emissions from a variety of N-fertilizer managements...Estimates of direct N2O loss on an annual basis were developed and presented for each of the selected treatments. All direct and indirect nonrenewable energy going into the manufacture, formulation, packaging, distribution, transportation, maintenance, and application of all inputs used in each crop production system were tabulated....Considering grain yields over all sites, crops and years, the results from this study confirm that fall banded N and broadcasted urea tend to be less efficient than their spring banded counterparts. Interestingly, urea appeared to provide slightly better yields at Indian Head, but AA and urea appeared to perform equally at the other three sites. This "lack of difference" between N-formulation is of some significance in two respects. Firstly, it suggests that sideband placement of AA is as effective as urea. Secondly, it has long been assumed that AA is not effective in the Swift Current area, but our results imply that AA is equal to urea in this region....The results of this study confirm that N2O emissions increase with fertilizer N applications. They also suggest that, within the range of rates applied in this study, emissions increase in a linear fashion. In other words, the percentage of fertilizer-N lost as N2O did not increase as fertilizer rates increased. The great majority of the percent-loss values calculated, fell at or below 0.4 % with and overall mean value of 0.2 %. Despite the high degree of uncertainty surrounding our estimates, we feel the results clearly indicate a need to modify the current N2O loss coefficient of 1.25 % that is applied to fertilizer-N use in western Canada. We

conclude that N2O emissions are similar from AA compared to urea. There was a weak trend for emissions to be higher when urea was broadcast rather than banded, and when fertilizer-N was mid-row rather than side-row banded.

Lemus, R. and R. Lal (2005). "Bioenergy crops and carbon sequestration." Critical Reviews in Plant Sciences **24**(1): 1–21.

Greenhouse gas (GHG) emissions constitute a global problem. The need for agricultural involvement in GHG mitigation has been widely recognized since the 1990s. The concept of C sinks, C credits, and emission trading has attracted special interests in herbaceous and woody species as energy crops and source of biofuel feedstock. Bioenergy crops are defined as any plant material used to produce bioenergy. These crops have the capacity to produce large volume of biomass, high energy potential, and can be grown in marginal soils. Planting bioenergy crops in degraded soils is one of the promising agricultural options with C sequestration rates ranging from 0.6 to 3.0 Mg C ha−1 yr−1. About 60 million hectares (Mha) of land is available in the United States and 757 Mha in the world to grow bioenergy crops. With an energy offset of 1 kg of C in biomass per 0.6 kg of C in fossil fuel, there exists a vast potential of offsetting fossil fuel emission. Bioenergy crops have the potential to sequester approximately 318 Tg C yr−1 in the United States and 1631 Tg C yr−1 worldwide. Bioenergy crops consist of herbaceous bunch-type grasses and short-rotation woody perennials. Important grasses include switchgrass (Panicum virgatum L.), elephant grass (Pennissetum purpureum Schum.), tall fescue (Fetusca arundinacea L.), etc. Important among short-rotation woody perennials are poplar (Populus spp.), willow (Salix spp.), mesquite (Prosopis spp.), etc. The emissions of CO2 from using switchgrass as energy crop is 1.9 kg C Gj−1 compared with 13.8, 22.3, and 24.6 kg C Gj−1 from using gas, petroleum, and coal, respectively. Mitigation of GHG emissions cannot be achieved by C sinks alone, a substantial reduction in fossil fuel combustion will be necessary. Carbon sequestration and fossil fuel offset by bioenergy crops is an important component of a possible total societal response to a GHG emission reduction initiative.

Li, C. (1995). Modeling impact of agricultural practices on soil C and N_2O emissions. Soil Management and the Greenhouse Effect. R. Lal, J. M. Kimble, E. Levine and B. A. Stewart. Boca Raton, FL, CRC Press**:** 101–112.

Li, C., S. Frolking, et al. (2005). "Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing." Climatic Change **72**(3): 321–338.

Strategies for mitigating the increasing concentration of carbon dioxide (CO2) in the atmosphere include sequestering carbon (C) in soils and vegetation of terrestrial ecosystems. Carbon and nitrogen (N) move through terrestrial ecosystems in coupled biogeochemical cycles, and increasing C stocks in soils and vegetation will have an impact on the N cycle. We conducted simulations with a biogeochemical model to evaluate the impact of different cropland management strategies on the coupled cycles of C and N, with special emphasis on C-sequestration and emission of the greenhouse gases methane (CH4) and nitrous oxide (N2O). Reduced tillage, enhanced crop residue incorporation, and farmyard manure application each increased soil C-sequestration, increased N2O emissions, and had little effect on CH4 uptake. Over 20 years, increases in N2O emissions, which were converted into CO2-equivalent emissions with 100-year global warming potential multipliers, offset 75–310% of the carbon sequestered, depending on the scenario. Quantification of these types of biogeochemical interactions must be incorporated into assessment frameworks and trading mechanisms to accurately evaluate the value of agricultural systems in strategies for climate protection.

Li, C., S. Frolking, et al. (2005). "Modeling impacts of farming management alternatives on CO_2, CH_4, and N_2O emissions: A case study for water management of rice agriculture of China." Global Biogeochemical Cycles **19**(3): GB3010.

Since the early 1980s, water management of rice paddies in China has changed substantially, with midseason drainage gradually replacing continuous flooding. This has provided an opportunity to estimate how a management alternative impacts greenhouse gas emissions at a large regional scale. We integrated a process-based model, DNDC, with a GIS database of paddy area, soil properties, and management factors. We simulated soil carbon sequestration (or net CO2 emission) and CH4 and N2O emissions from China's rice paddies (30 million ha), based on 1990 climate and management conditions, with two water management scenarios: continuous flooding and midseason drainage. The results indicated that this change in water management has reduced aggregate CH4 emissions about 40%, or 5 Tg CH4 yr-1, roughly 5-10% of total global methane emissions from rice paddies. The mitigating effect of midseason drainage on CH4 flux was highly uneven across the country; the highest flux reductions (>200 kg CH4-C ha-1 yr-1) were in Hainan, Sichuan, Hubei, and Guangdong provinces, with warmer weather and multiple-cropping rice systems. The smallest flux reductions (<25 kg CH4-C ha-1 yr-1) occurred in Tianjin, Hebei, Ningxia, Liaoning, and Gansu Provinces, with relatively cool weather and single cropping systems. Shifting water management from continuous flooding to midseason drainage increased N2O emissions from Chinese rice paddies by 0.15 Tg N yr-1 (~50% increase). This offset a large fraction of the greenhouse gas radiative forcing benefit gained by the decrease in CH4 emissions. Midseason drainage-induced N2O fluxes were high (>8.0 kg N/ha) in Jilin, Liaoning, Heilongjiang, and Xinjiang provinces, where the paddy soils contained relatively high organic matter. Shifting water management from continuous flooding to midseason drainage reduced total net CO2 emissions by 0.65 Tg CO2-C yr-1, which made a relatively small contribution to the net climate impact due to the low radiative potential of CO2. The change in water management had very different effects on net greenhouse gas mitigation when implemented across climatic zones, soil types, or cropping systems. Maximum CH4 reductions and minimum N2O increases were obtained when the mid-season draining was applied to rice paddies with warm weather, high soil clay content, and low soil organic matter content, for example, Sichuan, Hubei, Hunan, Guangdong, Guangxi, Anhui, and Jiangsu provinces, which have 60% of China's rice paddies and produce 65% of China's rice harvest.

Li, C., A. Mosier, et al. (2004). "Modeling greenhouse gas emissions from rice-based production systems: Sensitivity and upscaling." Global Biogeochemistry Cycles **18**: GB1043.

A biogeochemical model, Denitrification-Decomposition (DNDC), was modified to enhance its capacity of predicting greenhouse gas (GHG) emissions from paddy rice ecosystems. The major modifications focused on simulations of anaerobic biogeochemistry and rice growth as well as parameterization of paddy rice management. The new model was tested for its sensitivities to management alternatives and variations in natural conditions including weather and soil properties. The test results indicated that (1) varying management practices could substantially

affect carbon dioxide (CO2), methane (CH4), or nitrous oxide (N2O) emissions from rice paddies; (2) soil properties affected the impacts of management alternatives on GHG emissions; and (3) the most sensitive management practices or soil factors varied for different GHGs. For estimating GHG emissions under certain management conditions at regional scale, the spatial heterogeneity of soil properties (e.g., texture, SOC content, pH) are the major source of uncertainty. An approach, the most sensitive factor (MSF) method, was developed for DNDC to bring the uncertainty under control. According to the approach, DNDC was run twice for each grid cell with the maximum and minimum values of the most sensitive soil factors commonly observed in the grid cell. The simulated two fluxes formed a range, which was wide enough to include the “real” flux from the grid cell with a high probability. This approach was verified against a traditional statistical approach, the Monte Carlo analysis, for three selected counties or provinces in China, Thailand, and United States. Comparison between the results from the two methods indicated that 61-99% of the Monte Carlo-produced GHG fluxes were located within the MSA-produced flux ranges. The result implies that the MSF method is feasible and reliable to quantify the uncertainties produced in the upscaling processes. Equipped with the MSF method, DNDC modeled emissions of CO2, CH4, and N2O from all of the rice paddies in China with two different water management practices, i.e., continuous flooding and midseason drainage, which were the dominant practices before 1980 and in 2000, respectively. The modeled results indicated that total CH4 flux from the simulated 30 million ha of Chinese rice fields ranged from 6.4 to 12.0 Tg CH4-C per year under the continuous flooding conditions. With the midseason drainage scenario, the national CH4 flux from rice agriculture reduced to 1.7–7.9 Tg CH4-C. It implied that the water management change in China reduced CH4 fluxes by 4.2–4.7 Tg CH4-C per year. Shifting the water management from continuous flooding to midseason drainage increased N2O fluxes by 0.13–0.20 Tg N2O-N/yr, although CO2 fluxes were only slightly altered. Since N2O possesses a radiative forcing more than 10 times higher than CH4, the increase in N2O offset about 65% of the benefit gained by the decrease in CH4 emissions.

Li, F., Y. Miao, et al. (2009). "In-season optical sensing improves nitrogen-use efficiency for wineter wheat." Soil Science Society of America Journal **73**(5): 1566–1574.

Optical sensor-based N management strategies are promising approaches to improve N-use efficiency (NUE) and reduce environmental pollution risk. The objective of this study was to evaluate an active optical sensor-based in-season N management strategy for winter wheat (Triticum aestivum L.) in the North China Plain (NCP). Initially, 10 field experiments were conducted at four villages in NCP in the 2004/05, 2005/06, and 2006/07 growing seasons to evaluate the in-season N requirement prediction developed by Oklahoma State University. Then the N application rates, winter wheat grain yield, NUE, economic returns, residual N content after harvest and apparent N loss were compared among three different management systems on a total of 16 farmer fields in 2005/2006 and 14 farmer fields in 2006/2007. The systems included a sensor-based system, a soil test-based approach crediting soil residual mineral N (N-min) to different depth at different growth stages, and common farmer practices. Averaged across site-years, the sensor-based, soil N-min-based N management strategies, and farmer practices produced similar grain yields but used 67, 88, and 372 kg N ha(-1), respectively. Nitrogen-use efficiencies were 61.3, 51.0, and 13.1% for the three methods of N recommendations, correspondingly. Their residual N content in the soil and apparent N loss were 115, 122, and 208 kg N ha(-1), and 4, 15, and 205 kg N ha(-1), respectively. The optical sensor-based N management strategy is relatively easy to use, has better potential to improve

NUE and economic returns, and reduces residual soil N content and apparent N loss than other methods currently used in the NCP.

Liebig, M. A., J. R. Gross, et al. (2010). "Grazing management contributions to net global warming potential: A long-term evaluation in the northern Great Plains." Journal of Environmental Quality **39**(3): 799–809.

The role of grassland ecosystems as net sinks or sources of greenhouse gases (GHGs) is limited by a paucity of information regarding management impacts on the flux of nitrous oxide (N2O) and methane (CH4). Furthermore, no long-term evaluation of net global warming potential (GWP) for grassland ecosystems in the northern Great Plains (NGP) of North America has been reported. Given this need, we sought to determine net GWP for three grazing management systems located within the NGP. Grazing management systems included two native vegetation pastures (moderately grazed pasture [MGP], heavily grazed pasture [HGP]) and a heavily grazed crested wheatgrass [Agropyron desertorum (Fisch. ex. Link) Schult.] pasture (CWP) near Mandan, ND. Factors evaluated for their contribution to GWP included (i) CO2 emissions associated with N fertilizer production and application, (ii) literature-derived estimates of CH4 production for enteric fermentation, (iii) change in soil organic carbon (SOC) over 44 yr using archived soil samples, and (iv) soil–atmosphere N2O and CH4 fluxes over 3 yr using static chamber methodology. Analysis of SOC indicated all pastures to be significant sinks for SOC, with sequestration rates ranging from 0.39 to 0.46 Mg C ha-1 yr-1. All pastures were minor sinks for CH4 (<2.0 kg CH4–C ha-1 yr-1). Greater N inputs within CWP contributed to annual N2O emission nearly threefold greater than HGP and MGP. Due to differences in stocking rate, CH4 production from enteric fermentation was nearly threefold less in MGP than CWP and HGP. When factors contributing to net GWP were summed, HGP and MGP were found to serve as net CO2equiv. sinks, while CWP was a net CO2equiv. source. Values for GWP and GHG intensity, however, indicated net reductions in GHG emissions can be most effectively achieved through moderate stocking rates on native vegetation in the NGP.

Liebig, M. A., H. A. Johnson, et al. (2005). "Soil carbon under switchgrass stands and cultivated cropland." Biomass & Bioenergy **28**(4): 347–354.

Switchgrass (Panicum virgatum L.) is considered to be a valuable bioenergy crop with significant potential to sequester soil organic carbon (SOC). A study was conducted to evaluate soil carbon stocks within established switchgrass stands and nearby cultivated cropland on farms throughout the northern Great Plains and northern Cornbelt. Soil from 42 paired switchgrass/cropland sites throughout MN, ND, and SD was sampled to a depth of 120 cm and analyzed for soil carbon in depth increments of 0-5, 5-10, 10-20, 20-30, 30-60, 60-90, and 90-120 cm. SOC was greater ($P < 0.1$) in switchgrass stands than cultivated cropland at 0-5, 30-60, and 60-90 cm. Differences in SOC between switchgrass stands and cultivated cropland were especially pronounced at deeper soil depths, where treatment differences were 7.74 and 4.35 Mg ha(-1) for the 30-60 and 60-90 cm depths, respectively. Greater root biomass below 30 cm in switchgrass likely contributed to trends in SOC between switchgrass stands and cultivated cropland. Switchgrass appears to be effective at storing SOC not just near the soil surface, but also at depths below 30 cm where carbon is less susceptible to mineralization and loss.

Liebig, M. A., J. A. Morgan, et al. (2005). "Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada." Soil & Tillage Research **83**(1): 25–52.

Liu, C., X. Zheng, et al. (2010). "Nitrous oxide and nitric oxide emissions from an irrigated cotton field in Northern China." Plant and Soil **332**(1–2): 123–134.

Cotton is one of the major crops worldwide and delivers fibers to textile industries across the globe. Its cultivation requires high nitrogen (N) input and additionally irrigation, and the combination of both has the potential to trigger high emissions of nitrous oxide (N2O) and nitric oxide (NO), thereby contributing to rising levels of greenhouse gases in the atmosphere. Using an automated static chamber measuring system, we monitored in high temporal resolution N2O and NO fluxes in an irrigated cotton field in Northern China, between January 1st and December 31st 2008. Mean daily fluxes varied between 5.8 to 373.0 μg N2O-N m−2 h−1 and −3.7 to 135.7 μg NO-N m−2 h−1, corresponding to an annual emission of 2.6 and 0.8 kg N ha−1 yr−1 for N2O and NO, respectively. The highest emissions of both gases were observed directly after the N fertilization and lasted approximately 1 month. During this time period, the emission was 0.85 and 0.22 kg N ha−1 for N2O and NO, respectively, and was responsible for 32.3% and 29.0% of the annual total N2O and NO loss. Soil temperature, moisture and mineral N content significantly affected the emissions of both gases (p<0.01). Direct emission factors were estimated to be 0.95% (N2O) and 0.24% (NO). We also analyzed the effects of sampling time and frequency on the estimations of annual cumulative N2O and NO emissions and found that low frequency measurements produced annual estimates which differed widely from those that were based on continuous measurements.

Liu, X. J., A. R. Mosier, et al. (2006). "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 **280**(1): 177–188.

To evaluate the impact of N placement depth and no-till (NT) practice on the emissions of NO, N2O, CH4 and CO2 from soils, we conducted two N placement experiments in a long-term tillage experiment site in northeastern Colorado in 2004. Trace gas flux measurements were made 2–3 times per week, in zero-N fertilizer plots that were cropped continuously to corn (Zea mays L.) under conventional-till (CT) and NT. Three N placement depths, replicated four times (5, 10 and 15 cm in Exp. 1 and 0, 5 and 10 cm in Exp. 2, respectively) were used. Liquid urea–ammonium nitrate (UAN, 224 kg N ha)1) was injected to the desired depth in the CT- or NT-soils in each experiment. Mean flux rates of NO, N2O, CH4 and CO2 ranged from 3.9 to 5.2 lg N m)2 h)1, 60.5 to 92.4 lg N m)2 h)1,)0.8 to 0.5 lg C m)2 h)1, and 42.1 to 81.7 mg C m)2 h)1 in both experiments, respectively. Deep N placement (10 and 15 cm) resulted in lower NO and N2O emissions compared with shallow N placement (0 and 5 cm) while CH4 and CO2 emissions were not affected by N placement in either experiment. Compared with N placement at 5 cm, for instance, averaged N2O emissions from N placement at 10 cm were reduced by more than 50% in both experiments. Generally, NT decreased NO emission and CH4 oxidation but increased N2O emissions compared with CT irrespective of N placement depths. Total net global warming potential (GWP) for N2O, CH4 and CO2 was reduced by deep N placement only in Exp. 1 but was increased by NT in both experiments. The study results suggest that deep N placement (e.g., 10 cm) will be an effective option for reducing N oxide emissions and GWP from both fertilized CT- and NT-soils.

Lockeretz, W., G. Shearer, et al. (1981). "Organic farming in the Corn Belt." Science **211**(4482): 540–547.

A small minority of farmers in the Midwest produces crops on a commercial scale without using modern fertilizers and pesticides. On the basis of a 5-year study, it appears that these farmers have more in common with the majority of farmers in the region than with certain stereotypes of organic farmers. Their farming practices (other than chemical use), the size and labor requirements of their farms, and the production and profitability they achieve differ from those of conventional farmers by considerably less than might be expected on the basis of the fundamental importance of chemicals in modern agricultural production. Compared to conventional methods, organic methods consume less fossil energy and cause less soil erosion, but have mixed effects on soil nutrient status and grain protein content.

Lucier, G., S. Pollack, et al. (2006). Fruit and Vegetable Backgrounder. Washington, DC, U.S. Department of Agriculture, Economic Research Service**:** 55.

The U.S. fruit and vegetable industry accounts for nearly a third of U.S. crop cash receipts and a fifth of U.S. agricultural exports. A variety of challenges face this complex and diverse industry in both domestic and international markets, ranging from immigration reform and its effect on labor availability to international competitiveness. The national debate on diet and health frequently focuses on the nutritional role of fruit and vegetables, and a continued emphasis on the benefits of eating produce may provide opportunities to the industry. In the domestic market, Americans are eating more fruit and vegetables than they did 20 years ago, but consumption remains below recommended levels. In terms of per capita consumption expressed on a fresh-weight basis, the top five vegetables are potatoes, tomatoes, lettuce, sweet corn, and onions while the top five fruit include oranges, grapes (including wine grapes), apples, bananas, and pineapples. The industry also faces a variety of trade-related issues, including competition with imports. During 2002-04, imports accounted for 21 percent of domestic consumption of all fresh and processed fruit and vegetables, up from 16 percent during 1992-94.

Lynch, D. H., R. D. H. Cohen, et al. (2005). "Management of Canadian prairie region grazed grasslands: Soil C sequestration, livestock productivity and profitability." Canadian Journal of Soil Science **85**(2): 183–192.

The GrassGro model (a computer simulation of management-induced changes in range and pasture forage and livestock productivity) was combined with spreadsheet analyses to estimate the influence of improved grazing practices on soil organic carbon (SOC), and farm profitability, across native rangelands and tame pastures of the southern Canadian Prairies. Improved practices included complementary grazing (CG) and reduced stocking density (RSD) on rangeland; and N fertilization (FERT), seeded grass/legumes grazed continuously (GLGC) or rotationally (GLGR), and RSD on tame pastures. The analysis was stratified into three ecoregions on the basis of similarities in climate and soil type. Averaged over 30 yr and ecoregions, SOC rates of gain through improved management were 5 (RSD) to 26 (CG) kg C ha(-1) yr(-1) for rangelands, and 86 (RSD), 75 (GLGC), 62 (GLGR) and 222 (FERT) kg C ha(-1) yr(-1) for tame pastures. Gains with FERT were considered largely negated by associated energy (C) costs, N2O emissions, and shifts in grassland species. The CG system alone improved net returns to the producer. The estimated potential combined SOC gain on prairie grazinglands (11.5 Mha) was 1.63 MMT CO2 yr(-1) (or 0.465 MMT C yr(-1)), slightly less than the 1.70 MMT CO2 yr(-1) currently emitted from agricultural soils in Canada.

Lyon, D. J., D. C. Nielsen, et al. (2007). "Choice of summer fallow replacement crops impacts subsequent winter wheat." Agronomy Journal **99**(2): 578–584.

Winter wheat (Triticum aestivum L.) is the foundation of dryland cropping systems in the Central Great Plains. The objective of this study was to quantify the effects of four short-season spring-planted crops used to replace summer fallow on the subsequent winter wheat crop. Wheat was seeded into four crop stubbles [spring triticale (xTriticosecale Wittmack), dry pea (Pisum sativum L.), foxtail millet (Setaria italica L. Beauv.), and proso millet (Panicum miliaceum L.)] at sites near Akron, CO, and Sidney, NE, in the fall of 2004 and 2005. These summer fallow replacement crops were planted into silt loam soils at three different soil water levels at planting (low, medium, and high). Winter wheat water use was 3.6 cm greater, and grain yield was 662 kg ha-1 greater in the high water treatment compared with the low water treatment averaged across all sites and years. Winter wheat used an average of 4.3 cm more water following early planted summer crops (triticale and dry pea) than after late planted summer crops (foxtail and proso millet), but this increased water use did not consistently translate into increased grain yield as a result of terminal drought at Sidney in 2006. The high water treatment always had a positive net return. The high cost of pea seed ($3.30 kg-1, USD) strongly reduced profitability. The flexible summer fallow cropping system appears to be most applicable when using short-duration summer annual forage crops such as triticale and foxtail millet.

Machado, S., K. Rhinhart, et al. (2006). "Long-term cropping system effects on carbon sequestration in eastern Oregon." Journal of Environmental Quality **35**(4): 1548–1553.

Soil organic carbon (SOC) has beneficial effects on soil quality and productivity. Cropping systems that maintain and/or improve levels of SOC may lead to sustainable crop production. This study evaluated the effects of long-term cropping systems on C sequestration. Soil samples were taken at 0- to 10-, 10- to 20-, 20- to 30-, and 30- to 40-cm soil depth profiles from grass pasture (GP), conventional tillage (CT) winter wheat (Triticum aestivum L.)-fallow (CTWF), and fertilized and unfertilized plots of continuous winter wheat (WW), spring wheat (SW), and spring barley (Hordeum vulgare L.) (SB) monocultures under CT and no-till (NT). The samples were analyzed for soil organic matter (SOM) and SOC was derived. Ages of experiments ranged from 6 to 73 yr. Compared to 1931 SOC levels (initial year), CTWF reduced SOC by 9 to 12 Mg ha-1 in the 0- to 30-cm zone. Grass pasture increased SOC by 6 Mg ha-1 in the 0- to 10-cm zone but decreased SOC by 3 Mg ha-1 in the 20- to 30-cm zone. Continuous CT monocultures depleted SOC in the top 0- to 10-cm zone and the bottom 20- to 40-cm zone but maintained SOC levels close to 1931 SOC levels in the 10- to 20-cm layer. Continuous NT monocultures accumulated more SOC in the 0- to 10-cm zone than in deeper zones. Total SOC (0- to 40-cm zone) was highest under GP and continuous cropping and lowest under CTWF. Fertilizer increased total SOC only under CTWW and CTSB by 13 and 7 Mg ha-1 in 13 yr, respectively. Practicing NT for only 6 yr had started to reverse the effect of 73 yr of CTWF. Compared to CTWF, NTWW and NTSW sequestered C at rates of 2.6 and 1.7 Mg ha-1 yr-1, respectively, in the 0- to 40-cm zone. This study showed that the potential to sequester C can be enhanced by increasing cropping frequency and eliminating tillage.

Machefert, S. E., N. B. Dise, et al. (2002). "Nitrous oxide emissions from a range of land uses across Europe." Hydrology and Earth System Sciences **6**(3): 325–337.

> The results of a literature study examining quantitative estimates of N2O emission rates are presented for a range of land-uses across Europe. The analysis shows that the highest N2O emission rates are for agricultural lands compared to forests and grasslands. The main factors regulating these rates are available mineral nitrogen, soil temperature, soil water content and the available labile organic compounds. These controls operate across different time-scales, all must exceed a certain threshold for N2O emission to occur. The results support the need for an emission factor function of land-use and climate within models describing nitrogen dynamics in catchments. This would allow the assessment of the net N2O emission within catchments in terms of current levels and potential changes associated with climate variability, climate change and land use change.

MacKenzie, A. F., M. X. Fan, et al. (1998). "Nitrous oxide emission in three years as affected by tillage, corn-soybean-alfalfa rotations, and nitrogen fertilization." Journal of Environmental Quality **27**(3): 698–703.

> Nitrous oxide (N2O) produced from agricultural activities must be determined if management procedures to reduce emissions are to be established. From 1994 to 1996, N2O emissions were determined using a closed chamber technique. Continuous corn (Zea mays L.) at four N rates of 0, 170, 285, and 400 kg of N ha-1 was used on a Ste. Rosalie heavy clay (a very-fine-silty, mixed, nonacid, frigid Typic Humaquept) and a Chicot sandy loam (a fine-loamy, frigid, Typic Hapludalf). On two additional sites, a Ste. Rosalie clay and an Ormstown silty clay loam (a fine-silty, mixed, nonacid, frigid Humaquept) no-till (NT) and conventional tillage (CT); monocultural corn (CCC), monocultural soybean (Glycine max L.) (SSS); corn-soybean (SSC, CCS); and soybean-corn-alfalfa (Medicago sativa L.) phased rotations (SAC, CSA, and ACS) were used. Nitrogen rates of 0, 90, and 180 kg of N ha-1 for corn and 0, 20, and 40 kg of N ha-1 for SSS were used. Rates of N2O emission were measured from April to November in 1994 and 1995, and from mid-March to mid-November in 1996. Maximum N2O emissions reached from 120 to 450 ng of N m-2 s-1 at the Ormstown site to 50 to 240 ng of N m-2 s-1 at the Ste. Rosalie soil. Generally, N2O emissions were higher in the NT systems, with corn, and increased linearly with increasing N rates, and amounted to 1.0 to 1.6% of fertilizer N applied. The N2O emission rates were significantly related to soil denitrification rates, water-filled pore space, and soil NH4 and NO3 concentrations. A corn system using conventional tillage, legumes in rotation, and reduced N fertilizer would decrease N2O emission from agricultural fields.

Malhi, S. S., R. Lemke, et al. (2006). "Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions." Soil & Tillage Research **90**(1–2): 171–183.

> Management practices that simultaneously improve soil properties and yield are crucial to sustain high crop production and minimize detrimental impact on the environment. The objective of this study was to determine the influence of tillage and crop residue management on crop yield, N uptake and C removal in crop, soil organic C and N, inorganic N and aggregation, and nitrous oxide (N2O) emissions on a Gray Luvisol (Boralf) soil near Star City, Saskatchewan, Canada. The 4-year (1998-2001) field experiment was conducted with two tillage systems: no

tillage (NT), and conventional tillage (CT); two levels of straw: straw retained (S), and straw removed (NS); and four rates of fertilizer N: 0, 40, 80, and 120 kg N ha-1, except no N to pea phase of the rotation. The plots were seeded to barley (Hordeum vulgare L.) in 1998, pea (Pisum sativum L.) in 1999, wheat (Triticum aestivum L.) in 2000 and canola (Brassica napus L.) in 2001. Tillage and straw treatments generally had no effect on crop yield during the first three years. But in 2001, NT produced 55, 32, and 20% greater canola seed, straw and chaff than CT, respectively, whereas straw retention increased seed and straw yield by 33 and 19% compared to straw removal. Seed, straw and chaff yield of canola increased with N rate up to 40 kg N ha-1, and root mass (0-15 cm depth) with N rate to 80 kg N ha-1. Amount of N uptake and C removed in wheat and canola generally increased with N rate, but tillage and straw management had no consistent effect. After four crop seasons, total organic C (TOC) and N (TN), light fraction organic matter (LFOM), C (LFC), and N (LFN) were generally greater with S than NS treatments. Tillage did not affect TOC and TN in soil, but LFOM, LFC, and LFN were greater or tended to be greater under NT than CT. There was no effect of tillage, straw and N fertilization on NH4-N in soil, but CT and S tended to have higher NO3-N concentration in 0-15 cm soil than NT and NS, respectively. Concentration of NO3-N increased substantially with N rate >=80 kg ha-1. The NT + S treatment had the lowest proportion (34%) of wind-erodible (<0.83 mm diameter) aggregates and greatest proportion (37%) of larger (>12.7 mm) dry aggregates, compared to highest (50%) and lowest (18%) proportion of corresponding aggregates in CT + NS, indicating less potential for soil erosion when tillage was omitted and crop residues were retained. Amount of N lost as N2O was higher from N-fertilized than from zero-N plots, and it was substantially higher from N-applied CT plots than from N-applied NT plots. Retaining crop residues along with no-tillage improved soil properties and may also be better for the environment.

Manley, J. T., G. E. Schuman, et al. (1995). "Rangeland soil carbon and nitrogen responses to grazing." Journal of Soil and Water Conservation **50**(3): 294–298.

Manley, W. A., R. H. Hart, et al. (1997). "Vegetation, cattle, and economic responses to grazing strategies and pressures." Journal of Range Management **50**(6): 638–646.

Martens, D. A., W. Emmerich, et al. (2005). "Atmospheric carbon mitigation potential of agricultural management in the southwestern USA." Soil & Tillage Research **83**(1): 95–119.

Agriculture in the southwestern USA is limited by water supply due to high evaporation and limited seasonal precipitation. Where water is available, irrigation allows for production of a variety of agricultural and horticultural crops. This review assesses the impacts of agriculture on greenhouse gas emission and sequestration of atmospheric C in soils of the hot, dry region of the southwestern USA. In Texas, conservation tillage increased soil organic C by 0.28 Mg C ha(-1) year(-1) compared with more intensive tillage. Conversion of tilled row crops to the conservation reserve program or permanent pastures increased soil organic C by 0.32 +/- 0.50 Mg C ha(-1) year(-1). Soil organic C sequestration was dependent on rotation, previous cropping, and type of conservation tillage employed. Relatively few studies have interfaced management and C cycling to investigate the impacts of grazing management on soil organic C, and therefore, no estimate of C balance was available. Irrigated crop and pasture land in Idaho had soil organic C content 10-40 Mg C ha(-1) greater than in dryland, native grassland. Soil salinity must be controlled in cropland as soil organic C content was lower with increasing salinity. Despite 75% of the region's soils being classified as calcic, the potential for sequestration of C as soil carbonate has been only scantly investigated. The region may be a significant sink for atmospheric methane, although in general, trace gas flux from semiarid soils lacks adequate characterization. Agricultural impacts on C cycling will have to be better understood in order for effective C sequestration strategies to emerge.

Matson, P. A. and P. M. Vitousek (2006). "Agricultural intensification: will land spared from farming be land spared for nature?" Conservation Biology **20**(3): 709–710.

McCarl, B. A., C. Peacocke, et al. (2009). Economics of biochar production, utilisation and GHG offsets. Biochar for Environmental Management: Science and Technology. J. Lehmann and S. Joseph. London, UK, Earthscan Publications**:** 341–358.

McCaughey, W. P., K. Wittenberg, et al. (1997). "Methane production by steers on pasture." Canadian Journal of Animal Science **77**(3): 519–524.

In order to determine the quantity of methane (CH4) produced by steers on pasture, 16 steers with a mean weight of 356 ± 25 kg were randomly selected from a larger group of cattle (n = 48) to evaluate the effects of grazing management and monensin controlled release capsule (CRC) administration on ruminal CH4 production using the sulphur hexafluoride (SF6) tracer-gas technique. Pasture management treatments consisted of two grazing systems (continuous stocking or 10-paddock rotational stocking) at each of two stocking rates (low, 1.1 steer ha–1 or high, 2.2 steers ha–1) with two replications of each pasture treatment. Half of the animals on each pasture treatment were administered a monensin CRC delivering 270 mg d–1, and untreated animals served as controls. During the 140-d grazing season, one steer from each treatment-replicate combination was sampled to determine daily intake and CH4 production on four occasions. The chemical composition of diets differed between grazing management treatments and sampling periods. Voluntary intake and CH4 production, adjusted for differences in body weight, were unaffected by grazing management, sampling period or by monensin CRC administration and averaged 0.69 ± 0.1 L kg BW–1 d–1 across all grazing management treatments. The energy lost through eructation of CH4 averaged 4.5 ± 1.4% of gross energy intake.

McPherson, B., R. Allis, et al. (2006). Southwest Regional Partnership on Carbon Sequestration, Final Report. Socorro, NM, New Mexico Institute of Mining and Technology**:** 2715.

The Southwest Partnership on Carbon Sequestration completed its Phase I program in December 2005. The main objective of the Southwest Partnership Phase I project was to evaluate and demonstrate the means for achieving an 18% reduction in carbon intensity by 2012. Many other goals were accomplished on the way to this objective, including (1) analysis of CO2 storage options in the region, including characterization of storage capacities and transportation

options, (2) analysis and summary of CO2 sources, (3) analysis and summary of CO2 separation and capture technologies employed in the region, (4) evaluation and ranking of the most appropriate sequestration technologies for capture and storage of CO2 in the Southwest Region, (5) dissemination of existing regulatory/permitting requirements, and (6) assessing and initiating public knowledge and acceptance of possible sequestration approaches.

Results of the Southwest Partnership's Phase I evaluation suggested that the most convenient and practical "first opportunities" for sequestration would lie along existing CO2 pipelines in the region. Action plans for six Phase II validation tests in the region were developed, with a portfolio that includes four geologic pilot tests distributed among Utah, New Mexico, and Texas. The Partnership will also conduct a regional terrestrial sequestration pilot program focusing on improved terrestrial MMV methods and reporting approaches specific for the Southwest region. The sixth and final validation test consists of a local-scale terrestrial pilot involving restoration of riparian lands for sequestration purposes. The validation test will use desalinated waters produced from one of the geologic pilot tests.

The Southwest Regional Partnership comprises a large, diverse group of expert organizations and individuals specializing in carbon sequestration science and engineering, as well as public policy and outreach. These partners include 21 state government agencies and universities, five major electric utility companies, seven oil, gas and coal companies, three federal agencies, the Navajo Nation, several NGOs, and the Western Governors Association. This group is continuing its work in the Phase II Validation Program, slated to conclude in 2009.

McSwiney, C. P. and G. P. Robertson (2005). "Nonlinear response of N_2O flux to incremental fertilizer addition in a continuous maize (*Zea mays* L.) cropping system." Global Change Biology **11**(10): 1712–1719.

> The relationship between nitrous oxide (N_2O) flux and N availability in agricultural ecosystems is usually assumed to be linear, with the same proportion of nitrogen lost as N2O regardless of input level. We conducted a 3-year, high-resolution N fertilizer response study in southwest Michigan USA to test the hypothesis that N_2O fluxes increase mainly in response to N additions that exceed crop N needs. We added urea ammonium nitrate or granular urea at nine levels (0-292 kg N ha^{-1}) to four replicate plots of continuous maize. We measured N_2O fluxes and available soil N biweekly following fertilization and grain yields at the end of the growing season. From 2001 to 2003 N_2O fluxes were moderately low (ca. 20 g N_2O-N ha^{-1} day^{-1}) at levels of N

addition to 101 kg N ha^{-1}, where grain yields were maximized, after which fluxes more than doubled (to >50 g N_2O-N ha^{-1} day^{-1}). This threshold N_2O response to N fertilization suggests that agricultural N_2O fluxes could be reduced with no or little yield penalty by reducing N fertilizer inputs to levels that just satisfy crop needs.

McTaggart, I. P., H. Clayton, et al. (1997). "Nitrous oxide emissions from grassland and spring barley, following N fertiliser application with and without nitrification inhibitors." Biology and Fertility of Soils **25**: 261–268.

The aims of this study were to assess the effectiveness of the nitrification inhibitors dicyandiamide (DCD) and nitrapyrin on reducing emissions of nitrous oxide (N2O) following application of NH4+ or NH4 +-forming fertilisers to grassland and spring barley. DCD was applied to grassland with N fertiliser applications in April and August in 1992 and 1993, inhibiting N2O emissions by varying amounts depending on the fertiliser form and the time of application. Over periods of up to 2 months following each application of DCD, emissions of N2O were reduced by 58–78% when applied with urea (U) and 41–65% when applied with ammonium sulphate (AS). Annual emissions (April to March) of N2O were reduced by up to 58% and 56% in 1992–1993 and 1993–1994, respectively. Applying DCD to ammonium nitrate (AN) fertilised grassland did not reduce emissions after the April 1993 fertilisation, but emissions following the August application were reduced. Nitrapyrin was only applied once, with the April fertiliser applications in 1992, reducing N2O emissions over the following 12 months by up to 40% when applied with U. When N fertiliser was applied in June without DCD, the DCD applied in April was still partly effective; N2O emissions were reduced 50%, 60% and 80% as effectively as the emissions following the April applications, for AS in 1993, U in 1992 and 1993, respectively. In 1992 the persistence of an inhibitory effect was greater for nitrapyrin than for DCD, increasing after the June fertiliser application as overall emissions from U increased. There was no apparent reduction in effectiveness following repeated applications of DCD over the 2 years. N2O emissions from spring barley, measured only in 1993, were lower than from grassland. DCD reduced emissions from applied U by 40% but there was no reduction with AN. The results demonstrate considerable scope for reducing emissions by applying nitrification inhibitors with NH4 + or NH4 + -forming fertilisers; this is especially so for crops such as intensively managed grass where there are several applications of fertiliser nitrogen per season, as the effect of inhibitors applied in April persists until after a second fertiliser application in June.

Milchunas, D. G. and W. K. Lauenroth (1993). "Quantitative effects of grazing on vegetation and soils over a global range of environments." Ecological Monographs **63**(4): 327-366.

Multiple regression analyses were performed on a worldwide 236—site data set compiled from studies that compared species composition, aboveground net primary production (ANPP), root biomass, and soil nutrients of grazed vs. protected, ungrazed sites. The objective was to quantitatively assess factors relating to differential sensitivities of ecosystems to grazing by large herbivores. A key question in this assessment was: Do empirically based, broad—scale relationships correspond to ecological theories of plant—animal interactions and conceptual frameworks for management of the world's grazing lands? Changes in species composition with grazing were primarily a function of ANPP and the evolutionary history of grazing of the site, with level of consumption third in importance. Changes in species composition increased with increasing productivity and with longer, more intense evolutionary histories of grazing. These three variables explained >50% of the variance in the species response of grasslands or grasslands—plus—shrublands to grazing, even though methods of measurement and grazing systems varied among studies. Years of protection from grazing was a significant variable only in the model for shrublands. Similar variables entered models of change in the dominant species with grazing. As with species composition, sensitivities of change in dominant species were greater to varying ecosystem—environmental variables than to varying grazing variables, from low to high values. Increase of the dominant species under grazing were predicted under some conditions, and decreases were more likely among bunch grasses than other life—forms and more likely among perennials than annuals. The response of shrublands was different from that of grasslands, both in terms of species composition and the dominant species. Our analyses support the perception of grazing as a factor in the conversion of grasslands to less desirable shrublands, but also suggest that we may be inadvertently grazing shrublands more intensively than grasslands. Percentage differences in ANPP between grazed and ungrazed sites decreased with increasingly long evolutionary histories of grazing and increased with increasing ANPP, levels of consumption, or years of treatment. Although most effects of grazing on ANPP were negative, some were not, and the statistical models predicted increases in ANPP with grazing under conditions of long evolutionary history, low consumption, few years of treatment, and low ANPP for grasslands—plus—shrublands. The data and the models support the controversial hypothesis that grazing can increase ANPP in some situations. Similar to species variables, percentage differences in ANPP between grazed and ungrazed treatments were more sensitive to varying ecosystem—environmental variables than to varying grazing variables. Within levels not considered to be abusive "overgrazing," the geographical location where grazing occurs may be more important than how many animals are grazed or how intensively an area is grazed. Counter to the commonly held view that grazing negatively impacts root systems, there was no relationship between difference in ANPP with grazing and difference in root mass; as many positive as negative differences occurred, even though most ANPP differences were negative. Further, there was a weak relationship between change in species composition and change in ANPP, and no relationship with root mass, soil organic matter, or soil nitrogen. All three belowground variables displayed both positive and negative values in response to grazing. Current management of much of the world's grazing lands based on species composition criteria may lead to erroneous conclusions concerning the long—term ability of a system to sustain productivity.

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Millar, N., G. P. Robertson, et al. (2010). "Nitrogen fertilizer management for nitrous oxide (N_2O) mitigation in intensive corn (Maize) production: an emissions reduction protocol for U.S. Midwest agriculture." Mitigation and Adaptation Strategies for Global Change **15**(2): 185–204.

Nitrous oxide (N_2O) is a major greenhouse gas (GHG) product of intensive agriculture. Fertilizer nitrogen (N) rate is the best single predictor of N_2O emissions in row-crop agriculture in the US Midwest. We use this relationship to propose a transparent, scientifically robust protocol that can be utilized by developers of agricultural offset projects for generating fungible GHG emission reduction credits for the emerging US carbon cap and trade market. By coupling predicted N_2O flux with the recently developed maximum return to N (MRTN) approach for determining economically profitable N input rates for optimized crop yield, we provide the basis

for incentivizing N_2O reductions without affecting yields. The protocol, if widely adopted, could reduce N_2O from fertilized row-crop agriculture by more than 50%. Although other management and environmental factors can influence N_2O emissions, fertilizer N rate can be viewed as a single unambiguous proxy—a transparent, tangible, and readily manageable commodity. Our protocol addresses baseline establishment, additionality, permanence, variability, and leakage, and provides for producers and other stakeholders the economic and environmental incentives necessary for adoption of agricultural N_2O reduction offset projects.

Morgan, J. A., R. F. Follett, et al. (2010). "Carbon sequestration in agricultural lands of the United States." Journal of Soil and Water Conservation **65**(1): 6A–13A.

Reducing concentrations of greenhouse gases has been identified as one of the most pressing modern-day environment issues. In agricultural systems, the sequestering of C in mostly soils is thought to be one of the best options for reducing atmospheric concentrations of one of the most important greenhouse gases, carbon dioxide. This review article discusses the potential role of US agriculture to mitigate climate change primarily through the sequestering of carbon, and also identifies critical knowledge gaps where further research is needed to enhance the country"s C sequestering capability. The discussion is directed within several agricultural sectors: cropping systems, grazinglands, agroforestry, horticulture, turfgrass and potential high C emission areas. Logistical issues of how to track C sequestration are discussed, and problems associated with the emerging issues of biofuels and climate-change feed-backs on C sequestration are presented. Although major advancements have been made in research on agricultural C sequestration, further research is needed to better develop a suite of best management options and to cover unrepresented agricultural areas in order for the US to move forward with an effective C sequestration strategy for agriculture.

Mortenson, M. C., G. E. Schuman, et al. (2004). "Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*)." Environmental Management **33**(Suppl. 1): S475–481.

Management practices can significantly influence carbon sequestration by rangeland ecosystems. Grazing, burning, and fertilization have been shown to increase soil carbon storage in rangeland soils of the Great Plains. Research was initiated in 2001 in northwestern South Dakota to evaluate the role of interseeding a legume, Medicago sativa ssp. falcata, in northern mixed-grass rangelands on carbon sequestration. Sampling was undertaken on a chronosequence of sites interseeded in 1998, 1987, and 1965 as well as immediately adjacent untreated native rangeland sites. Soil organic carbon exhibited an increase of 4% in the 1998, 8% in the 1987, and 17% in the 1965 interseeding dates compared to their respective native untreated rangeland sites. Nitrogen fixation by the legume led to significant increases in total soil nitrogen and increased forage production in the interseeded treatments. Increases in organic carbon mass in this rangeland ecosystem can be attributed to the increase in soil organic carbon storage and the increased aboveground biomass resulting from the increased nitrogen in the ecosystem. The practice of interseeding adaptable cultivars of alfalfa into native rangelands may help in the mitigation of elevated atmospheric carbon dioxide and enhance the long-term sustainability of the ecosystem.

Mosier, A. R., J. M. Duxbury, et al. (1998). "Mitigating agricultural emissions of methane " Climatic Change **40**(1): 39–80.

Agricultural crop and animal production systems are important sources and sinks for atmospheric methane (CH4). The major CH4 sources from this sector are ruminant animals, flooded rice fields, animal waste and biomass burning which total about one third of all global emissions. This paper discusses the factors that influence CH4 production and emission from these sources and the aerobic soil sink for atmospheric CH4 and assesses the magnitude of each source. Potential methods of mitigating CH4 emissions from the major sources could lead to improved crop and animal productivity. The global impact of using the mitigation options suggested could potentially decrease agricultural CH4 emissions by about 30%.

Mosier, A. R., A. D. Halvorson, et al. (2006). "Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado." Journal of Environmental Quality **35**(4): 1584–1598.

The impact of management on global warming potential (GWP), crop production, and greenhouse gas intensity (GHGI) in irrigated agriculture is not well documented. A no-till (NT) cropping systems study initiated in 1999 to evaluate soil organic carbon (SOC) sequestration potential in irrigated agriculture was used in this study to make trace gas flux measurements for 3 yr to facilitate a complete greenhouse gas accounting of GWP and GHGI. Fluxes of CO2, CH4, and N2O were measured using static, vented chambers, one to three times per week, year round, from April 2002 through October 2004 within conventional-till continuous corn (CT-CC) and NT continuous corn (NT-CC) plots and in NT corn-soybean rotation (NT-CB) plots. Nitrogen fertilizer rates ranged from 0 to 224 kg N ha-1. Methane fluxes were small and did not differ between tillage systems. Nitrous oxide fluxes increased linearly with increasing N fertilizer rate each year, but emission rates varied with years. Carbon dioxide efflux was higher in CT compared to NT in 2002 but was not different by tillage in 2003 or 2004. Based on soil respiration and residue C inputs, NT soils were net sinks of GWP when adequate fertilizer was added to maintain crop production. The CT soils were smaller net sinks for GWP than NT soils. The determinant for the net GWP relationship was a balance between soil respiration and N2O emissions. Based on soil C sequestration, only NT soils were net sinks for GWP. Both estimates of GWP and GHGI indicate that when appropriate crop production levels are achieved, net CO2 emissions are reduced. The results suggest that economic viability and environmental conservation can be achieved by minimizing tillage and utilizing appropriate levels of fertilizer.

Mosier, A. R., C. Kroeze, et al. (1998). "Closing the global N_2O budget: Nitrous oxide emissions through the agricultural nitrogen cycle." Nutrient Cycling in Agroecosystems **52**(2): 225–248.

Mulvaney, R. L., S. A. Khan, et al. (2009). "Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production." Journal of Environmental Quality **38**(6): 2295–2314.

Cereal production that now sustains a world Population of more than 6.5 billion has tripled during the past 40 yr, concurrent with an increase from 12 to 164 Tg yr(-1) of synthetic N applied largely in ammoniacal fertilizers. These Fertilizers have been managed as a cost-effective form of insurance against low yields, without regard to the inherent effect of mineral N in

promoting microbial C utilization. Such an effect is consistent with a net loss of soil organic C recently observed for the Morrow Plots, Americas oldest experiment field, after 40 to 50 yr of synthetic N fertilization that substantially exceeded grain N removal. A similar decline in total soil N is reported herein for the same site and would be expected from the predominantly organic occurrence of soil N. This decline is in agreement with numerous long-term baseline data sets, from, chemical-based cropping systems involving a wide variety of soils, geographic regions, and tillage practices. The loss of organic N decreases soil productivity and the agronomic efficiency (kg grain kg(-1) N) of fertilizer N and has been implicated in wide spread reports of yield stagnation or even decline for grain production in Asia. A major global evaluation of current cereal production systems should be undertaken, witha view toward using scientific and technological advances to increase input efficiencies. As one aspect of this strategy, the input of ammoniacal N should be more accurately matched to crop N requirement. Long-term sustainability may require agricultural diversification involving a gradual transition from intensive synthetic N inputs to legume-based crop rotations.

Murray, B. C. and J. S. Baker (2011). "An output-based intensity approach for crediting greenhouse gas mitigation in agriculture: Explanation and policy implications." Greenhouse Gas Measurement and Management **1**(1): 27–36.

US legislators have recently proposed output-based emissions intensity metrics as an approach to credit greenhouse gas (GHG) offsets from agriculture and other uncapped sectors. This article explains the features and rationale of the output-based offset (OBO) approach, outlines a candidate accounting methodology, discusses the potential advantages and limitations of such an approach relative to the area-based offset (ABO) approach that is standard practice in some settings, and introduces possible policy implications. By incentivizing improvements in agricultural efficiency, the OBO approach strives to achieve the dual goals of food security and climate change mitigation. It expands the toolkit for achieving reductions in agricultural emissions, rewards technological advancement in both emission reductions and yields, and offers promise for addressing the problem of accounting for leakage. But because it is based on improvements in GHG efficiency in agriculture rather than on absolute reductions, emissions and climate risks could continue to rise while credits are being issued. An OBO approach might work best as a transitional strategy to address emissions from sectors or countries likely to remain outside a strict regulatory cap. Because it is the total atmospheric concentration of GHGs that creates the environmental threat of climate change, policies should ultimately focus not on the intensity of emissions but rather on their absolute levels.

Murray, B. C., B. Sohngen, et al. (2005). Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture. Washington, DC, U.S. Environmental Protection Agency, Office of Atmospheric Programs.

From executive summary: "This report evaluates the potential for additional carbon sequestration and GHG reductions in U.S. forestry and agriculture over the next several decades and beyond. It reports these reductions as changes from baseline trneds, starting in 2010 and projected out 100 years to 2110. The report employs the Forest and Agriculture Sector Optimization Model with Greenhouse Gases (FASOMGHG). FASOMGHG is a partial equilibrium economic model of the U.S. forest and agriculture sectors, with land use competition between them, and linkages to international trade. FASOMGHG includes most major GHG mitigation options in U.S. forestry and agriculture; accounts fo rchanges in CO2, GH4, and N2O from most

activities; and tracks carbon sequestration and carbon losses over time. It also projects a dynamic baseline and reports all additional GHG mitigation as changes from that baseline. FASOMGHG tracks five forest product categories and over 2,000 production possibilities for field crops, livestock, and biofuels for private lands in the conterminous United States broken into 11 regions. Public lands are not included. FASOMGHG evaluates the joint economic and biophysical effects of a range of GHG mitigation scenarios, under which costs, mitigation levels, eligible activities, and GHG coverage may vary. The six scenarios evaluated in this report are constant GHG prices, rising GHG prices, fixed national mitigation levels, inclusion of selected mitigation activities only, incentive payments for CO2 only, and payments on a per-acre versus per-tonne basis. GHG mitigation incentives are estimated by dollars per tonne of CO2 equivalent ($/t CO2 Eq.) payments for four of the six scenarios above. The model and analysis cover the 100 years from 2010 to 2110, but three focus dates are highlighted: 2015, 2025, and 2055. FASOMGHG's standard GHG accounting and payment approach is a comprehensive, pay-as-you-go system, for all applicable GHGs and activities over time. The analysis reported here is unique from other studies conducted on forestry and agricultural mitigation options on a number of fronts. First, the range of covered activities across the sectors is wide. Most comparable studies look at just one of the sectors or at one or a small subset of activities within each secvtor, which this report examines a fairly comprehensive set of activites across the two sectos covering a vast majority of all GHG effects. Of particular note are the inclusions of biofuels and non-CO2 mitigation options in agriculture. Second, the intertemporal dynamics of the economic and biophysical systems within FASOMGHG allow for an accounting of mitigation over time and by region, and for quantification of leakage effects that other studies generally have not produced. And third, the inclusion of non-GHG co-effects allows insights into the multiple environmental and economic tradeoffs that pertain to GHG mitigation in these sectors.

Nabuurs, G. J. and G. M. J. Mohren (1993). Carbon fixation through forestation activities: A study of the carbon sequestering potential of selected forest types. Institute for Forestry and Nature Research, Wageningen. IBN Research Report. Arnhem/Wageningen, The Netherlands, Face/Institute for Forstry and Nature Research.

Nair, P. K. R. and V. D. Nair (2003). Carbon storage in North American agroforestry systems. The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. J. Kimble, L. S. Heath, R. Birdsey and R. Lal. Boca Raton, FL, CRC Press.

Agroforestry is a new concept of land management, especially in North America; therefore quantitative data are rare if not nonexistent on most aspects of it. Carbon sequestration potential of agroforestry systems is one such little-studied area. In the discussion on C storage potential of any land-use system, it is important that the system characteristics and processes governing their functioning are understood adequately. Since such basic information about agroforestry systems is not widely known, in this chapter we will first present background information on the key concepts of agroforestry and major types of agroforestry systems in North America. We then examine the C sequestration potential of agroforestry systems and discuss management considerations and research needs for exploiting the potential.

National Research Council (2010). The Impact of Genetically Engineered Crops on Farm Sustainability in the United States. Washington, DC, National Academies Press.

Nelson, D. E., P. P. Repetti, et al. (2007). "Plant nuclear factor Y (NF-Y) B subunits confer drought tolerance and lead to improved corn yields on water-limited acres." Proceedings of the National Academy of Sciences **104**(42): 16450–16455.

Commercially improved crop performance under drought conditions has been challenging because of the complexity of the trait and the multitude of factors that influence yield. Here we report the results of a functional genomics approach that identified a transcription factor from the nuclear factor Y (NF-Y) family, AtNF-YB1, which acts through a previously undescribed mechanism to confer improved performance in Arabidopsis under drought conditions. An orthologous maize transcription factor, ZmNF-YB2, is shown to have an equivalent activity. Under waterlimited conditions, transgenic maize plants with increased ZmNFYB2 expression show tolerance to drought based on the responses of a number of stress-related parameters, including chlorophyll content, stomatal conductance, leaf temperature, reduced wilting, and maintenance of photosynthesis. These stress adaptations contribute to a grain yield advantage to maize under water-limited environments. The application of this technology has the potential to significantly impact maize production systems that experience drought.

Nelson, R. G. (2002). "Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States – Rainfall and wind-induced soil erosion methodology." Biomass & Bioenergy **22**(5): 349–363.

The focus of this study was to develop a methodology to estimate “hectare-weighted”, county-level, corn stover and spring and winter wheat straw removable residue quantities in the USA for 1995–1997 in 37 states (north–south line from North Dakota to Texas and all states east) such that tolerable rainfall and wind soil loss limits were not exceeded. The methodology developed and employed in this study was based on the revised universal soil loss equation (RUSLE) and the wind erosion equation (WEQ), which were used to predict individual county-level corn or wheat yields required at harvest to insure that the amount of soil loss would not exceed the tolerable soil loss limit. These yields were then compared to actual county-level corn or wheat yields to determine the quantity of removable residue. Results of this study indicate an annual average of over 42 and 8 million metric tons of corn stover and straw (spring and winter wheat), respectively (46.2 and 8.8 million tons) were potentially available for removal between 1995 and 1997 in these 37 states.

Ogle, S. M., F. J. Breidt, et al. (2005). "Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions." Biogeochemistry **72**(1): 87–121.

We conducted a meta-analysis to quantify the impact of changing agricultural land use and management on soil organic carbon (SOC) storage under moist and dry climatic conditions of temperate and tropical regions. We derived estimates of management impacts for a carbon accounting approach developed by the Intergovernmental Panel on Climate Change, addressing the impact of long-term cultivation, setting-aside land from crop production, changing tillage management, and modifying C input to the soil by varying cropping practices. We found 126 articles that met our criteria and analyzed the data in linear mixed-effect models. In general, management impacts were sensitive to climate in the following order from largest to smallest

changes in SOC: tropical moist>tropical dry>temperate moist>temperate dry. For example, long-term cultivation caused the greatest loss of SOC in tropical moist climates, with cultivated soils having 0.58 ± 0.12, or 58% of the amount found under native vegetation, followed by tropical dry climates with 0.69 ± 0.13, temperate moist with 0.71 ± 0.04, and temperate dry with 0.82 ± 0.04. Similarly, converting from conventional tillage to no-till increased SOC storage over 20 years by a factor of 1.23 ± 0.05 in tropical moist climates, which is a 23% increase in SOC, while the corresponding change in tropical dry climates was 1.17 ± 0.05, temperate moist was 1.16 ± 0.02, and temperate dry was 1.10 ± 0.03. These results demonstrate that agricultural management impacts on SOC storage will vary depending on climatic conditions that influence the plant and soil processes driving soil organic matter dynamics.

Omonode, R. A., T. J. Vyn, et al. (2007). "Soil carbon dioxide and methane fluxes from long-term tillage systems in continuous corn and corn-soybean rotations." Soil & Tillage Research **95**(1–2): 182–195.

Although the Midwestern United States is one of the world's major agricultural production areas, few studies have assessed the effects of the region's predominant tillage and rotation practices on greenhouse gas emissions from the soil surface. Our objectives were to (a) assess short-term chisel (CP) and moldboard plow (MP) effects on soil CO_2 and CH_4 fluxes relative to no-till (NT) and, (b) determine how tillage and rotation interactions affect seasonal gas emissions in continuous corn and corn-soybean rotations on a poorly drained Chalmers silty clay loam (Typic Endoaquoll) in Indiana. The field experiment itself began in 1975. Short-term gas emissions were measured immediately before, and at increasing hourly intervals following primary tillage in the fall of 2004, and after secondary tillage in the spring of 2005, for up to 168 h. To quantify treatment effects on seasonal emissions, gas fluxes were measured at weekly or biweekly intervals for up to 14 sampling dates in the growing season for corn. Both CO_2 and CH_4 emissions were significantly affected by tillage but not by rotation in the short-term following tillage, and by rotation during the growing season. Soil temperature and moisture conditions in the surface 10 cm were significantly related to CO_2 emissions, although the proportion of variation explained by temperature and moisture was generally very low (never exceeded 27%) and varied with the tillage system being measured. In the short-term, CO_2 emissions were significantly higher for CP than MP and NT. Similarly, mean seasonal CO_2 emissions during the 2-year period were higher for CP (6.2 Mg CO_2-C ha-1 year-1) than for MP (5.9 Mg CO_2-C ha-1 year-1) and NT (5.7 Mg CO_2-C ha-1 year-1). Both CP and MP resulted in low net CH_4 uptake (7.6 and 2.4 kg CH_4-C ha-1 year-1, respectively) while NT resulted in net emissions of 7.7 kg CH_4-C ha-1 year-1. Mean emissions of CO_2 were 16% higher from continuous corn than from rotation corn during the two growing seasons. After 3 decades of consistent tillage and crop rotation management for corn and soybean producing grain yields well above average in the Midwest, continuous NT production in the corn-soybean rotation was identified as the system with the least soil-derived C emissions to the atmosphere from among those evaluated prior to and during corn production.

Ortega, R. A., G. A. Peterson, et al. (2002). "Residue accumulation and changes in soil organic matter as affected by cropping intensity in no-till dryland agroecosystems." Agronomy Journal **94**(4): 944–954.

Crop residue is a valuable resource in Great Plains dryland agroecosystems because it aids in water conservation and soil erosion control. The objectives of our research were to (i) determine the effect of cropping intensity, climate gradient, and soil depth on levels and

changes in soil C, soil N, and residue parameters after 8 yr of no-till management in dryland cropping systems and (ii) relate soil and residue parameters to soil C and N levels. Surface soil properties and residue parameters were compared in two cropping systems, wheat (Triticum aestivum L.)-fallow (WF) and wheat-corn (Zea mays L.) or sorghum [Sorghum bicolor (L.) Moench]-proso millet (Panicum miliaceum L.)-fallow (WCMF). The effects were examined on the summit position of a catenary sequence of soils across three environments representing an evapotranspiration (ET) gradient. Soils at the low- and medium-ET sites are classified as Argiustols, and the soil at the high-ET site is an Ustochrept. There was 3.0 Mg ha-1 of residue in the surface 10 cm of soil compared with 2.7 Mg ha-1 of residue on the soil surface averaged over ET gradient and cropping systems. About 90% of the residue in the soil was found within the 2.5-cm soil depth. The highest soil organic C (SOC) and soil organic N (SON) were observed in the surface 0- to 2.5-cm depth. There was a trend (P [<=] 0.16) for the more intense WCMF cropping system to have higher SOC and SON contents than the traditional WF system (C = 6.6 g kg-1 for WF compared with 7.5 g kg-1 for WCMF and N = 0.70 g kg-1 for WF compared with 0.74 g kg-1 for WCMF). From 1985 to 1993, gains in SOC (967 kg ha-1) and SON (74 kg ha-1) occurred in the surface 0- to 2.5- and 2.5- to 5-cm depths while losses were observed in the 5- to 10-cm depth (SOC = -694 kg ha-1; SON = -44 kg ha-1). Climate strongly modified these effects but did not reflect a clear ET gradient effect. The results suggest that higher levels of surface SOC and SON can be attained by increasing cropping intensity under no-till management.

Ortiz-Monasterio, J. I., K. D. Sayre, et al. (1997). "Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen rates." Crop Science **37**(3): 898–904.

The adaptation and performance of CIMMYT's bread wheat germplasm (Triticum aesttvum L.) under conditions of low N fertility have been questioned because they were developed under medium-high levels of N fertility. The objectives of this research were to (i) compare the performance of a set of tall vs. semidwarf cultivars developed by CIMMYT that were widely grown by farmers in the Yaqui Valley of Mexico at low and high N fertility, (ii) measure the genetic progress in grain yield and N use efficiency (NUE), and (iii) evaluate the contribution of N uptake efficiency (UPE) and utilization efficiency (UTE) to NUE. Ten wheat cultivars, two tall and eight semidwarf, produced by CIMMYT and released in the Yaqui Valley of Sonora, by the Mexican government from 1950 to 1985 were grown with 0, 75, 150, or 300 kg N ha-' in a 3-yr field study at Ciudad Obregon, Sonora, Mexico. Genetic gains in both grain yield and NUE during 1950 to 1985 were 1.1, 1.0, 1.2, and 1.9% yr-1 on a relative basis or 32, 43, 59, and 89 kg ha-1 yr-1 on an absolute basis, when provided 0, 75,150, and 300 kg ha-1 N, respectively. Progress in NUE resulted in an improvement of both UPE and UTE. However, the relative importance of these two components was affected by the level of applied N. These results contradict the belief that modern semidwarf cultivars require more N than older cultivars. Instead, they respond more to N, which translates into higher economic rates and higher returns when N fertilizer is available.

Osmond, D. L. and J. Kang (2008). Soil Facts: Nutrient Removal by Crops in North Carolina. Raleigh, NC, North Carolina Cooperative Extension Service.

Parkin, T. B. and J. L. Hatfield (2010). "Influence of nitrapyrin on N_2O losses from soil receiving fall-applied anhydrous ammonia." Agriculture, Ecosystems & Environment **136**: 81–86.

Fertilizer application in crop production agriculture has been identified as a major source of the greenhouse gas nitrous oxide. Thus, management strategies that increase fertilizer N use efficiency will reduce N2O emission. Anhydrous ammonia applied to cropland in the fall is recognized as amanagement practice that increases the risk of N loss from the rooting zone, however, this practice is still common in the U.S. Midwest Corn Belt. The nitrification inhibitor, nitrapyrin has been shown to decrease soil N losses during the fall and spring, and maintain fertilizer N availability to the crop. Additionally, nitrification inhibitors have shown promise in reducing soil N2O emissions. However, there have been no studies evaluating the effectiveness of nitrapyrin to reduce annual N2O emissions from land receiving fall-applied anhydrous ammonia. This study was conducted over 2 years to measure N2O emissions from corn plots with fall-applied anhydrous ammonia with and without nitrapyrin. Based on soil NO3 and NH4 analyses, we observed that nitrapyrin delayed nitrification, and in 1 year, reduced late fall/early spring N2O emission. However, annual N2O emissions were not significantly reduced. Significantly higher corn grain yields were observed in the nitrapyrin treatment in both years.

Parkin, T. B. and T. C. Kaspar (2006). "Nitrous oxide emissions from corn-soybean systems in the Midwest." Journal of Environmental Quality **35**(4): 1496–1506.

Soil N2O emissions from three corn (Zea mays L.)-soybean [Glycine max (L.) Merr.] systems in central Iowa were measured from the spring of 2003 through February 2005. The three managements systems evaluated were full-width tillage (fall chisel plow, spring disk), no-till, and no-till with a rye (Secale cereale L. Rymin') winter cover crop. Four replicate plots of each treatment were established within each crop of the rotation and both crops were present in each of the two growing seasons. Nitrous oxide fluxes were measured weekly during the periods of April through October, biweekly during March and November, and monthly in December, January, and February. Two polyvinyl chloride rings (30-cm diameter) were installed in each plot (in and between plant rows) and were used to support soil chambers during the gas flux measurements. Flux measurements were performed by placing vented chambers on the rings and collecting gas samples 0, 15, 30, and 45 min following chamber deployment. Nitrous oxide fluxes were computed from the change in N2O concentration with time, after accounting for diffusional constraints. We observed no significant tillage or cover crop effects on N2O flux in either year. In 2003 mean N2O fluxes were 2.7, 2.2, and 2.3 kg N2O-N ha-1 yr-1 from the soybean plots under chisel plow, no-till, and no-till + cover crop, respectively. Emissions from the chisel plow, no-till, and no-till + cover crop plots planted to corn averaged 10.2, 7.9, and 7.6 kg N2O-N ha-1 yr-1, respectively. In 2004 fluxes from both crops were higher than in 2003, but fluxes did not differ among the management systems. Fluxes from the corn plots were significantly higher than from the soybean plots in both years. Comparison of our results with estimates calculated using the Intergovernmental Panel on Climate Change default emission factor of 0.0125 indicate that the estimated fluxes underestimate measured emissions by a factor of 3 at our sites.

Pattey, E., M. K. Trzcinski, et al. (2005). "Quantifying the reduction of greenhouse gas emissions as a result of composting dairy and beef cattle manure." Nutrient Cycling in Agroecosystems **72**: 173–187.

Greenhouse gas emissions from the agricultural sector can be reduced through implementation of improved management practices. For example, the choice of manure storage method should be based on environmental decision criteria, as well as production capacity. In this study, greenhouse gas emissions from three methods of storing dairy and beef cattle manure were compared during the summer period. The emissions of CH4, N2O and CO2 from manure stored as slurry, stockpile, and compost were measured using a flow-through closed chamber. The largest combined N2O–CH4 emissions in CO2 equivalent were observed from the slurry storage, followed by the stockpile and lastly the passively aerated compost. This ranking was governed by CH4 emissions in relation to the degree of aerobic conditions within the manure. The radiative forcing in CO2 equivalent from the stockpiled manure was 1.46 times higher than from the compost for both types of cattle manure. It was almost twice as high from the dairy cattle manure slurry and four to seven times higher from the beef cattle manure slurry than from the compost. The potential reduction of GHG was estimated, by extrapolating the results of the study to all of Canada. By composting all the cattle manure stored as slurry and stockpile, a reduction of 0.70 Tg CO2-eq year-1 would be achieved. Similarly, by collecting and burning CH4 emissions from existing slurry facilities, a reduction of 0.76 Tg CO2-eq year-1 would be achieved. New CH4 emission factors were estimated based on these results and incorporated into the IPCC methodology. For North-America under cool conditions, the CH4 emission factors would be 45 kg CH4 hd-1year-1for dairy cattle manure rather than 36 kg CH4 hd-1 year-1, and 3kgCH4 hd-1 year-1 for beef cattle manure rather than 1 kg CH4 hd-1 year-1.

Paul, E. A., R. F. Follett, et al. (1997). "Radiocarbon dating for determination of soil organic matter pool sizes and dynamics." Soil Science Society of America Journal **61**(4): 1058–1067.

The size and turnover rate of the resistant soil organic matter (SOM) fractions were measured by 14C dating and 13C/12C measurements. This involved soils archived in 1948, and recent samples, from a series of long-term sites in the North American Great Plains. A reevaluation of C dates obtained in the 1960s expanded the study scope. The 14C ages of surface soils were modern in some native sites and near modern in the low, moist areas of the landscape. They were much older at the catena summits. The 14C ages were not related to latitude although this strongly influenced the total SOM content. Cultivation resulted in lower C contents and increased the 14C age by an average of 900 yr. The 10- to 20-cm depths from both cultivated and native sites were 1200 yr older than the 0- to 10-cm depth. The 90- to 120-cm depth of a cultivated site at 7015 yr before present (BP) was 6000 yr older than the surface. The nonhydrolyzable C of this depth dated 9035 yr BP. The residue of 6 M HCl hydrolysis comprised 23 to 70% of the total soil C and was, on the average, 1500 yr older. The percentage of nonhydrolyzable C and its 14C age analytically identify the amount and turnover rate of the old resistant soil C.

Paustian, K. H., O. Andrén, et al. (1997). "Agricultural soils as a sink to mitigate CO_2 emissions." Soil Use and Management **13**(s4): 230–244.

Agricultural soils, having been depleted of much of their native carbon stocks, have a significant CO2 sink capacity. Global estimates of this sink capacity are in the order of 20-30 Pg C over the next 50-100 years. Management practices to build up soil C must increase the input of organic matter to soil and/or decrease soil organic matter decomposition rates. The most appropriate management practices to increase soil C vary regionally, dependent on both environmental and socioeconomic factors. In temperate regions, key strategies involve increasing cropping frequency and reducing bare fallow, increasing the use of perennial forages (including N-fixing species) in crop rotations, retaining crop residues and reducing or eliminating tillage (i.e. no-till).

In North America and Europe, conversion of marginal arable land to permanent perennial vegetation, to protect fragile soils and landscapes and/or reduce agricultural surpluses, provides additional opportunities for C sequestration. In the tropics, increasing C inputs to soil through improving the fertility and productivity of cropland and pastures is essential. In extensive systems with vegetated fallow periods (e.g. shifting cultivation), planted fallows and cover crops can increase C levels over the cropping cycle. Use of no-till, green manures and agroforestry are other beneficial practices. Overall, improving the productivity and sustainability of existing agricultural lands is crucial to help reduce the rate of new land clearing, from which large amounts of CO2 from biomass and soil are emitted to the atmosphere. Some regional analyses of soil C sequestration and sequestration potential have been performed, mainly for temperate industrialized countries. More are needed, especially for the tropics, to capture region-specific interactions between climate, soil and management resources that are lost in global level assessments. By itself, C sequestration in agricultural soils can make only modest contributions (e.g. 3-6% of total fossil C emissions) to mitigating greenhouse gas emissions. However, effective mitigation policies will not be based on any single 'magic bullet' solutions, but rather on many modest reductions which are economically efficient and which confer additional benefits to society. In this context, soil C sequestration is a significant mitigation option. Additional advantages of pursuing strategies to increase soil C are the added benefits of improved soil quality for improving agricultural productivity and sustainability.

Paustian, K. H., B. A. Babcock, et al. (2004). Climate Change and Greenhouse Gas Mitigation: Challenges and Opportunities for Agriculture. Ames, IA, Council for Agricultural Science and Technology.

Agriculture is both a source and a sink for greenhouse gases (GHGs). As a source, agriculture can be burdened by regulations designed to curtail the growth in GHGs. As a sink (where carbon dioxide is removed from the atmosphere to increase storage of carbon [C] in soils), agriculture can benefit from those same regulations. This report synthesizes research on both mitigation of agricultural GHG emissions and enhancement of agriculture's ability to mitigate GHGs from nonagricultural sources. An improved understanding of the biophysical and public policy processes involved in translating a change in farming practices to a change in GHG emissions is essential to minimize the loss and maximize the gain from any future regulations.

Paustian, K. H., J. Six, et al. (2000). "Management options for reducing CO_2 emissions from agricultural soils." Biogeochemistry **48**(1): 147–163.

Crop-based agriculture occupies 1.7 billion hectares, globally, with a soil C stock of about 170 Pg. Of the past anthropogenic CO2 additions to the atmosphere, about 50 Pg C came from the loss of soil organic matter (SOM) in cultivated soils. Improved management practices, however, can rebuild C stocks in agricultural soils and help mitigate CO2 emissions. Increasing soil C stocks requires increasing C inputs and/or reducing soil heterotrophic respiration. Management options that contribute to reduced soil respiration include reduced tillage practices (especially no-till) and increased cropping intensity. Physical disturbance associated with intensive soil tillage increases the turnover of soil aggregates and accelerates the decomposition of aggregate-associated SOM. No-till increases aggregate stability and promotes the formation of recalcitrant SOM fractions within stabilized micro- and macroaggregate structures. Experiments using13 C natural abundance show up to a two-fold increase in mean residence time of SOM under no-till vs intensive tillage. Greater cropping intensity, i.e., by reducing the frequency of bare fallow in

crop rotations and increasing the use of perennial vegetation, can increase water and nutrient use efficiency by plants, thereby increasing C inputs to soil and reducing organic matter decomposition rates. Management and policies to sequester C in soils need to consider that: soils have a finite capacity to store C, gains in soil C can be reversed if proper management is not maintained, and fossil fuel inputs for different management practices need to be factored into a total agricultural CO2 balance.

Perlack, R. D., L. L. Wright, et al. (2005). Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge, TN, U.S. Department of Energy & USDA**:** 78.

Peterson, G. A., A. D. Halvorson, et al. (1998). "Reduced tillage and increasing cropping intensity in the Great Plains conserves soil C." Soil & Tillage Research **47**(3–4): 207–218.

Concern about soil organic matter losses as a result of cultivation has been voiced consistently since the early part of the 20th century. Scientists working in the US. Great Plains recognized that organic matter losses from an already small pool could have major negative consequences on soil physical properties and N supplying capacity. The advent of reduced- and no-till systems has greatly improved our ability to capture and retain precipitation in the soil during the non-crop periods of the cropping cycle, and has made it possible to reduce fallow frequency and intensify cropping systems. The purpose of this paper is to summarize the effects of reduced tillage and cropping system intensification on C storage in soils using data from experiments in North Dakota, Nebraska, Kansas, Colorado, and Texas. Decades of farming with the wheat (Triticum aestivum L.)-fallow system, the dominant farming system in the Great Plains, have accentuated soil C losses. More intensive cropping systems, made possible by the greater water conservation associated with no-till practices, have produced more grain, produced more crop residue and allowed more of it to remain on the soil surface. Combined with less soil disturbance in reduced- and no-till systems, intensive cropping has increased C storage in the soil. We also conclude that the effects of cropping system intensification on soil C should not be investigated independent of residue C still on the surface. There are many unknowns regarding how rapidly changes in soil C will occur when tillage and cropping systems are changed, but the data summarized in this paper indicate that in the surface 2.5 cm of soil, changes can be detected within 10 years. It is imperative that we continue long-term experiments to evaluate rates of change over an extended period. It is also apparent that we should include residue C, both on the surface of the soil and within the surface 2.5 cm, in our system C budgets if we are to accurately depict residue±soil C system status. The accounting of soil C must be done on a mass basis rather than on a concentration basis.

Pimentel, D., P. Hepperly, et al. (2005). "Environmental, energetic, and economic comparisons of organic and conventional farming systems." BioScience **55**(7): 573–582.

Various organic technologies have been utilized for about 6000 years to make agriculture sustainable while conserving soil, water, energy, and biological resources. Among the benefits of organic technologies are higher soil organic matter and nitrogen, lower fossil energy inputs, yields similar to those of conventional systems, and conservation of soil moisture and water resources (especially advantageous under drought conditions). Conventional agriculture can be made more sustainable and ecologically sound by adopting some traditional organic farming technologies.

Poirier, V., D. A. Angers, et al. (2009). "Interactive effects of tillage and mineral fertilization on soil carbon profiles." Soil Science Society of America Journal **73**(1): 255–261.

Both tillage and fertilizer management influence soil organic C (SOC) storage, but their interactive effects remain to be determined for various soil and climatic conditions. We evaluated the long-term effects of tillage (no-till, NT, and moldboard plowing, MP), and N and P fertilization on SOC stocks and concentrations in profiles of a clay loam soil (clayey, mixed, mesic Typic Humaquept). Corn (Zea mays L.) and soybean [Glycine max (L) Merr.] were grown in a yearly rotation for 14 yr. Our results showed that NT enhanced the SOC content in the soil surface layer, but MP resulted in greater SOC content near the bottom of the plow layer. When the entire soil profile (0-60 cm) was considered, both effects compensated each other, which resulted in statistically equivalent SOC stocks for both tillage practices. Nitrogen and P fertilization with MP increased the estimated crop C inputs to the soil but did not significantly influence SOC stocks in the whole soil profile. At the 0- to 20-cm depth, however, lower C stocks were measured in the plowed soil with the highest N fertilizer level than in any other treatment, which was probably caused by a greater decomposition of crop residues and soil organic matter. Conversely, the highest SOC stocks of the 0- to 20-cm soil layer were observed in the NT treatment with the highest N rates, reflecting a greater residue accumulation at the soil Surface. When accounting for the whole soil profile, the variations in surface SOC due to tillage and fertilizer interactions were masked by tillage-induced differences in the 20- to 30-cm soil layer.

Pork Technical Working Group (2005). Liquid Swine Manure Application to Land in Canada: Deriving N_2O Coefficients. Ottawa, ON, Pork Technical Working Group/National Offsets Quantification Team (Canada)**:** 13.

Potter, K. N. and J. D. Derner (2006). "Soil carbon pools in central Texas: Prairies, restored grasslands, and croplands." Journal of Soil and Water Conservation **61**(3): 124–128.

Establishment of perennial grasses on degraded soils has been suggested as a means to improve soil quality and sequester carbon in the soil. Particulate organic carbon may be an important component in the increased soil carbon content. We measured particulate organic carbon [defined as organic carbon in the 53 to 2000 PM (0.002 to o.o8 in) size fraction] and mineral associated organic carbon (defined as the less than 53 PM (0.002 in) size fraction) at three locations in central Texas. Each location had a never-tilled native grassland site, a long-term agricultural site and a restored grassland on a previously tilled site. Organic carbon pool sizes varied in the surface 40 cm (16 in) of native grassland, restored grasslands and agricultural soils. The native grasslands contained the largest amounts of total organic carbon, while the restored grasslands and agricultural soils contained similar amounts of total organic carbon. Both particulate organic carbon and mineral associated carbon pools were reduced beyond the depth of tillage in the restored grass and agricultural soils compared to the native grassland soils. The restored grassland soils had a larger particulate organic carbon content than the agricultural soils, but the increase in particulate organic carbon was limited to the surface 5 cm (2 in) of soil.

Trends in particulate organic carbon accumulation over time from nine to 30 years were not significant in this study.

Potter, K. N., O. R. Jones, et al. (1997). "Crop rotation and tillage effects on organic carbon sequestration in the semiarid southern Great Plains." Soil Science **162**(2): 140–147.

Limited information is available regarding soil organic carbon (SOC) distribution and the total amounts that occur in dryland cropping situations in semiarid regions. We determined crop rotation, tillage, and fertilizer effects on SOC distribution and mass in the semiarid southern Great Plains. A cropping system study was conducted for 10-years at Bushland, TX, to compare no-till and stubblemulch management on four dryland cropping systems: continuous wheat (CW) (Triticum aestivum L.); continuous grain sorghum (CS) (Sorghum bicolor [L.] Moench.); wheat/fallow/sorghum/fallow (WSF); and wheat/fallow (WF). Fertilizer (45 kg N ha-1) was added at crop planting to main plots. Subplots within each tillage and cropping treatment combination received no fertilizer. Ten years after treatment initiation, soil cores were taken incrementally to a 65-cm depth and subdivided for bulk density and SOC determination. The no-till treatments resulted in significant differences in SOC distribution in the soil profile compared with stubblemulch tillage in all four crop rotations, although differences were largest in the continuous cropping systems. Continuous wheat averaged 1.71% SOC in the surface 2 cm of soil compared with 1.02% SOC with stubblemulch tillage. Continuous sorghum averaged 1.54% SOC in the surface 2 cm of soil in no-till compared with 0.97% SOC with stubblemulch tillage. Total SOC content in the surface 20 cm was increased 5.6 t C ha-1 in the CW no-till treatment and 2.8 t C ha-1 in the CS no-till treatment compared with the stubblemulch treatment. Differences were not significantly different between tillage treatments in the WF and WSF systems. No-till management with continuous crops sequestered carbon in comparison to stubblemulch management on the southern Great Plains.

Powlson, D. S., D. S. Jenkinson, et al. (2010). "Comments on "Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production," by RL Mulvaney, SA Khan, and TR Ellsworth in the Journal of Environmental Quality 2009 38:2295-2314." Journal of Environmental Quality **39**(2): 749-752.

Pray, C. E., J. Huang, et al. (2002). "Five years of Bt cotton in China – the benefits continue." The Plant Journal **31**(4): 423–430.

Bt cotton is spreading very rapidly in China, in response to demand from farmers for technology that will reduce both the cost of pesticide applications and exposure to pesticides, and will free up time for other tasks. Based on surveys of hundreds of farmers in the Yellow River cotton-growing region in northern China in 1999, 2000 and 2001, over 4 million smallholders have been able to increase yield per hectare, and reduce pesticide costs, time spent spraying dangerous pesticides, and illnesses due to pesticide poisoning. The expansion of this cost-saving technology is increasing the supply of cotton and pushing down the price, but prices are still sufficiently high for adopters of Bt cotton to make substantial gains in net income.

Qaim, M. and A. De Janvry (2005). "Bt cotton and pesticide use in Argentina: Economic and environmental effects." Environment and Development Economics **10**(2): 179–200.

This article analyzes effects of insect-resistant Bt cotton on pesticide use and agricultural productivity in Argentina. Based on farm survey data, it is shown that the technology reduces application rates of toxic chemicals by 50 per cent, while significantly increasing yields. Using a damage control framework, the effectiveness of Bt versus chemical pesticides is estimated, and technological impacts are predicted for different farm types.Gross benefits could be highest for smallholder farmers, who are not currently using the technology. The durability of the advantages is analyzed by using biological models to simulate resistance development in pest populations. Rapid resistance buildup and associated pest outbreaks appear to be unlikely if minimum non-Bt refuge areas are maintained. Thus, promoting a more widespread diffusion of Bt cotton could amplify the efficiency, equity, and environmental gains. Conclusive statements about the technology's sustainability, however, require longer-term monitoring of possible secondary effects and farmers' behavior in maintaining refuges.

Ranney, J. W., L. L. Wright, et al. (1991). Carbon storage and recycling in short-rotation energy crops. Bioenergy and the Greenhouse Effect, Stockholm, Sweden, IEA Bioenergy Agreement and National Energy Administration.

Short-rotation energy crops can play a significant role in storing carbon compared to the agricultural land uses they would displace. However, the benefits from these plantations in avoiding further use of fossil fuel and in taking pressure off native forests for energy uses provides longer term carbon benefits than the plantation carbon sequestration itself. The fast growth and harvest frequency of plantations tends to limit the amount of above- and below-ground carbon storage in them. The primary components of plantation carbon sequestering compared to sustained agricultural practices involve above ground wood, possible increased soil carbon, litter layer formation, and increased root biomass. On the average, short-rotation plantations in total may increase carbon inventories by about 10 to 40 tons per hectare over about a 20 to 50 year period when displacing cropland. This is about doubling in storage over cropland and about one-half the storage in human- impacted forests. The sequestration benefit of wood energy crops over cropland would be negated in about 75 to 100 years by the use of fossil fuels to tend the plantations and handle biomass. Plantation interactions with other land uses and total landscape carbon inventory is important in assessing the relative role plantations play in terrestrial and atmospheric carbon dynamics. It is speculated that plantations, when viewed in this context, could generate a global Leveling of net carbon emissions for approximately 10 to 20 years.

Raun, W. R., J. B. Solie, et al. (2002). "Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application." Agronomy Journal **94**(4): 815–820.

In 2001, N fertilizer prices nearly doubled as a result of increased natural gas prices. This was further troubling when considering that the world N use efficiency (NUE) in cereal grain production averages only 33%. Methods to improve NUE in winter wheat (Triticum aestivum L.) have not included high spatial-resolution management based on sensed plant growth properties nor on midseason prediction of grain yield. Our objective was to determine the validity of using in-season estimates of grain yield (INSEY) and a response index (RI) to modulate N at 1-m(2)

spatial resolution. Four winter wheat field experiments were conducted that evaluated prescribed midseason N applications compared with uniform rates that simulated farmer practices. Our methods recognize that each 1-m(2) area in wheat fields needs to be sensed and managed independently and that the need for fertilizer N is temporally dependent. Averaged over locations, NUE was improved by >15% when N fertilization was based on optically sensed INSEY, determined for each 1-m(2) area, and a RI compared with traditional practices at uniform N rates.

Redeker, K. R., N.-Y. Wang, et al. (2000). "Emissions of methyl halides and methane from rice paddies." Science **290**: 266–269.

Methyl halide gases are important sources of atmospheric inorganic halogen compounds, which in turn are central reactants in many stratospheric and tropospheric chemical processes. By observing emissions of methyl chloride, methyl bromide, and methyl iodide from flooded California rice fields, we estimate the impact of rice agriculture on the atmospheric budgets of these gases. Factors influencing methyl halide emissions are stage of rice growth, soil organic content, halide concentrations, and field-water management. Extrapolating our data implies that about 1 percent of atmospheric methyl bromide and 5 percent of methyl iodide arise from rice fields worldwide. Unplanted flooded fields emit as much methyl chloride as planted, flooded rice fields.

Reeder, J. D., G. E. Schuman, et al. (1998). "Soil C and N changes on conservation reserve program lands in the Central Great Plains." Soil & Tillage Research **47**(3–4): 339–349.

The Conservation Reserve Program (CRP) was initiated to reduce water and wind erosion on marginal, highly erodible croplands by removing them from production and planting permanent, soil-conserving vegetation such as grass. We conducted a field study at two sites in Wyoming, USA, in order to quantify changes in soil C and N of marginal croplands seeded to grass, and of native rangeland plowed and cropped to wheat-fallow. Field plots were established on a sandy loam site and a clay loam site on wheat-fallow cropland that had been in production for 60+ years and on adjacent native rangeland. In 1993, 6 years after the study was initiated, the surface soil was sampled in 2.5 cm depth increments, while the subsurface soil was composited as one depth increment. All soil samples were analyzed for total organic C and N, and potential net mineralized C and N. After 60+ years of cultivation, surface soils at both study sites were 18-26% lower (by mass) in total organic C and N than in the A horizons of adjacent native range. Six years after plowing and converting native rangeland to cropland (three wheat-fallow cycles), both total and potential net mineralized C and N in the surface soil had decreased and NO3-N at all depths had increased to levels found after 60+ years of cultivation. We estimate that mixing of the surface and subsurface soil with tillage accounted for 40-60% of the decrease in surface soil C and N in long-term cultivated fields; in the short-term cultivated fields, mixing with tillage may have accounted for 60-75% of the decrease in C, and 30-60% of the decrease in N. These results emphasize the need to evaluate C and N in the entire soil solum, rather than in just the surface soil, if actual losses of C and N due to cultivation are to be distinguished from vertical redistribution. Five years after reestablishing grass on the sandy loam soil, both total and potential net mineralized C and N in the surface soil had increased to levels equal to or greater than those observed in the A horizon of the native range. On the clay loam soil, however, significant increases in total organic C were observed only in the surface 2.5 cm of N-fertilized

grass plots, while total organic N had not significantly increased from levels observed in the long-term cultivated fields.

Reeder, J. D., G. E. Schuman, et al. (2004). "Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe " Environmental Management **33**(4): 485–495.

We investigated the influence of long-term (56 years) grazing on organic and inorganic carbon (C) and nitrogen (N) contents of the plant–soil system (to 90 cm depth) in shortgrass steppe of northeastern Colorado. Grazing treatments included continuous season-long (May–October) grazing by yearling heifers at heavy (60–75% utilization) and light (20–35% utilization) stocking rates, and nongrazed exclosures. The heavy stocking rate resulted in a plant community that was dominated (75% of biomass production) by the C 4 grass blue grama (Bouteloua gracilis), whereas excluding livestock grazing increased the production of C 3 grasses and prickly pear cactus (Opuntia polycantha). Soil organic C (SOC) and organic N were not significantly different between the light grazing and nongrazed treatments, whereas the heavy grazing treatment was 7.5 Mg ha −1 higher in SOC than the nongrazed treatment. Lower ratios of net mineralized N to total organic N in both grazed compared to nongrazed treatments suggest that long-term grazing decreased the readily mineralizable fraction of soil organic matter. Heavy grazing affected soil inorganic C (SIC) more than the SOC. The heavy grazing treatment was 23.8 Mg ha −1 higher in total soil C (0–90 cm) than the nongrazed treatment, with 68% (16.3 Mg ha −1) attributable to higher SIC, and 32% (7.5 Mg ha −1) to higher SOC. These results emphasize the importance in semiarid and arid ecosystems of including inorganic C in assessments of the mass and distribution of plant–soil C and in evaluations of the impacts of grazing management on C sequestration.

Reitz, L. P. (1970). "New wheats and social progress: Improved varieties of wheat have helped make possible unprecedentedly high levels of food production." Science **169**(3949): 952–955.

Will the upward trend in all food production, so dramatically exemplified by the new wheats, be adequate to meet the needs of the growing population? Yes, for a while. No one knows for how long (14). The prophets of doom will undeniably be proved right in the long run unless their basic assumptions are nullified by concrete acts, and soon. At some point in time, either a zero population growth must be achieved or vast new sources of food must be developed, and purchasing power increased. There is nothing on the research horizon to reject "a prodigious need for mankind to practice human husbandry" (12). Our waste products have reached levels that cause major concern, and it may well be that both agricultural and social advancement will be halted by the demands dictated by population growth and the by-products of what now passes for progress but also brings environmental unbalance (15). At least, life will be different, and it may be catastrophic (16, 28). The "Three Ancients" (29) who helped plan and then, after a quarter of a century, reviewed the agricultural research and development work of the Rockefeller Foundation in developing nations concluded:

Renner, R. (2007). "Rethinking biochar." Environmental Science & Technology **41**(17): 5932–5933.

Rice, C. W. and C. E. Owensby (2001). The effects of fire and grazing on soil carbon in rangelands. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R. F. Follett, J. M. Kimble and R. Lal. Boca Raton, FL, CRC Press.

Risse, L. M., M. L. Cabrera, et al. (2006). Land application of manure for beneficial reuse. Animal Agriculture and the Environment: National Center for Manure and Animal Waste Management. J. M. Rice, D. F. Caldwell and F. J. Humenik. St. Joseph, MI, ASABE**:** 283–316.

> The concentration of animal production systems has increased efficiency and improved overall economic return for animal producers. This concentration, along with the advent of commercial fertilizers, has led to a change in the way animal producers view manure. Manure, once valued as a resource by farmers, is now treated as a waste. Air and water quality concerns that arise primarily from the under-utilization or inefficient use of manure contribute to these changing views. However, when properly used, manure is a resource and should be regulated as such. In the United States, the USDA/EPA Unified National Strategy for Animal Feeding Operations outlines how animal feeding operations should be regulated and acknowledges that land application at proper agronomic rates is the preferred use for manures. However, many limitations such as water quality concerns, uncertainty in manure nutrient availability, high transportation costs, and odor concerns cause some to question land application. This paper documents the benefits of land application of manure, discusses limitations that hinder greater manure utilization, and outlines research and extension needs for improving manure utilization.

Rixon, A. J. (1966). "Soil fertility changes in a red-brown earth under irrigated pastures. I. Changes in organic carbon, C:N ratio, CEC and pH." Australian Journal of Agricultural Research **17**(3): 303–316.

> Organic matter and soil fertility changes under irrigated pastures were followed for 5 years at Deniliquin, N.S.W. The effects of three annual pastures and of three perennial pastures were studied. Four years after their establishment an organic matter layer (mat) had formed under all pastures, and after its ofrmation there was no further accumulation of organic carbon in the 0 - 3 in. soil horizon. The mean annual increase in organic carbon was 625 lb/acre under annual pastures and 1146 lb/acre under perennial pastures. The carbon/nitrogen ratios of both soil and mats, and the relationships of both organic carbon and nitrogen to the cation exchange capacity of the mats, were similarly affected by the annual and perennial pastures. The heterogeneous nature of the mats obscured any differences in their carbon/nitrogen ratios, which ranged from 12:8 to 22:0. The cation exchange capacity of the 0-3 in. soil horizon remained unchanged. The cation exchange capacity of the organic matter of the mats was approximately 100 m-equiv./100 g. After mat formation the underlying soil had a pH of approximately 6.0 under clovers and 6.5 under ryegrasses. The pH values of the mats ranged from 5.0 to 6.6.

Roberts, K. G., B. A. Gloy, et al. (2010). "Life cycle assessment of biochar systems: Estimating the energetic, economic, and climate change potential." Environmental Science & Technology **44**(2): 827–833.

> Biomass pyrolysis with biochar returned to soil is a possible strategy for climate change mitigation and reducing fossil fuel consumption. Pyrolysis with biochar applied to soils results in four coproducts: long-term carbon (C) sequestration from stable C in the biochar, renewable

energy generation, biochar as a soil amendment, and biomass waste management. Life cycle assessment was used to estimate the energy and climate change impacts and the economics of biochar systems. The feedstocks analyzed represent agricultural residues (corn stover), yard waste, and switchgrass energy crops. The net energy of the system is greatest with switchgrass (4899 MJ t(-1) dry feedstock). The net greenhouse gas (GHG) emissions for both stover and yard waste are negative, at -864 and -885 kg CO2 equivalent (CO(2)e) emissions reductions per tonne dry feedstock, respectively. Of these total reductions, 62-66% are realized from C sequestration in the biochar. The switchgrass biochar-pyrolysis system can be a net GHG emitter (+36 kg CO(2)e t(-1) dry feedstock), depending on the accounting method for indirect land-use change impacts. The economic viability of the pyrolysis-biochar system is largely dependent on the costs of feedstock production, pyrolysis, and the value of C offsets. Biomass sources that have a need for waste management such as yard waste have the highest potential for economic profitability (+$69 t(-1) dry feedstock when CO(2)e emission reductions are valued at $80 t(-1) CO(2)e). The transportation distance for feedstock creates a significant hurdle to the economic profitability of biochar-pyrolysis systems. Biochar may at present only deliver climate change mitigation benefits and be financially viable as a distributed system using waste biomass.

Roberts, T. L. (2006). Improving nutrient use efficiency. IFA Agriculture Conference “Optimizing Resource Use Efficiency for Sustainable Intensification of Agriculture”, Kunming, China, International Fertilizer Industry Association (IFA), Paris, France.

Robertson, G. P., E. A. Paul, et al. (2000). "Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere." Science **289**(5486): 1922–1925.

Agriculture plays a major role in the global ßuxes of the greenhouse gases carbon dioxide, nitrous oxide, and methane. From 1991 to 1999, we measured gas ßuxes and other sources of global warming potential (GWP) in cropped and nearby unmanaged ecosystems. Net GWP (grams of carbon dioxide equivalents per square meter per year) ranged from 110 in our conventional tillage systems to 2211 in early successional communities. None of the annual cropping systems provided net mitigation, although soil carbon accumulation in no-till systems came closest to mitigating all other sources of GWP. In all but one ecosystem, nitrous oxide production was the single greatest source of GWP. In the late successional system, GWP was neutral because of signiÞcant methane oxidation. These results suggest additional opportunities for lessening the GWP of agronomic systems.

Robinson, C. A., R. M. Cruse, et al. (1996). "Cropping system and nitrogen effects on Mollisol organic carbon." Soil Science Society of America Journal **60**(1): 264–269.

Time, fertilizer, tillage, and cropping systems may alter soil organic carbon (SOC) levels. Our objective was to determine the effect of long-term cropping systems and fertility treatments on SOC. Five rotations and two N fertility levels at three Iowa sites (Kanawha, Nashua, and Sutherland) maintained for 12 to 36 yr were evaluated. A 75-yr continuous corn (Zea mays L.) site (Ames) with a 40-yr N-P-K rate study also was evaluated. Soils were Typic and Aquic Hapludolls and Typic Haplaquolls. Four-year rotations consisting of corn, oat (Avena sativa L.), and meadow (alfalfa [Medicago sativa L.], or alfalfa and red clover [Trifolium pratense L.]) had the highest SOC (Kanawha, 32.1 g/kg; Nashua, 21.9 g/kg; Sutherland, 27.9 g/kg). Corn silage

treatments (Nashua, [≤] 18.9 g/kg; Sutherland, [≤]23.2 g/kg) and no-fertilizer treatments (Kanawha, 25.3 g/kg; Nashua, [≤]20.9 g/kg; Sutherland, [≤]23.5 g/kg) had the lowest SOC. A corn-oat-meadow-meadow rotation maintained initial SOC (27.9 g/kg) after 34 yr at Sutherland. Continuous corn resulted in loss of 30% of SOC during 35 yr of manure and lime treatments. SOC increased 22% when N-P-K treatments were imposed. Fertilizer N, initial SOC levels, and previous management affected current SOC levels. Residue additions were linearly related to SOC (Ames, r2 = 0.40; Nashua, r2 = 0.82; Sutherland, r2 = 0.89). All systems had 22 to 49% less SOC than adjacent fence rows. Changing cropping systems to those that conserve SOC could sequester as much as 30% of C released since cropping began, thereby increasing SOC.

Robles, M. D. and I. C. Burke (1998). "Soil organic matter recovery on conservation reserve program fields in southeastern Wyoming." Soil Science Society of America Journal **62**: 725–730.

Soil C and N changes following cessation of cultivation in semiarid soils is not well understood. We hypothesized that returning cultivated fields in southeastern Wyoming to perennial grasses through the Conservation Reserve Program (CRP) would (i) increase labile pools of soil organic matter (SOM), and (ii) increase small-scale heterogeneity of SOM. Carbon and N in labile and passive pools of SOM were measured in CRP fields seeded with perennial grasses intermediate wheatgrass (Elytrigia intermedia [Host] Nevski ssp. intermedia), pubescent wheatgrass (Elytrigia intermedia [Schur.] A. Love ssp. barbulata) and smooth brome (Bromus inermis Leysser), and in winter wheat (Triticum aestivum L.)-fallow fields. Mineralizable C increased from 0.37 g m~2 d-1 in wheat-fallow fields to 0.99 g m~2d-1 in CRP fields; mineralizable N and coarse particulate C were consistently but not significantly higher in CRP fields. Fine particulate and total soil C and IN were not significantly different between CRP and wheat-fallow. Within CRP fields, mineralizable C was significantly higher under grasses than in interspaces (1.96 vs. 0.73 g m~2d ', respectively), and mineralizable N and coarse particulate C and N were consistently but not significantly higher under grasses than in interspaces. Soil C and N have increased only slightly after 6 yr of CRP management, and future changes in land use management on these CRP fields, including grazing and cropping, may accrue some small benefits associated with improved soil fertility status.

Rochette, P. (2008). "No-till only increases N_2O emissions in poorly-aerated soils." Soil & Tillage Research **101**(1–2): 97–100.

Denitrification rates are often greater in no-till than in tilled soils and net soil-surface greenhouse gas emissions could be increased by enhanced soil N2O emissions following adoption of no-till. The objective of this study was to summarize published experimental results to assess whether the response of soil N2O fluxes to the adoption of no-till is influenced by soil aeration. A total of 25 field studies presenting direct comparisons between conventional tillage and no-till (approximately 45 site-years of data) were reviewed and grouped according to soil aeration status estimated using drainage class and precipitation during the growing season. The summary showed that no-till generally increased N2O emissions in poorly-aerated soils but was neutral in soils with good and medium aeration. On average, soil N2O emissions under no-till were 0.06 kg N ha-1 lower, 0.12 kg N ha-1 higher and 2.00 kg N ha-1 higher than under tilled soils with good, medium and poor aeration, respectively. Our results therefore suggest that the impact of no-till on N2O emissions is small in well-aerated soils but most often positive in soils where aeration is reduced by conditions or properties restricting drainage. Considering typical soil C gains following adoption of no-till, we conclude that increased N2O losses may result in a negative greenhouse gas balance for many poorly-drained fine-textured agricultural soils under no-till located in regions with a humid climate.

Rochette, P., D. A. Angers, et al. (2004). "Emissions of N_2O from alfalfa and soybean crops in eastern Canada." Soil Science Society of America Journal **68**(2): 493–506.

There is considerable uncertainty relative to the emissions of N2O from legume crops. A study was initiated to quantify N2O fluxes from soils cropped to alfalfa (Medicago sativa L.) and soybean (Glycine max L.), and to improve our understanding of soil and climatic factors controlling N2O emissions from these crops. Measurements were made on three soils cropped to alfalfa, soybean, or timothy (Phleum pratense L.), a perennial grass used as a control. In situ soil-surface N2O emissions (FN2O) were measured 47 times during the 2001 and 2002 growing seasons. Soil water, NH4-N, NO3-N, and N2O contents, and soil temperature were also determined to explain the variation in gas fluxes. Emissions of N2O were small under the grass where very low soil mineral N content probably limited denitrification and N2O production. Soil mineral N contents under legumes were up to 10 times greater than under timothy. However, soil mineral N contents and FN2O were not closely related, thus suggesting that the soil mineral N pool alone was a poor indicator of the intensity of N2O production processes. Higher FN2O were measured under legume than under timothy in only 6 out of 10 field comparisons (site-years). Moreover, the emissions associated with alfalfa (0.67-1.45 kg N ha-1) and soybean (0.46-3.08 kg N ha-1) production were smaller than those predicted using the emission coefficient proposed for the national inventory of greenhouse gases (alfalfa = 1.60-5.21 kg N ha-1; soybean = 2.76-4.97 kg N ha-1). We conclude that the use of the current emission coefficient may overestimate the N2O emissions associated with soybean and alfalfa production in eastern Canada.

Rochette, P., D. A. Angers, et al. (2008). "Nitrous oxide emissions respond differently to no-till in a loam and a heavy clay soil." Soil Science Society of America Journal **72**(5): 1363–1369.

The anticipated benefits of increased soil C stocks on net soil-surface greenhouse gas (GHG) emissions after adoption of soil conservation practices can be offset by increases in soil N2O emissions. The objective of this study was to assess the short-term impacts of no-till (NT) on soil N2O emissions. The study was conducted in eastern Canada in the 3rd, 4th, and 5th yr after initiation of NT and fall moldboard plowing (MP) on heavy clay and gravelly loam soils. Annual emissions of N2O were exceptionally high in the heavy clay soil, varying from 12 to 45 kg N2O-N ha-1 during the 3 yr of the study. Such high emissions were probably not associated with fertilizer N inputs but rather with denitrification sustained by the decomposition of large soil organic matter stocks (192 Mg C ha-1 in the top 0.5 m). On average, NT more than doubled N2O emissions compared with MP in the heavy clay soil. The influence of plowing on N2O flux in the heavy clay soil was probably the result of increased soil porosity that maintained soil aeration and water content at levels restricting denitrification and N2O production in the top 0.20 m. In the loam soil, average emissions during the 3 yr were similar in the NT and MP plots. The results of this study indicate that the potential of NT for decreasing net GHG emissions may be limited in fine-textured soils rich in organic matter that are prone to high water content and reduced aeration.

Rochette, P., D. A. Angers, et al. (2000). "Soil carbon and nitrogen dynamics following application of pig slurry for the 19th consecutive year: I. Carbon dioxide fluxes and microbial biomass carbon." Soil Science Society of America Journal **64**(4): 1389–1395.

Agricultural soils often receive annual applications of manure for long periods. The objective of this study was to quantify the effects of 19 consecutive years of pig (Sus scrofa) slurry (PS) application on CO2 emissions and soil microbial biomass. Soil temperature, soil moisture, sad extractable soil C were also determined to explain the variations in CO2 emissions and soil microbial biomass. Long-term (19 Sr) treatments were 60 (PS60) and 120 Mg ha(-1) yr(-1) (PS120) of pig slurry and a control receiving mineral fertilizers at a dose of 150 kg ha(-1) yr(-1) each of N, P2O5, and K2O. Very high CO2 emissions (up to 1.5 mg CO2 m(-2) s(-1)) occurred during the first 2 d after PS application. Following that peak, decomposition of PS was rapid, with one-half the total emissions occurring during the first meek after slurry application. The rapid initial decomposition was exponential and was attributed to the decomposition of the labile fraction. of the slurry C. The second phase was linear and much slower and probably involved more recalcitrant C material. Cumulative annual decomposition was proportional to the application rate, with 769 and 1658 kg C ha(-1) lost from the 60 and 120 Mg ha(-1) doses, respectively. Pig slurry application caused a rapid increase in soil microbial biomass (from approximate to 100 to up to 370 mg C kg(-1) soil), which coincided with a peak in the concentration of extractable C and in CO2 emissions. Field estimates of the microbial specific respiratory activity suggested that the difference in soil respiration between the two slurry treatments was due to differences in the size of the induced microbial biomass rather than to differences in specific activity.

Rochette, P., N. Tremblay, et al. (2010). "N_2O emissions from an irrigated and non-irrigated organic soil in eastern Canada as influenced by N fertilizer addition." European Journal of Soil Science **61**(2): 186–196.

Drainage and cultivation of organic soils often result in large nitrous oxide (N2O) emissions. The objective of this study was to assess the impacts of nitrogen (N) fertilizer on N2O emissions from a cultivated organic soil located south of Montreal, QC, Canada, drained in 1930 and used since then for vegetable production. Fluxes of N2O were measured weekly from May 2004 to November 2005 when snow cover was absent in irrigated and non-irrigated plots receiving 0, 100 or 150 kg N ha(-1) as NH4NO3. Soil mineral N content, gas concentrations, temperature, water table height and water content were also measured to help explain variations in N2O emissions. Annual emissions during the experiment were large, ranging from 3.6 to 40.2 kg N2O-N ha(-1) year(-1). The N2O emissions were decreased by N fertilizer addition in the non-irrigated site but not in the irrigated site. The absence of a positive influence of soil mineral N content on N2O emissions was probably in part because up to 571 kg N ha(-1) were mineralized during the snow-free season. Emissions of N2O were positively correlated to soil CO2 emissions and to variables associated with the extent of soil aeration such as soil oxygen concentration, precipitation and soil water table height, thereby indicating that soil moisture/aeration and carbon bioavailability were the main controls of N2O emission. The large N2O emissions observed in this study indicate that drained cultivated organic soils in eastern Canada have a potential for N2O-N losses similar to, or greater than, organic soils located in northern Europe.

Rochette, P., D. E. Worth, et al. (2008). "Estimation of N_2O emissions from agricultural soils in Canada. I. Development of a country-specific methodology." Canadian Journal of Soil Science **88**(5): 641–654.

International initiatives such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol require that countries calculate national inventories of their greenhouse gas emissions. The objective of the present study was to develop a country-specific (Tier II) methodology to calculate the inventory of N2O emissions from agricultural soils in Canada. Regional fertilizer-induced emission factors (EFreg) were first determined using available field experimental data. Values for EFreg were 0.0016 kg N2O-N kg-1 N in the semi-arid Brown and 0.008 kg N2O-N kg N-1 in the sub-humid Black soil zones of the Prairie region, and 0.017 kg N2O-N kg-1 N in the humid provinces of Quebec and Ontario. A function relating EFreg to the "precipitation to potential evapotranspiration" ratio was determined to estimate annual emission factors (EFeco) at the ecodistrict scale (≈ 150 000 ha) in all agricultural regions of Canada. Country-specific coefficients were also developed to account for the effect of several additional factors on soil N2O emissions. Emissions from fine-textured soils were estimated as being 50% greater than from coarse- and medium-textured soils in eastern Canada; emissions during winter and spring thaw corresponded to 40% of emissions during the snow-free season in eastern Canada; increased emissions from lower (wetter) sections of the landscape and irrigated areas were accounted for; emissions from no-till soils were 10% greater in eastern, but 20% lower in western Canada than from those under conventional tillage practices; emissions under summerfallow were estimated as being equal to those from soils under annual cropping. This country-specific methodology therefore accounts for regional climatic and land use impacts on N2O emission factors, and includes several sources/offsets that are not included in the Intergovernmental Panel on Climate Change (IPCC) default approach.

Rogovska, N., P. Fleming, et al. (2008). Greenhouse gas emissions from soils as affected by addition of biochar. ASA-CSSA-SSSA Annual Meeting, Houston, TX.

Rondon, M., J. A. Ramirez, et al. (2005). Charcoal additions reduce net emissions of greenhouse gases to the atmosphere. 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration, Baltimore.

Charcoal is a ubiquitous material that has been used in agriculture by several cultures throughout history. Increasing evidence indicates that in very low fertility soils, additions of charcoal could increase plant yield and improve several soil quality indicators. Charcoal is a very stable material in soils, with residence times in the order of thousands of years contrasting with mean residence times of decades to centuries for most other soil organic matter pools. Charcoal additions could be used as a mechanism for long-term storage of C in soils and can play a key role for mitigation of climate change and to improve naturally unfertile or degraded soils. There is no information so far, however, related to the effects of charcoal additions to soils on net fluxes of greenhouse gases and on the overall global warming potential of soils amended with charcoal. Here we present results from a glasshouse pot experiment, where very acid, low-fertility oxisols (typic haplustox) from Colombian savannas were amended with 0, 7.5, 15, and 30 g kg-1 of charcoal. Soybeans and a tropical grass (B. humidicola) were planted and allowed to grow for 50 days. Plant yield and total biomass were measured at harvest time and the soil tested for various nutrients. Monitoring of fluxes of nitrous oxide and methane was done using the closed vented chamber approach. Gas samples were collected at two-weeks intervals after planting. Analysis of methane and nitrous oxide was conducted by gas chromatography using

FID and ECD detectors. Total net fluxes of methane and nitrous oxide from pots cropped to soybean and B. humidicola were significantly reduced by the addition of charcoal. Methane emissions were virtually suppressed in the grass pots already at charcoal additions of 20g kg-1 soil. Nitrous oxide emissions were reduced by up to 50% on soybean and by 80% in grass pots. At the same time, biomass production of soybean was positively affected by increasing charcoal additions, with a 60% increase after charcoal additions of 20 g charcoal kg-1 soil. In contrast, biomass of B. humidicola did not change with charcoal additions. Charcoal effectively increased soil pH, CEC and availability of various soil nutrients. This study showed that additions of moderate doses of charcoal to very acid and nutrient-limited soils not only enhance plant yields especially of legume species, but also result in drastic reductions in net emissions of methane and nitrous oxide from soils. Given that most of the added charcoal-C remains unmineralized in the soil due to its chemical recalcitrance, a clear positive effect of charcoal additions to soils was observed on net reductions of total emissions of greenhouse gases to the atmosphere. To our knowledge, this is the first study in exploring charcoal effect on GHG emissions. Further research is needed to establish the response of different charcoals in contrasting soil types and with other plants species.

Rudel, T. K., L. Schneider, et al. (2009). "Agricultural intensification and changes in cultivated areas, 1970–2005." Proceedings of the National Academy of Sciences **106**(49): 20675–20680.

Does the intensification of agriculture reduce cultivated areas and, in so doing, spare some lands by concentrating production on other lands? Such sparing is important for many reasons, among them the enhanced abilities of released lands to sequester carbon and provide other environmental services. Difficulties measuring the extent of spared land make it impossible to investigate fully the hypothesized causal chain from agricultural intensification to declines in cultivated areas and then to increases in spared land. We analyze the historical circumstances in which rising yields have been accompanied by declines in cultivated areas, thereby leading to land-sparing. We use national-level United Nations Food and Agricultural Organization data on trends in cropland from 1970–2005, with particular emphasis on the 1990–2005 period, for 10 major crop types. Cropland has increased more slowly than population during this period, but paired increases in yields and declines in cropland occurred infrequently, both globally and nationally. Agricultural intensification was not generally accompanied by decline or stasis in cropland area at a national scale during this time period, except in countries with grain imports and conservation set-aside programs. Future projections of cropland abandonment and ensuing environmental services cannot be assumed without explicit policy intervention.

Saggar, S., N. S. Bolan, et al. (2004). "A review of emissions of methane, ammonia, and nitrous oxide from animal excreta deposition and farm effluent application in grazed pastures." New Zealand Journal of Agricultural Research **47**(4): 513–544.

The agricultural sector in New Zealand is the major contributor to ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) emissions to the atmosphere. These gases cause environmental degradation through their effects on soil acidification, eutrophication, and stratospheric ozone depletion. With its strong agricultural base and relatively low level of heavy industrial activity, New Zealand is unique in having a greenhouse-gas-emissions inventory dominated by the agricultural trace gases, CH_4 and N_2O, instead of carbon dioxide which dominates in most other countries. About 96% of this anthropogenic CH_4 is emitted by ruminant animals as a by-product during the process of enteric fermentation. Methane is also produced by anaerobic fermentation of animal manure and many other organic substrates.

Sahrawat, K. L. (2003). "Organic matter accumulation in submerged soils." Advances in Agronomy **81**: 169–201.

The decomposition and accumulation of organic materials in submerged (anaerobic) soils and sediments differ considerably from those in their aerobic counterparts. This is caused by the lack of oxygen or anaerobiosis. Compared to aerobic soils, there is preferential accumulation of organic matter in submerged rice soils. This paper reviews the current literature to establish basis or bases for organic matter accumulation in wetland soils and sediments. The decomposition or destruction of organic materials is lessened and incomplete, and the humification of organic matter is decreased under flooded conditions. Consequently, the overall organic matter decomposition rates are slower in submerged soils than those in aerobic soils and this results in net accumulation of organic matter in soils or sites that remain flooded for several years. Also, high organic matter soils or Histosols are developed in permanently waterlogged sites or soils because the rate of organic matter destruction is slower than its accumulation. The balance between organic matter inputs and decomposition is the primary determinant of organic matter accumulation or depletion. Several hypotheses have been postulated to explain the accumulation of organic matter in submerged soils. They include the deleterious effects on microbial activity of reduction products produced such as hydrogen sulfide or volatile fatty acids and toxic concentrations of ammonia, aluminum, iron, and other cations in soil solution. The absence of electron acceptors such as iron oxides and hydroxides in submerged soils and sediments slows down organic matter oxidation and mineralization. Formation of recalcitrant complex organic molecules with organic matter fractions, e.g., through enrichment of organic matter with phenolics in intensified irrigated rice production system, may render them less available for microbial attack and utilization. Moreover, the net primary productivity of wetlands is higher than other ecosystems. There is need for further research to fully understand the mechanism(s) involved in the accumulation of organic matter in submerged soils as wetlands offer an excellent example of conservation and maintenance of organic matter and storage of organic C.

Sainju, U. M., A. Lenssen, et al. (2006). "Tillage and crop rotation effects on dryland soil and residue carbon and nitrogen." Soil Science Society of America Journal **70**(2): 668–678.

Sustainable management practices are needed to enhance soil productivity in degraded dryland soils in the northern Great Plains. We examined the effects of two tillage practices [conventional till (CT) and no-till (NT)], five crop rotations [continuous spring wheat (Triticum aestivum L.) (CW), spring wheat-fallow (W-F), spring wheat-lentil (Lens culinaris Medic.) (W-L), spring wheat-spring wheat-fallow (W-W-F), and spring wheat-pea (Pisum sativum L.)-fallow (W-P-F)], and a Conservation Reserve Program (CRP) on plant biomass returned to the soil, residue C and N, and soil organic C (SOC), soil total N (STN), and particulate organic C and N (POC and PON) at the 0- to 20-cm depth. A field experiment was conducted in a mixture of Scobey clay loam (fine, smectitic, frigid Aridic Argiustolls) and Kevin clay loam (fine-loamy, mixed, superactive, frigid Aridic Argiustolls) from 1998 to 2003 near Havre, MT. Mean annualized plant biomass returned to the soil from 1998 to 2003 was greater in W-F (2.02 Mg ha-1) than in W-L and W-W-F, regardless of tillage. In 2004, residue cover was greater in CW (60%) than in other rotations, except in W-W-F. Residue amount and C and N contents were greater in NT with CW (2.47 Mg ha-1 and 963 and 22 kg ha-1, respectively) than in NT with W-L and CT with other crop rotations. The POC at 0 to 5 cm was greater in W-W-F and W-P-F (2.1-2.2 Mg ha-1) than in W-L. Similarly, STN at 5 to 20 cm was greater in CT with W-L (2.21 Mg ha-1) than in other treatments, except in NT with W-W-F. Reduced tillage and increased cropping intensity, such as NT with CW and W-L, conserved C and N in dryland soils and crop residue better than the traditional practice, CT with W-F, and their contents were similar to or better than in CRP planting.

Sainju, U. M., B. P. Singh, et al. (2002). "Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA." Soil & Tillage Research **63**(3–4): 167–179.

Maintaining and/or conserving organic carbon (C) and nitrogen (N) concentrations in the soil using management practices can improve its fertility and productivity and help to reduce global warming by sequestration of atmospheric CO_2 and N_2. We examined the influence of 6 years of tillage (no-till, NT; chisel plowing, CP; and moldboard plowing, MP), cover crop (hairy vetch (Vicia villosa Roth.) vs. winter weeds), and N fertilization (0, 90, and 180 kg N ha-1) on soil organic C and N concentrations in a Norfolk sandy loam (fine-loamy, siliceous, thermic, Typic Kandiudults) under tomato (Lycopersicon esculentum Mill.) and silage corn (Zea mays L.). In a second experiment, we compared the effects of 7 years of non-legume (rye (Secale cereale L.)) and legume (hairy vetch and crimson clover (Trifolium incarnatum L.)) cover crops and N fertilization (HN (90 kg N ha-1 for tomato and 80 kg N ha-1 for eggplant)) and FN (180 kg N ha-1 for tomato and 160 kg N ha-1 for eggplant)) on soil organic C and N in a Greenville fine sandy loam (fine-loamy, kaolinitic, thermic, Rhodic Kandiudults) under tomato and eggplant (Solanum melogena L.). Both experiments were conducted from 1994 to 2000 in Fort Valley, GA. Carbon concentration in cover crops ranged from 704 kg ha-1 in hairy vetch to 3704 kg ha-1 in rye in 1999 and N concentration ranged from 77 kg ha-1 in rye in 1996 to 299 kg ha-1 in crimson clover in 1997. With or without N fertilization, concentrations of soil organic C and N were greater in NT with hairy vetch than in MP with or without hairy vetch (23.5-24.9 vs. 19.9-21.4 Mg ha-1 and 1.92-2.05 vs. 1.58-1.76 Mg ha-1, respectively). Concentrations of organic C and N were also greater with rye, hairy vetch, crimson clover, and FN than with the control without a cover crop or N fertilization (17.5-18.4 vs. 16.5 Mg ha-1 and 1.33-1.43 vs. 1.31 Mg ha-1, respectively). From 1994 to 1999, concentrations of soil organic C and N decreased by 8-16% in NT and 15-25% in CP and MP. From 1994 to 2000, concentrations of organic C and N decreased by 1% with hairy vetch and crimson clover, 2-6% with HN and FN, and 6-18% with the control. With rye, organic C and N increased by 3-4%. Soil organic C and N concentrations can be conserved and/or maintained by reducing their loss through mineralization and erosion, and by sequestering atmospheric CO_2 and N_2 in the soil using NT with cover crops and N fertilization. These changes in soil management improved soil quality and productivity. Non-legume (rye) was better than legumes (hairy vetch and crimson clover) and N fertilization in increasing concentrations of soil organic C and N.

Sartori, F., R. Lal, et al. (2006). "Potential soil carbon sequestration and CO_2 offset by dedicated energy crops in the USA." Critical Reviews in Plant Sciences **25**(5): 441–472.

Energy crops are fast-growing species whose biomass yields are dedicated to the production of more immediately usable energy forms, such as liquid fuels or electricity. Biomass-based energy

sources can offset, or displace, some amount of fossil-fuel use. Energy derived from biomass provides 2 to 3% of the energy used in the U.S.A.; but, with the exception of corn-(Zea mays L.)-to-ethanol, very little energy is currently derived from dedicated energy crops. In addition to the fossil-fuel offset, energy cropping might also mitigate an accentuated greenhouse gas effect by causing a net sequestration of atmospheric C into soil organic C (SOC). Energy plantations of short-rotation woody crops (SRWC) or herbaceous crops (HC) can potentially be managed to favor SOC sequestration. This review is focused primarily on the potential to mitigate atmospheric CO2 emissions by fostering SOC sequestration in energy cropping systems deployed across the landscape in the United States. We know that land use affects the dynamics of the SOC pool, but data about spatial and temporal variability in the SOC pool under SRWC and HC are scanty due to lack of well-designed, long-term studies. The conventional methods of studying SOC fluxes involve paired-plot designs and chronosequences, but isotopic techniques may also be feasible in understanding temporal changes in SOC. The rate of accumulation of SOC depends on land-use history, soil type, vegetation type, harvesting cycle, and other management practices. The SOC pool tends to be enhanced more under deep-rooted grasses, N-fixers, and deciduous species. Carbon sequestration into recalcitrant forms in the SOC pool can be enhanced with some management practices (e.g., conservation tillage, fertilization, irrigation); but those practices can carry a fossil-C cost. Reported rates of SOC sequestration range from 0 to 1.6 Mg C ha(-1) yr(-1) under SRWC and 0 to 3 Mg C ha(-1) yr(-1) under HC. Production of 5 EJ of electricity from energy crops-a perhaps reasonable scenario for the U.S.A.-would require about 60 Mha. That amount of land is potentially available for conversion to energy plantations in the U.S.A. The land so managed could mitigate C emissions (through fossil C not emitted and SOC sequestered) by about 5.4 Mg C ha(-1) yr(-1). On 60 Mha, that would represent 324 Tg C yr(-1)-a 20% reduction from current fossil-fuel CO2 emissions. Advances in productivity of fast-growing SRWC and HC species suggest that deployment of energy cropping systems could be an effective strategy to reduce climate-altering effects of anthropogenic CO2 emissions and to meet global policy commitments.

Sass, R. L. and R. J. Cicerone (2002). "Photosynthate allocations in rice plants: Food production or atmospheric methane?" Proceedings of the National Academy of Sciences of the United States of America **99**(19): 11993–11995.

Sass, R. L. and F. M. Fisher, Jr. (1997). "Methane emissions from rice paddies: a process study summary." Nutrient Cycling in Agroecosystems **49**(1): 119–127.

Irrigated rice cultivation is one of the largest sources (approximately 15–20% of the annual total) of atmospheric methane, a potent greenhouse gas. This review examines the results of work performed over the past six years in which we have investigated the processes leading to the emission of methane from irrigated rice cultivation. These studies describe the daily and seasonal effects on methane production and emission of different planting dates, water management, organic amendments, soil texture, and cultivar choice. Because rice agriculture is one of the few sources of methane where emission reduction through management is considered possible, it promises to be a critical focus of mitigation efforts. We have identified several potential management practices for rice cultivation that may stabilize or reduce the emission of methane even in the face of future increased grain production necessary to meet the demands of an expanding world population.

Scheer, C., R. Wassmann, et al. (2008). "Methane and nitrous oxide fluxes in annual and perennial land-use systems of the irrigated areas in the Aral Sea Basin." Global Change Biology **14**(10): 2454–2468.

Land use and agricultural practices can result in important contributions to the global source strength of atmospheric nitrous oxide (N2O) and methane (CH4). However, knowledge of gas flux from irrigated agriculture is very limited. From April 2005 to October 2006, a study was conducted in the Aral Sea Basin, Uzbekistan, to quantify and compare emissions of N2O and CH4 in various annual and perennial land-use systems: irrigated cotton, winter wheat and rice crops, a poplar plantation and a natural Tugai (floodplain) forest. In the annual systems, average N2O emissions ranged from 10 to 150 mu g N2O-N m(-2) h(-1) with highest N2O emissions in the cotton fields, covering a similar range of previous studies from irrigated cropping systems. Emission factors (uncorrected for background emission), used to determine the fertilizer-induced N2O emission as a percentage of N fertilizer applied, ranged from 0.2% to 2.6%. Seasonal variations in N2O emissions were principally controlled by fertilization and irrigation management. Pulses of N2O emissions occurred after concomitant N-fertilizer application and irrigation. The unfertilized poplar plantation showed high N2O emissions over the entire study period (30 mu g N2O-N m(-2) h(-1)), whereas only negligible fluxes of N2O (< 2 mu g N2O-N m(-2) h(-1)) occurred in the Tugai. Significant CH4 fluxes only were determined from the flooded rice field: Fluxes were low with mean flux rates of 32 mg CH4 m(-2) day(-1) and a low seasonal total of 35.2 kg CH4 ha(-1). The global warming potential (GWP) of the N2O and CH4 fluxes was highest under rice and cotton, with seasonal changes between 500 and 3000 kg CO2 eq. ha(-1). The biennial cotton-wheat-rice crop rotation commonly practiced in the region would average a GWP of 2500 kg CO2 eq. ha(-1) yr(-1). The analyses point out opportunities for reducing the GWP of these irrigated agricultural systems by (i) optimization of fertilization and irrigation practices and (ii) conversion of annual cropping systems into perennial forest plantations, especially on less profitable, marginal lands.

Schlamadinger, B. and G. Marland (1996). "Full fuel cycle carbon balances of bioenergy and forestry options." Energy Conversion and Management **37**(6–8): 813–818.

Forestry projects can - at least temporarily - mitigate the net flux of anthropogenic CO2 to the atmosphere by removing C from the atmosphere and sequestering it in growing trees. The net flux of C to the atmosphere can also be reduced if trees are burned to displace the burning of fossil fuels and are then replanted to recycle the C back into the biosphere, or if wood is used for products that store carbon and are otherwise made from other, more energy-intensive materials. A computer model is employed to calculate carbon balances of two land management and biomass utilization scenarios - conventional forest management and short-rotation forestry. Sensitivity analyses reveal that the most important site and system dependent parameters for the net reduction of carbon emissions are the site occupancy prior to the project, growth rate, efficiency of biomass conversion into energy and non-energy products, and carbon emission rates and efficiencies of displaced fossil fuel cycles. The results demonstrate that time is another important consideration and that projects can look considerably different, in terms of C balance, when the endpoint of the analysis is 20, 50, or 100 years.

Schlesinger, W. H. (2000). "Carbon sequestration in soils: Some cautions amidst optimism." Agriculture, Ecosystems & Environment **82**(1-3): 121–127.

A sink for atmospheric carbon (i.e., CO2) in soils may derive from the application of conservation tillage and the regrowth of native vegetation on abandoned agricultural land. Accumulations of soil organic matter on these lands could offset emissions of CO2 from fossil fuel combustion, in the context of the Kyoto protocol. The rate of accumulation of soil organic matter is often higher on fertilized fields, but this carries a carbon "cost" that is seldom assessed in the form of CO2 emissions during the production and application of inorganic fertilizer. Irrigation of semiarid lands may also produce a sink for carbon in plant biomass, but its contribution to a sink for carbon in soils must be discounted by CO2 that is emitted when energy is used to pump irrigation water and when CaCO3 precipitates in the soil profile. No net sink for carbon is likely to accompany the use of manure on agricultural lands.

Schmidt, J. P., A. E. Dellinger, et al. (2009). "Nitrogen recommendations for corn: An on-the-go sensor compared with current recommendation methods." Agronomy Journal **101**(4): 916–924.

Precision agriculture technologies provide the capability to spatially vary N fertilizer applied to corn (Zea mays L.), potentially improving N use efficiency. The focus of this study was to evaluate the potential of improving N recommendations based on crop canopy reflectance. Corn was grown at four field sites in each of 2 yr in Centre County, Pennsylvania. Preplant treatments included: zero fertilizer, 56 kg N ha(-1), and manure. Split-plot treatments included the following N sidedress rates as NH4NO3: 0, 22, 45, 90, 135, 180, and 280 kg N ha(-1), and one at-planting N rate of 280 kg N ha(-1). Light energy reflectance (590 and 880 nm), chlorophyll meter (SPAD) measurements, and the presidedress NO3 test (PSNT) results were obtained at sidedress. The late-season stalk NO3 (LSSN) test was determined. The economic optimum nitrogen rate (EONR) was determined based on grain yield response to sidedress N rates. Relative green normalized difference vegetation index (GNDVI) and relative SPAD were based on relative measurements from the zero sidedress treatment to the 280 kg N ha(-1) at-planting treatment. The EONR from 24 preplant treatment-site combinations was related to relative GNDV1 (R-2 = 0.76), the PSNT (R-2 = 0.78), relative SPAD (R-2 = 0.72), and the LSSN test (R-2 = 0.64), suggesting that relative GNDVI was as good an indicator of EONR as these other, more conventional tests. Because relative GNDVI can be obtained simultaneously with a sidedress N fertilizer application, the potential to accommodate within-field spatial and season-to-season temporal variability in N availability should improve N management decisions for corn production.

Schnabel, R. R., A. J. Franzluebbers, et al. (2001). The effects of pasture management practices The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R. F. Follett, J. M. Kimble and R. Lal. Boca Raton, FL, CRC Press.

Schnepf, R. (2004). Energy Use in Agriculture: Background and Issues. Washington, DC, Congressional Research Service, The Library of Congress.

Agriculture requires energy as an important input to production. Agriculture uses energy directly as fuel or electricity to operate machinery and equipment, to heat or cool buildings, and for lighting on the farm, and indirectly in the fertilizers and

chemicals produced off the farm. In 2002, the U.S. agricultural sector used an estimated 1.7 quadrillion Btu of energy from both direct (1.1 quadrillion Btu) and indirect (0.6 quadrillion Btu) sources.

However, agriculture's total use of energy is low relative to other U.S. producing sectors. In 2002, agriculture's share of total U.S. direct energy consumption was about 1%. Agriculture's shares of nitrogen and pesticide use — two of the major indirect agricultural uses identified by the U.S. Dept of Agriculture (USDA) — are signficantly higher at about 56% and 67%, respectively. U.S. farm production — whether for crop or animal products — has become increasingly mechanized and requires timely energy supplies at particular stages of the production cycle to achieve optimum yields. Energy's share of agricultural production expenses varies widely by activity, production practice, and locality. Since the late 1970s, total agricultural use of energy has fallen by about 28%, as a result of efficiency gains related to improved machinery, equipment, and production practices. Despite these efficiency gains, total energy costs of $28.8 billion in 2003 represented 14.4% (5.2% direct and 9.3% indirect) of annual production expenses of $198.9 billion. As a result, unexpected changes in energy prices or availability can substantially alter farm net revenues, particularly for major field crop production. High fuel and fertilizer prices in 2004, and increasing energy import dependence for petroleum fuels and nitrogen fertilizers has led to concerns about the impact this would have on agriculture. High natural gas prices have already contributed to a substantial reduction in U.S. nitrogen fertilizer production capacity — over a 23% decline from 1998 through 2003. In the short run, price- or supply-related disruptions to agriculture's energy supplies could result in unanticipated shifts in the production of major crop and livestock products, with subsequent effects on farm incomes and rural economies. In the long run, a sustained rise in energy prices may have serious consequences on energy-intensive industries like agriculture by reducing profitability and driving resources away from the sector. This report provides information relevant to the U.S. agricultural sector on energy use, emerging issues, and related legislation. It will be updated as events warrant.

Schuman, G. E., J. E. Herrick, et al. (2001). The dynamics of soil carbon in rangelands. The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R. F. Follett, J. M. Kimble and R. Lal. Boca Raton, FL, CRC Press.

Schuman, G. E., H. H. Janzen, et al. (2002). "Soil carbon dynamics and potential carbon sequestration by rangelands." Environmental Pollution **116**(3): 391–396.

The USA has about 336 Mha of grazing lands of which rangelands account for 48%. Changes in rangeland soil C can occur in response to a wide range of management and environmental factors. Grazing, fire, and fertilization have been shown to affect soil C storage in rangelands, as has converting marginal croplands into grasslands. Carbon losses due to soil erosion can influence soil C storage on rangelands both by reducing soil productivity in source areas and potentially increasing it in depositional areas, and by redistributing the C to areas where soil organic matter mineralization rates are different. Proper grazing management has been estimated to increase soil C storage on US rangelands from 0.1 to 0.3 Mg C ha^{-1} $year^{-1}$ and new grasslands have been shown to store as much as 0.6 Mg C ha^{-1} $year^{-1}$. Grazing lands are estimated to contain 10-30% of the world's soil organic carbon. Given the size of the C pool in grazing lands we need to better understand the current and potential effects of management on soil C storage.

Schuman, G. E., J. D. Reeder, et al. (1999). "Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland." Ecological Applications **9**(1): 65–71.

Rangeland grazing management strategies have been developed in an effort to sustain efficient use of forage resources by livestock. However, the effects of grazing on the redistribution and cycling of carbon (C) and nitrogen (N) within the plant–soil system are not well understood. We examined the plant–soil C and N balances of a mixedgrass rangeland under three livestock stocking rates using an area that had not been grazed by domestic livestock for more than 40 years. We established nongrazed exclosures and pastures subjected to continuous season-long grazing at either a light stocking rate (20 steer-days/ha) or a heavy stocking rate (59 steer-days/ha, ;50% utilization of annual production). Twelve years of grazing under these stocking rates did not change the total masses of C and N in the plant–soil (0–60 cm) system but did change the distribution of C and N among the system components, primarily via a significant increase in the masses of C and N in the root zone (0–30 cm) of the soil profile. The mass of soil C (0–60 cm) under heavy grazing was comparable to that of the light grazing treatment. Grazing at the heavy stocking rate resulted in a decrease in peak standing crop (PSC) of aboveground live phytomass, an increase in blue grama (Bouteloua gracilis [H.B.K.] Lag. Ex Steud.), and a decrease in western wheatgrass (Pascopyrum smithii [Rydb.] A. Love) compared to the light grazing treatment. The dominant species under light grazing was western wheatgrass, whereas in the nongrazed exclosures, forbs were dominant and appeared to have increased at the expense of western wheatgrass. The observed increase of soil C and N in the surface soil where roots dominate indicates a greater opportunity for nutrient availability and cycling, and hence enhanced grazing quality.

Searchinger, T. D. (2010). "Biofuels and the need for additional carbon." Environmental Research Letters **5**(2): Art. No. 024007.

Use of biofuels does not reduce emissions from energy combustion but may offset emissions by increasing plant growth or by reducing plant residue or other non-energy emissions. To do so, biofuel production must generate and use 'additional carbon', which means carbon that plants would not otherwise absorb or that would be emitted to the atmosphere anyway. When biofuels cause no direct land use change, they use crops that would grow regardless of biofuels so they do not directly absorb additional carbon. All potential greenhouse gas reductions from such biofuels, as well as many potential emission increases, result from indirect effects, including reduced crop consumption, price-induced yield gains and land conversion. If lifecycle analyses ignore indirect effects of biofuels, they therefore cannot properly find greenhouse gas reductions. Uncertainties in estimating indirect emission reductions and increases are largely symmetrical. The failure to distinguish 'additional' carbon from carbon already absorbed or withheld from the atmosphere also leads to large overestimates of global bioenergy potential. Reasonable confidence in greenhouse gas reductions requires a precautionary approach to estimating indirect effects that does not rely on any single model. Reductions can be more directly assured, and other adverse indirect effects avoided, by focusing on biofuels from directly additional carbon.

Sehy, U., R. Ruser, et al. (2003). "Nitrous oxide fluxes from maize fields: Relationship to yield, site-specific fertilization, and soil conditions." Agriculture, Ecosystems & Environment **99**(1–3): 97–111.

Nitrous oxide emissions and selected soil properties in a high and a low yielding area of a maize field were monitored weekly over a 1-year period. In both the high and the low yielding area, N2O emissions from a treatment subject to site-specific N-fertilization were compared to a conventionally fertilized control. Emission peaks were measured following N fertilization, rainfall, harvest, tillage and freeze-thaw cycles from all treatments in conditions favorable for denitrification. Between 80 and 90% of annual emissions were released between April and September. A value of 60% WFPS was identified as a threshold for the induction of elevated N2O emissions (>50 mug N2O-N m(-2) h(-1)). A significant relationship (r(2) = 0.41) between N2O flux rates and WFPS was found when neither soil nitrate contents nor temperature were limiting for microbial denitrification. Mean cumulative N2O emissions from the control treatments in the high yielding area, located in a footslope position and thus receiving lateral water and nutrient supply, more than doubled those from the control treatments in the low yielding area in a shoulder position (8.7 and 3.9 kg N2O-N ha(-1), respectively). Higher average WFPS in the high yielding area was identified as responsible for this difference. The site-specific fertilized treatments in the low yielding area were supplied with 125 kg N fertilizer ha-1 as compared to 150 kg N fertilizer ha(-1) (control treatments). This reduction resulted in 34% less N2O released in roughly 10 months following differentiated fertilization while crop yield remained the same. In the high yielding area, N fertilizer supply in the site-specific fertilized treatment was 175 kg N ha(-1) as compared to 150 kg N ha(-1) in the control. Neither crop yield nor N2O emissions were significantly affected by the different fertilizer rates.

Senthilkumar, S., B. Basso, et al. (2009). "Contemporary evidence of soil carbon loss in the U.S. corn belt." Soil Science Society of America Journal **73**(6): 2078–2086.

Temporal changes in soil C content vary as a result of complex interactions among different factors including climate, baseline soil C levels, soil texture, and agricultural management practices. The study objectives were: to estimate the changes in soil total C contents that occurred in the past 18 to 21 yr in soils under agricultural management and in never-tilled grassland in southwest Michigan; to explore the relationships between these changes and soil properties, such as baseline C levels and soil texture; and to simulate C changes using a system approach model (SALUS). The data were collected from two long-term experiments established in 1986 and 1988. Georeferenced samples were collected from both experiments before establishment and then were resampled in 2006 and 2007. The studied agricultural treatments included the conventional chisel-plow and no-till management systems with and without N fertilization and the organic chisel-plow management with cover crops. Total C was either lost in the conventional chisel-plowed systems or was only maintained at the 1980s levels by the conservation management systems. The largest loss in the agricultural treatments was 4.5 Mg ha(-1) total C observed in the chisel-plow system without N fertilization. A loss of 17.3 Mg ha(-1) occurred in the virgin grassland sod. Changes in C content tended to be negatively related to baseline C levels. Under no-till, changes in C were positively related to silt + clay contents. The SALUS predictions of soil C changes were in excellent agreement with the observed data for most of the agricultural treatments and for the virgin soil.

Sharrow, S. H. and S. Ismail (2004). "Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA." Agroforestry Systems **60**(2): 123–130.

Pastures store over 90% of their carbon and nitrogen below-ground as soil organic matter. In contrast, temperate conifer forests often store large amounts of organic matter above-ground in woody plant tissue and fibrous litter. Silvopastures, which combine managed pastures with forest trees, should accrete more carbon and nitrogen than pastures or timber plantations because they may produce more total annual biomass and have both forest and grassland nutrient cycling patterns active. This hypothesis was investigated by conducting carbon and nitrogen inventories on three replications of 11 year-old Douglas-fir (Pseudotsuga menziesii)/perennial ryegrass (Lolium perenne)/subclover (Trifolium subterraneum) agroforests, ryegrasss/subclover pastures, and Douglas-fir timber plantations near Corvallis, Oregon in August 2000. Over the 11 years since planting, agroforests accumulated approximately 740 kg ha–1 year –1 more C than forests and 520 kg ha–1 year–1 more C than pastures. Agroforests stored approximately 12% of C and 2% of N aboveground compared to 9% of C and 1% of N above ground in plantations and less than 1% of N and C aboveground in pastures. Total N content of agroforests and pastures, both of which included a nitrogen-fixing legume, were approximately 530 and 1200 kg ha–1 greater than plantations, respectively. These results support the proposition that agroforests, such as silvopastures, may be more efficient at accreting C than plantations or pasture monocultures. However, pastures may accrete more N than agroforests or plantations. This apparent separation of response in obviously interrelated agroecosystem processes, points out the difficulty in using forest plantation or pasture research results to predict outcomes for mixed systems such as agroforests.

Sherrod, L. A., G. A. Peterson, et al. (2003). "Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystem." Soil Science Society of America Journal **67**(5): 1533–1543.

Soil organic C (SOC) has decreased under cultivated wheat (Triticum aestivum)-fallow (WF) in the central Great Plains.We evaluated the effect of no-till systems of WF, wheat–corn (Zea Mays)-fallow (WCF), wheat–corn–millet (Panicum miliaceum)-fallow, continuous cropping (CC) without monoculture, and perennial grass (G) on SOC and total N (TN) levels after 12 yr at three eastern Colorado locations. Locations have long-term precipitation averages of 420 mm but increase in potential evapotranspiration (PET) going from north to south. Within each PET location, cropping systems were imposed across a topographic sequence of summit, sideslope, and toeslope. Cropping intensity, slope position, and PET gradient (location) independently impacted SOC and TN to a 5-cm soil depth. Continuous cropping had 35 and 17% more SOC and TN, respectively, than the WF system. Cropping intensity still impacted SOC and TN when summed to 10 cm with CC > than WF. Soil organic C and TN 20% in the CC system compared with WF in the 0- to 10-cm depth. The greatest impact was found in the 0- to 2.5-cm layer, and decreased with depth. Soil organic C and TN levels at the high PET site were 50% less than at the low and medium PET sites, and toeslope soils were 30% greater than summit and sideslopes. Annualized stover biomass explained 80% of the variation in SOC and TN in the 0- to 10-cm soil profile. Cropping systems that eliminate summer fallowing are maximizing the amount of SOC and TN sequestered.

Shneour, E. A. (1966). "Oxidation of graphitic carbon in certain soils." Science **151**(3713): 991–992.

Artificial graphitic carbon-14 was oxidized to carbon-14 dioxide in the presence of certain nonsterile soils. Treatment of these soils for the inhibition of biologic activity, by several methods including 5 megarads of electron-beam irradiation, yielded much-less-reactive systems in the oxidation of carbon. Intervention of a biologic agent in some of these oxidative processes is suggested.

Singh, B. P., B. J. Hatton, et al. (2010). "Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils." Journal of Environmental Quality **39**(4): 1224–1235.

The influence of biochar on nitrogen (N) transformation processes in soil is not fully understood. This study assessed the influence of four biochars (wood and poultry manure biochars synthesized at 400°C, nonactivated, and at 550°C, activated, abbreviated as: W400, PM400, W550, PM550, respectively) on nitrous oxide (N2O) emission and N leaching from an Alfisol and a Vertisol. Repacked soil columns were subjected to three wetting–drying (W–D) cycles to achieve a range of water-filled pore space (WFPS) over a 5-mo period. During the first two W–D cycles, W400 and W550 had inconsistent effects on N2O emissions and the soils amended with PM400 produced higher N2O emissions relative to the control. The initially greater N2O emission from the PM400 soils was ascribed to its higher labile intrinsic N content than the other biochars. During the third W–D cycle, all biochar treatments consistently decreased N2O emissions, cumulatively by 14 to 73% from the Alfisol and by 23 to 52% from the Vertisol, relative to their controls. In the first leaching event, higher nitrate leaching occurred from the PM400-amended soils compared with the other treatments. In the second event, the leaching of ammonium was reduced by 55 to 93% from the W550- and PM550-Alfisol and Vertisol, and by 87 to 94% from the W400- and PM400-Vertisol only (cf. control). We propose that the increased effectiveness of biochars in reducing N2O emissions and ammonium leaching over time was due to increased sorption capacity of biochars through oxidative reactions on the biochar surfaces with ageing.

Six, J., R. T. Conant, et al. (2002). "Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils." Plant and Soil **241**(2): 155–176.

The relationship between soil structure and the ability of soil to stabilize soil organicmatter (SOM) is a key element in soil C dynamics that has either been overlooked or treated in a cursory fashion when developing SOM models. The purpose of this paper is to review current knowledge of SOM dynamics within the framework of a newly proposed soil C saturation concept. Initially, we distinguishSOM that is protected against decomposition by various mechanisms from that which is not protected from decomposition. Methods of quantification and characteristics of three SOM pools defined as protected are discussed. Soil organic matter can be: (1) physically stabilized, or protected from decomposition, through microaggregation, or (2) intimate association with silt and clay particles, and (3) can be biochemically stabilized through the formation of recalcitrant SOM compounds. In addition to behavior of each SOM pool, we discuss implications of changes in land management on processes by which SOM compounds undergo protection and release. The characteristics and responses to changes in land use or land management are described for the light fraction (LF) and particulate organic matter (POM). We defined the LF and POM not occluded within microaggregates (53–250 μm sized aggregates as unprotected. Our conclusions are illustrated in a new conceptual SOM model that differs from most SOM models in that the model state variables are measurable SOM pools.We suggest that physicochemical characteristics inherent to soils define the maximum protective capacity of these pools, which limits increases in SOM (i.e. C sequestration) with increased organic residue inputs.

Six, J., C. Feller, et al. (2002). "Soil organic matter, biota and aggregation in temperate and tropical soils – Effects of no-tillage." Agronomie **22**(7–8): 755–775.

The long-term stabilization of soil organic matter (SOM) in tropical and temperate regions is mediated by soil biota (e. g. fungi, bacteria, roots and earthworms), soil structure (e. g. aggregation) and their interactions. On average, soil C turnover was twice as fast in tropical compared with temperate regions, but no major differences were observed in SOM quality between the two regions. Probably due to the soil mineralogy dominated by 1:1 clay minerals and oxides in tropical regions, we found a higher aggregate stability, but a lower correlation between C contents and aggregate stability in tropical soils. In addition, a smaller amount of C associated with clay and silt particles was observed in tropical versus temperate soils. In both tropical and temperate soils, a general increase in C levels (approximate to 325 +/- 113 kg C.ha(-1).yr(-1)) was observed under no-tillage compared with conventional tillage. On average, in temperate soils under no-tillage, compared with conventional tillage, CH4 uptake (approximate to0.42 +/- 0.10 kg C-CH4.ha(-1) yr(-1)) increased and N2O emissions increased (approximate to 1.95 +/- 0.45 kg N-N2O.ha(-1).yr(-1)). These increased N2O emissions lead to a negative global warming potential when expressed on a CO2 equivalent basis.

Six, J. and J. D. Jastrow (2006). Organic Matter Turnover. Encyclopedia of Soil Science, Second Edition. R. Lal. New York, NY, Taylor and Francis Group**:** 1210–1215.

Six, J., S. M. Ogle, et al. (2004). "The potential to mitigate global warming with no-tillage management is only realized when practised in the long term." Global Change Biology **10**(2): 155–160.

No-tillage (NT) management has been promoted as a practice capable of offsetting greenhouse gas (GHG) emissions because of its ability to sequester carbon in soils. However, true mitigation is only possible if the overall impact of NT adoption reduces the net global warming potential (GWP) determined by fluxes of the three major biogenic GHGs (i.e. CO2, N2O, and CH4). We compiled all available data of soil-derived GHG emission comparisons between conventional tilled (CT) and NT systems for humid and dry temperate climates. Newly converted NT systems increase GWP relative to CT practices, in both humid and dry climate regimes, and longer-term adoption (>10 years) only significantly reduces GWP in humid climates. Mean cumulative GWP over a 20-year period is also reduced under continuous NT in dry areas, but with a high degree of uncertainty. Emissions of N2O drive much of the trend in net GWP, suggesting improved nitrogen management is essential to realize the full benefit from carbon storage in the soil for purposes of global warming mitigation. Our results indicate a strong time dependency in the GHG mitigation potential of NT agriculture, demonstrating that GHG mitigation by adoption of NT is much more variable and complex than previously considered, and policy plans to reduce global warming through this land management practice need further scrutiny to ensure success.

Smart, L. B., T. A. Volk, et al. (2005). "Genetic improvement of shrub willow (Salix spp.) crops for bioenergy and environmental applications in the United States." Unasylva **221**(56): 51–55.

A willow breeding programme focuses on improving growth, optimizing relevant traits and lowering production costs to ensure the long-term viability of willow crop systems for producing energy, restoring degraded sites and improving water quality.

Smith, A., K. Brown, et al. (2001). Waste Management Options and Climate Change: Final Report. Luxembourg, AEA Technology, Abingdon, UK. *Prepared for* European Commission, DG Environment.

Smith, P., D. Martino, et al. (2008). "Greenhouse gas mitigation in agriculture." Philosophical Transactions of the Royal Society B: Biological Sciences **363**(1492): 789–813.

Agricultural lands occupy 37% of the earth's land surface. Agriculture accounts for 52 and 84% of global anthropogenic methane and nitrous oxide emissions. Agricultural soils may also act as a sink or source for CO, but the net flux is small. Many agricultural practices can potentially mitigate greenhouse gas (GHG) emissions, the most prominent of which are improved cropland and grazing land management and restoration of degraded lands and cultivated organic soils. Lower, but still significant mitigation potential is provided by water and rice management, set-aside, land use change and agroforestry, livestock management and manure management. The global technical mitigation potential from agriculture (excluding fossil fuel offsets from biomass) by 2030, considering all gases, is estimated to be approximately 5500-6000 Mt CO-eq./yr, with economic potentials of approximately 1500-1600, 2500-2700 and 4000-4300 Mt CO-eq./yr at carbon prices of up to 20, up to 50 and up to 100 US$ t CO-eq., respectively. In addition, GHG emissions could be reduced by substitution of fossil fuels for energy production by agricultural feedstocks (e.g. crop residues, dung and dedicated energy crops). The economic mitigation potential of biomass energy from agriculture is estimated to be 640, 2240 and 16 000 Mt CO-eq./yr at 0-20, 0-50 and 0-100 US$ t CO-eq., respectively.

Smith, P. and T. J. F. Smith (2000). "Transport carbon costs do not negate the benefits of agricultural carbon mitigation options." Ecology Letters **3**(5): 379–381.

It has been suggested that some agricultural carbon (C) mitigation options will yield no net C benefit under full carbon accounting (i.e. when costs are included alongside benefits). The largest likely C cost of implementing many options is the fuel cost associated with transporting resources from the place where they are produced to the place where they are used. In this article, we show that fuel C costs of transporting resources are much lower than the C benefits of agricultural mitigation options. These findings suggest that the agricultural C mitigation options examined here will yield a net C benefit, even under full carbon accounting.

Smith, R. F., K. M. Klonsky, et al. (2009). Sample Costs to Produce Iceberg Lettuce (Head Lettuce), Central Coast Region, Monterey & Santa Cruz Counties. Davis, CA, University of California Cooperative Extension.

Smith, R. F., K. M. Klonsky, et al. (2009). Sample Costs to Produce Romaine Hearts (Leaf Lettuce), Central Coast Region, Monterey & Santa Cruz Counties. Davis, CA, University of California Cooperative Extension.

Smukler, S. M., L. E. Jackson, et al. (2008). "Transition to large-scale organic vegetable production in the Salinas Valley, California." Agriculture, Ecosystems & Environment **126**(3–4): 168–188.

Studying the management strategies suited to large-scale organic production, particularly during the mandated 3-year transition period from conventional management, is a unique research challenge. Organic production traditionally relies on small, diverse plantings and complex management responses to cope with soil fertility and pest pressures, so research should represent decision-making options of an organic grower at the farm scale. This study analyzes crop, soil, pest and management changes during the organic transition period on two ranches (40 and 47 ha) in the Salinas Valley, California in cooperation with a large conventional vegetable producer, Tanimura and Antle, Inc. Permanent transects were established across the two ranches at the onset of adoption of organic practices, and soil and plants were sampled at harvest of almost all crops, while all management operations were recorded by the co-operator. The similar to 10 ha blocks were divided into many small plantings, and 17 different cash crop and cover crop species were planted during the transition period. Management inputs consisted of a range of organic fertilizers and amendments, sprinkler and drip irrigation, cultivation and hand-hoeing, and several types of organic pesticides. Results from the 3-year period followed these general trends: increase in soil biological indicators (microbial biomass and arbuscular mycorrhizae), low soil nitrate pools, adequate crop nutrients, minor disease and weed problems, and sporadic mild insect damage. Multivariate statistical analyses indicated that some crops and cultivars consistently produced higher yields than others, relative to the maximum yield for a given crop. Multi-factor contingency tables showed clear differences in insect and disease damage between crop taxa. Although Tanimura and Antle, Inc. used some of the principles of organic farming (e.g., crop diversity, crop rotation, and organic matter (OM) management), they also relied on substitution-based management, such as fertigation with soluble nutrients, initially heavy applications of organic pesticides, and use of inputs derived from off-farm sources. Their initial production of a large number of crop taxa in small plantings at staggered intervals proved to be an effective strategy for avoiding risks from low yields or crop failure and allowed them to move towards a smaller number of select, successful crops towards the end of the transition. This study demonstrates the feasibility of large-scale producers to transition to organic practices in a manner that was conducive to both production goals and environmental quality, i.e., increased soil C pools, low soil nitrate, and absence of synthetic pesticides.

Snyder, C. S., T. W. Bruulsema, et al. (2009). "Review of greenhouse gas emissions from crop production systems and fertilizer management effects." Agriculture, Ecosystems & Environment **133**(3–4): 247–266.

Fertilizer nitrogen (N) use is expanding globally to satisfy food, fiber, and fuel demands of a growing world population. Fertilizer consumers are being asked to improve N use efficiency through better management in their fields, to protect water resources and to minimize greenhouse gas (GHG) emissions, while sustaining soil resources and providing a healthy economy. A review of the available science on the effects of N source, rate, timing, and placement, in combination with other cropping and tillage practices, on GHG emissions was conducted. Implementation of intensive crop management practices, using principles of ecological intensification to enhance efficient and effective nutrient uptake while achieving high yields, was identified as a principal way to achieve reductions in GHG emissions while meeting production demands. Many studies identified through the review involved measurements of

GHG emissions over several weeks to a few months, which greatly limit the ability to accurately determine system-level management effects on net global warming potential. The current science indicates: (I) appropriate fertilizer N use helps increase biomass production necessary to help restore and maintain soil organic carbon (SOC) levels; (2) best management practices (BMPs) for fertilizer N play a large role in minimizing residual soil nitrate, which helps lower the risk of increased nitrous oxide (N2O) emissions; (3) tillage practices that reduce soil disturbance and maintain crop residue on the soil surface can increase SOC levels, but usually only if crop productivity is maintained or increased; (4) differences among fertilizer N sources in N2O emissions depend on site- and weather-specific conditions; and (5) intensive crop management systems do not necessarily increase GHG emissions per unit of crop or food production; they can help spare natural areas from conversion to cropland and allow conversion of selected lands to forests for GHG mitigation, while supplying the world's need for food, fiber, and biofuel. Transfer of the information to fertilizer dealers, crop advisers, farmers, and agricultural and environmental authorities should lead to increased implementation of fertilizer BMPs, and help to reduce confusion over the role of fertilizer N on cropping system emissions of GHGs. Gaps in scientific understanding were identified and will require the collaborative attention of agronomists, soil scientists, ecologists, and environmental authorities in serving the immediate and long-term interests of the human population.

Sohi, S. P., E. Krull, et al. (2010). "A review of biochar and its use and function in soil." Advances in Agronomy **105**: 47–82.

Agricultural activities and soils release greenhouse gases, and additional emissions occur in the conversion of land from other uses. Unlike natural lands, active management offers the possibility to increase terrestrial stores of carbon in various forms in soil. The potential to sequester carbon as thermally stabilized (charred) biomass using existing organic resource is estimated to be at least 1 Gt yr- 1 and "biochar," defined by its useful application to soil, is expected to provide a benefit from enduring physical and chemical properties. Studies of charcoal tend to suggest stability in the order of 1000 years in the natural environment, and various analytical techniques inform quantification and an understanding of turnover processes. Other types of biochar, such as those produced under zero-oxygen conditions have been studied less, but costs associated with logistics and opportunity costs from diversion from energy or an active form in soil demand certainty and predictability of the agronomic return, especially until eligibility for carbon credits has been established. The mechanisms of biochar function in soil, which appear to be sensitive to the conditions prevailing during its formation or manufacture, are also affected by the material from which it is produced. Proposed mechanisms and some experimental evidence point to added environmental function in the mitigation of diffuse pollution and emissions of trace gases from soil; precluding the possibility of contaminants accumulating in soil from the incorporation of biochar is important to ensure safety and regulatory compliance.

Sperow, M., M. D. Eve, et al. (2003). "Potential soil C sequestration on U.S. agricultural soils." Climatic Change **57**(3): 319–339.

Soil carbon sequestration has been suggested as a means to help mitigate atmospheric CO_2 increases, however there is limited knowledge aboutthe magnitude of the mitigation potential. Field studies across the U.S. provide information on soil C stock changes that result from changes in agricultural management. However, data from such studies are not readily extrapolated to changes at a national scale because soils, climate, and management regimes vary locally and regionally. We used a modified version of the Intergovernmental Panel on Climate Change (IPCC) soil organic C inventory method, together with the National Resources Inventory (NRI) and other data, to estimate agricultural soil C sequestration potential in the conterminous U.S. The IPCC method estimates soil C stock changes associated with changes in land use and/or land management practices. In the U.S., the NRI provides a detailed record of land use and management activities on agricultural land that can be used to implement the IPCC method. We analyzed potential soil C storage from increased adoption of no-till, decreased fallow operations, conversion of highly erodible land to grassland, and increased use of cover crops in annual cropping systems. The results represent potentials that do not explicitly consider the economic feasibility of proposed agricultural production changes, but provide an indication of the biophysical potential of soil C sequestration as a guide to policy makers. Our analysis suggests that U.S. cropland soils have the potential to increase sequestered soil C by an additional 60–70 Tg (10^{12}g) C yr^{-1}, over present rates of 17 Tg C yr^{-1} (estimated using the IPCC method), with widespread adoption of soil C sequestering management practices. Adoption of no-till on all currently annually cropped area (129 Mha) would increase soil C sequestration by 47 Tg C yr^{-1}. Alternatively, use of no-till on 50% of annual cropland, with reduced tillage practices on the other 50%, would sequester less – about 37 Tg C yr^{-1}. Elimination of summer fallow practices and conversion of highly erodible cropland to perennial grass cover could sequester around 20 and 28 Tg C yr^{-1}, respectively. The soil C sequestration potential from including a winter cover crop on annual cropping systems was estimated at 40 Tg C yr^{-1}. All rates were estimated for a fifteen-year projection period, and annual rates of soil C accumulations would be expected to decrease substantially over longer time periods. **The total sequestration potential we have estimated for the projection period (83 Tg C yr^{-1}) represents about 5% of 1999 total U.S. CO_2 emissions or nearly double estimated CO_2 emissions from agricultural production (43 Tg C yr^{-1}).** For purposes of stabilizing or reducing CO_2 emissions, e.g., by 7% of 1990 levels asoriginally called for in the Kyoto Protocol, total potential soil C sequestration would represent 15% of that reduction level from projected 2008 emissions (2008 total greenhouse gas emissions less 93% of 1990 greenhouse gasemissions). Thus, our analysis suggests that agricultural soil C sequestration could play a meaningful, but not predominant, role in helping mitigate greenhouse gas increases.

Spokas, K., J. Baker, et al. (2010). "Ethylene: Potential key for biochar amendment impacts." Plant and Soil **333**(1): 443–452.

Significant increases in root density, crop growth and productivity have been observed following soil additions of biochar, which is a solid product from the pyrolysis of biomass. In addition, alterations in the soil microbial dynamics have been observed following biochar amendments, with decreased carbon dioxide (CO2) respiration, suppression of methane (CH4) oxidation and reduction of nitrous oxide (N2O) production. However, there has not been a full elucidation of the mechanisms behind these effects. Here we show data on ethylene production that was observed from biochar and biochar-amended soil. Ethylene is an important plant hormone as well as an inhibitor for soil microbial processes. Our current hypothesis is that the ethylene is biochar derived, with a majority of biochars exhibiting ethylene production even without soil or microbial inoculums. There was increased ethylene production from non-sterile compared to sterile soil (215%), indicating a role of soil microbes in the observed ethylene production.

Production varied with different biomass sources and production conditions. These observations provide a tantalizing insight into a potential mechanism behind the biochar effects observed, particularly in light of the important role ethylene plays in plant and microbial processes.

Spokas, K. A. and D. C. Reicosky (2009). "Impacts of sixteen different biochars on soil greenhouse gas production." Annals of Environmental Science **3**: 179–193.

One potential abatement strategy to increasing atmospheric levels of carbon dioxide (CO2) is to sequester atmospheric CO2 captured through photosynthesis in biomass and pyrolysed into a more stable form of carbon called biochar. We evaluated the impacts of 16 different biochars from different pyrolysis/gasification processes and feed stock materials (corn stover, peanut hulls, macadamia nut shells, wood chips, and turkey manure plus wood chips) as well as a steam activated coconut shell charcoal on net CO2, methane (CH4) and nitrous oxide (N2O) production/consumption potentials through a 100 day laboratory incubation with a Minnesota agricultural soil (Waukegan silt loam, total organic carbon = 2.6%); Wisconsin forest nursery soil (Vilas loamy sand, total organic carbon = 1.1%); and a California landfill cover soil (Marina loamy sand plus green waste-sewage sludge, total organic carbon = 3.9%) at field capacity (soil moisture potential = -33 kPa). After correcting for the CO2, CH4 and N2O production of the char alone, the addition of biochars (10% w/w) resulted in different responses among the soils. For the agricultural soil, five chars increased, three chars reduced and eight had no significant impact on the observed CO2 respiration. In the forest nursery soil, three chars stimulated CO2 respiration, while the remainder of the chars suppressed CO2 respiration. In the landfill cover soil, only two chars increased observed CO2 respiration, with the remainder exhibiting lower CO2 respiration rates. All chars and soil combinations resulted in decreased or unaltered rates of CH4 oxidation, with no increases observed in CH4 oxidation or production activity. Biochar additions generally suppressed observed N2O production, with the exception being high nitrogen compost-amended biochar, which increased N2O production. The general conclusions are: (1) the impact on trace gas production is both dependent on the biochar and soil properties and (2) biochar amendments initially reduce microbial activity in laboratory incubations. These preliminary results show a wide diversity in biochar properties that point to the need for more research.

Steenwerth, K. and K. M. Belina (2008). "Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem." Applied Soil Ecology **40**(2): 359–369.

Impacts of soil tillage and cover crops on soil carbon (C) dynamics and microbiological function were investigated in a vineyard grown in California's mediterranean climate. We (1) compared soil organic matter (SOM), C dynamics and microbiological activity of two cover crops [Trios 102 (Triticale × Triosecale) ([`]Trios'), Merced Rye (Secale cereale) ([`]Rye')] with cultivation ([`]Cultivation') and (2) evaluated seasonal effects of soil temperature, water content, and precipitation on soil C dynamics (0-15 cm depth). From treatments established in November 2001, soils were sampled every 2-3 weeks from November 2005 to November 2006. Gravimetric water content (GWC) reflected winter and spring rainfall. Soil temperature did not differ among treatments, reflecting typical seasonal patterns. Few differences in C dynamics between cover crops existed, but microbial biomass C (MBC), dissolved organic C (DOC), and carbon dioxide (CO2) efflux in [`]Trios' and [`]Rye' were consistently 1.5-4-fold greater than [`]Cultivation'. Cover crops were more effective at adding soil C than [`]Cultivation'. Seasonal patterns in DOC, and

CO2 efflux reflected changes in soil water content, but MBC displayed no temporal response. Decreases in DOC and potential microbial respiration (RESPmic) (i.e., microbially available C) also corresponded to or were preceded by increases in CO2 efflux, suggesting that DOC provided C for microbial respiration. Despite similar MBC, DOC, RESPmic, annual CO2 efflux and aboveground C content between the two cover crops, greater aboveground net primary productivity and SOM in [`]Trios' indicated that [`]Trios' provided more soil C than [`]Rye'.

Stehfest, E. and L. Bouwman (2006). "N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions." Nutrient Cycling in Agroecosystems **74**(3): 207–228.

The number of published N2O and NO emissions measurements is increasing steadily, providing additional information about driving factors of these emissions and allowing an improvement of statistical N-emission models. We summarized information from 1008 N2O and 189 NO emission measurements for agricultural fields, and 207 N2O and 210 NO measurements for soils under natural vegetation. The factors that significantly influence agricultural N2O emissions were N application rate, crop type, fertilizer type, soil organic C content, soil pH and texture, and those for NO emissions include N application rate, soil N content and climate. Compared to an earlier analysis the 20% increase in the number of N2O measurements for agriculture did not yield more insight or reduced uncertainty, because the representation of environmental and management conditions in agro-ecosystems did not improve, while for NO emissions the additional measurements in agricultural systems did yield a considerable improvement. N2O emissions from soils under natural vegetation are significantly influenced by vegetation type, soil organic C content, soil pH, bulk density and drainage, while vegetation type and soil C content are major factors for NO emissions. Statistical models of these factors were used to calculate global annual emissions from fertilized cropland (3.3 Tg N_2O-N and 1.4 Tg NO-N) and grassland (0.8 Tg N2O-N and 0.4 Tg NO-N). Global emissions were not calculated for soils under natural vegetation due to lack of data for many vegetation types.

Stewardship Index for Specialty Crops (2010). "A System for Measuring Sustainable Performance Throughout the Specialty Crop Supply Chain." Retrieved 6 September, 2010, from http://www.stewardshipindex.org/what_we_are_measuring.php.

Stivers, L. J. and C. Shennan (1991). "Meeting the nitrogen needs for processing tomatoes through winter cover cropping." Journal of Production Agriculture (USA) **4**(3): 330–335.

A field study was initiated in 1986 in Davis, CA, to determine the long-term effects of "winter green manures/cover crops" on N dynamics and soil structural and biological properties in a semi-arid, irrigated cropping system. Results from the first 2 y of the experiment are used to compare the productivity of several legume green manures and to determine if they can provide adequate available soil N to support yields of a subsequent crop of processing tomatoes (Lycopersicon lycopersicum L. Karsten var. lycopersicum) typical for this area. Lana woolly-pod vetch (Vicia dasycarpa Ten.), bell beans (Vicia faba L.), berseem clover (Trifolium alexandrinum L.), Austrian winter peas (Pisum arvense L.), oats (Avena sativa L.), and an oats and vetch mixture, planted in October and disked under in April, were compared with various levels of ammonium sulfate fertilizer. Lana vetch produced the greatest biomass of the legumes, and fixed the most N (90 lb/acre by February, and 230 lb/acre by March in 1987, as determined by the difference method). Use of green manures, relative to winter fallow, dried out the soil (0-24 in. depth) by an amount equivalent to 0.4 to 0.8 in. of water depending on the cover crop. Tomato yields for the legume cover-cropped plots were as high as those in the fertilizer-treated plots, but the response to applied N was low. Nitrate levels in the top 8 in. of soil in vetch-treated plots remained as high as in the 200 lb N/acre ammonium sulfate fertilizer plots throughout the growing season.

Suddick, E., A. Hodson, et al. (2010). Ecosystem Functions and Greenhouse Gas Emissions as Affected By Bio-Char Amendments to Soil: Trade-offs. U.S. Biochar Conference, Ames, IA.

Svejcar, T., R. Angell, et al. (2008). "Carbon fluxes on North American rangelands." Rangeland Ecology & Management **61**(5): 465–474.

Rangelands account for almost half of the earth's land surface and may play an important role in the global carbon (C) cycle. We Studied net ecosystem exchange (NEE) of C on eight North American rangeland sites over a 6-yr period. Management practices and disturbance regimes can influence NEE; for consistency, we compared ungrazed and undisturbed rangelands including four Great Plains sites from Texas to North Dakota, two Southwestern hot desert sites in New Mexico and Arizona, and two Northwestern sagebrush steppe sites in Idaho and Oregon. We used the Bowen ratio-energy balance system for continuous measurements of energy, water vapor, and carbon dioxide (CO2) fluxes at each study site during the measurement period (1996 to 2001 for most sites). Data were processed and screened using standardized procedures, which facilitated across-location comparisons. Although almost any site could be either a sink or source for C depending on yearly weather patterns, five of the eight native rangelands typically were sinks for atmospheric CO2 during the study period. Both sagebrush steppe sites were sinks and three of four Great Plains grasslands were sinks, but the two Southwest hot desert sites were sources of C on an annual basis. Most rangelands were characterized by short periods of high C uptake (2 mo to 3 mo) and long periods of C balance or small respiratory losses of C. Weather patterns during the measurement period strongly influenced conclusions about NEE on any given rangeland site. Droughts tended to limit periods of high C uptake and thus cause even the most productive sites to become sources of C on an annual basis. Our results show that native rangelands are a potentially important terrestrial sink for atmospheric CO2, and maintaining the period of active C uptake will be critical if we are to manage rangelands for C sequestration.

Teasdale, J. R., C. B. Coffman, et al. (2007). "Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement." Agronomy Journal **99**(5): 1297–1305.

There have been few comparisons of the performance of no-tillage cropping systems vs. organic farming systems, particularly on erodible, droughty soils where reduced-tillage systems are recommended. In particular, there is skepticism whether organic farming can improve soils as well as conventional no-tillage systems because of the requirement for tillage associated with many organic farming operations. A 9-yr comparison of selected minimum-tillage strategies for grain production of corn (Zea mays L.), soybean [Glycine max (L.) Merr.], and wheat (Triticum aestivum L.) was conducted on a sloping, droughty site in Beltsville, MD, from 1994 to 2002.

Four systems were compared: (i) a standard mid-Atlantic no-tillage system (NT) with recommended herbicide and N inputs, (ii) a cover crop-based no-tillage system (CC) including hairy vetch (Vicia villosa Roth) before corn, and rye (Secale cereale L.) before soybean, with reduced herbicide and N inputs, (iii) a no-tillage crownvetch (Coronilla varia L.) living mulch system (CV) with recommended herbicide and N inputs, and (iv) a chisel-plow based organic system (OR) with cover crops and manure for nutrients and postplanting cultivation for weed control. After 9 yr, competition with corn by weeds in OR and by the crownvetch living mulch in CV was unacceptable, particularly in dry years. On average, corn yields were 28 and 12% lower in OR and CV, respectively, than in the standard NT, whereas corn yields in CC and NT were similar. Despite the use of tillage, soil combustible C and N concentrations were higher at all depth intervals to 30 cm in OR compared with that in all other systems. A uniformity trial was conducted from 2003 to 2005 with corn grown according to the NT system on all plots. Yield of corn grown on plots with a 9-yr history of OR and CV were 18 and 19% higher, respectively, than those with a history of NT whereas there was no difference between corn yield of plots with a history of NT and CC. Three tests of N availability (corn yield loss in subplots with no N applied in 2003-2005, presidedress soil nitrate test, and corn ear leaf N) all confirmed that there was more N available to corn in OR and CV than in NT. These results suggest that OR can provide greater long-term soil benefits than conventional NT, despite the use of tillage in OR. However, these benefits may not be realized because of difficulty controlling weeds in OR.

Teasdale, J. R., R. C. Rosecrance, et al. (2000). "Performance of reduced-tillage cropping systems for sustainable grain production in Maryland." American Journal of Alternative Agriculture **15**: 79–87.

Sustainable production systems are needed to maintain soil resources and reduce environmental contamination on erodible lands that are incompatible with tillage-intensive operation. A long-term cropping systems comparison was established at Beltsville, Maryland, on a site with 2 to 15% slope to evaluate the efficacy of sustainable strategies compatible with reduced-tillage systems. All systems followed a 2-year rotation of corn the first year and winter wheat followed by soybean the second year. Treatments included (1) no-tillage system with recomended fertilizer and herbicide inputs, (2) crownvetch living mulch system with similar inputs to the no-tillages system, (3) cover crop system including a hairy vetch cover crop before corn and a wheat cover crop before soybean with reduced fertilizer and herbicide inputs, (4) manure systemd including crimson clover green manure plus cow manure for nutrient sources, chisel plow/disk for incorporatin manure and rotary hoe plus cultication for weed control. Results from the initial 4 years demonstrated the relative productivity of these systems. Corn yields were similar in the no-tillage and cover crop systems in each year. both systems average 7.8 Mg ha-1 compared to 5.7 Mg ha-1 in both the croen vetch and manure systems.   Wheat yields were highest in the manure system in the first 2 years and in the crown vetch system in the last 2 years. Soybean yields were highest in the cover crop system in all years. The manure system usually had lower yields than the highest yielding system, partly because of competitions from uncontrolled weeds. Several measures of the efficience of grain production were evaluated. The no-tillage system produced the most grain per total vegetative biomass throughout the rotation. The cover crop system produced the most grain per unit of external N input and, along with the no-tillage system, had the highest corn water-use efficiency. The cover crop system also recycled the most vegetative residues and nutrients of all systems. No single system perfomed best according to all measures of comparison, suggesting that trade-offs will be required when choosing production systems.

Tenuta, M. and E. G. Beauchamp (2003). "Nitrous oxide production from granular nitrogen fertilizers applied to a silt loam soil." Canadian Journal of Soil Science **83**(5): 521–532.

> One field and two laboratory experiments were conducted to determine the relative magnitude and pattern of N2O production from several granular N fertilizers including urea, ammonium nitrate, calcium nitrate, ammonium sulfate and, in a laboratory experiment, monoammonium and diammonium phosphates. Several parameters, in particular soil water content, were studied for their roles in N2O production with these fertilizers. The field experiment was conducted at the Elora Research Station (20 km north of Guelph) on Conestoga silt loam during July on a site previously cropped to barley. Three methods were employed to assess N2O production following N fertilizer treatments in the field experiment, viz., soil cover, soil core and profile distribution. The data with each method revealed that incorporated urea produced the greatest quantity of N2O especially in the first few days following application. Shortly after urea application and incorporation (10 cm), N2O was detected at a depth of 50 cm indicating gas produced in the tilled layer was transported to lower depths. Data obtained with the intact core method showed that nitrification preceeded denitrification as the source of N2O produced during a wetting event as air-filled porosity decreased from 65% to less than 50%, respectively. The laboratory experiments showed that under aerobic conditions N2O production was generally greater with urea than the other N fertilizers. The greater production of N2O with urea was associated with NO2 – accumulation. In the second laboratory experiment, saturating the soil following 14 d of aerobic incubation showed enhanced N2O production with ammonium phosphate fertilizers. Our findings indicate refinement of methods to predict N2O emissions based on N fertilizer source use and moisture can reduce uncertainties in national estimates of N2O emissions from agricultural soils.

Thomas, S. M., M. H. Beare, et al. (2008). "Effects of tillage, simulated cattle grazing and soil moisture on N_2O emissions from a winter forage crop." Plant and Soil **309**(1–2): 131–145.

> Nitrous oxide (N2O) emissions to the atmosphere from grazed pasture can be high, especially from urine-affected areas. When pastoral soils are damaged by animal treading, N2O emissions may increase. In New Zealand, autumn-sown winter forage crops are often grown as a break-crop prior to re-sowing pasture. When these crops are grazed in situ over winter (as is common in New Zealand) there is high risk of soil damage from animal treading as soil moisture contents are often high at this time of year. Moreover, the risk of soil damage during grazing increases when intensive tillage practices are used to establish these forage crops. Consequently, winter grazed forage crops may be an important source of N2O emissions from intensive pastoral farming systems, and these emissions may be affected by the type of tillage used to establish them. We conducted a replicated field experiment to measure the effects of simulated cattle grazing (mowing followed by simulated treading and the application of synthetic urine) at three soil moisture contents (< field capacity, field capacity and > field capacity) on measured N2O emissions from soil under an autumn (March) sown winter forage crop (triticale) established with three levels of tillage intensity: (a) intensive, IT, (b) minimum, MT, or (c) no tillage, NT. In all treatments, bulk density in the top 7.5 cm of the soil was unaffected by treading when simulated grazing occurred at < field capacity. It was increased in the IT plots by 13 and 15% when treading occurred at field capacity and > field capacity, and by 10% in the MT plots trodden at > field capacity. Treading did not significantly increase the bulk density in the NT plots. Emissions of N2O from the tillage treatments decreased in the order IT > MT > NT. N2O

emissions were greatest from plots that were trodden at > field capacity and least from plots trodden at < field capacity. Simulated treading and urine application increased N2O emission 2 to 6-fold from plots that had no treading but did receive urine. Urine-amended plots had much greater emissions than plots that had no urine. Overall, the greatest emission of 14.4 kg N ha(-1) over 90 days (1.8% of the total urine N applied) was measured from urine-amended IT plots that were trodden at > field capacity. The N2O emission from urine-amended NT plots that were trodden at < field capacity was 2.0 kg ha(-1) over 90 days (0.25% of the total urine N applied). Decreasing the intensity of tillage used to establish crops and restricting grazing when soils are wet are two of the most effective ways to minimise the risk of high N2O emissions from grazed winter forage crops.

Thornton, F. C., B. R. Bock, et al. (1996). "Soil emissions of nitric oxide and nitrous oxide from injected andydrous ammonium and urea." Journal of Environmental Quality **25**(6): 1378–1384.

This study characterizes soil emissions of NO and N2O from banded applications of anhydrous ammonium (AA) and urea over the period from 6 May 1994 to 12 Sept. 1994 from a loess soil in western Tennessee. The N application rate for both sources was 168 kg ha−1. Fertilizer type strongly influenced emissions of N2O (F = 231; P = 0.0001) and NO (F = 69; P = 0.0001). During the 129 d measurement period, the AA treatment lost 12.33 kg of N2O-N or 7.33% of the applied N. The N2O-N loss from the urea treatment was about one-half that from AA; 6.34 kg ha−1 or 3.77% of the applied N. Loss of NO-N from both treatments was small compared with N2O-N loss. The urea treatment lost 0.27 kg ha−1 as NO-N and the AA treatment lost 0.2 kg ha−1 during the study period. While the measured loss rate of N2O-N from AA is similar to previous literature estimates, our values for urea are 20 to 40 times greater than the current literature reports of N2O-N loss of 0.1 to 0.2% of the urea applied. Higher N2O losses from urea in this study may be related to the fact that urea was banded below the soil surface, whereas urea has been broadcast on the soil surface in other N2O emissions studies.

Towprayoon, S., K. Smakgahn, et al. (2005). "Mitigation of methane and nitrous oxide emissions from drained irrigated rice fields." Chemosphere **59**(11): 1547–1556.

One of the important cultural practices that affect methane and nitrous oxide emissions from tropical rice plantations is the water drainage system. While drainage can reduce methane emissions, it can also increase nitrous oxide emissions, as well as reduce yields. In this experiment, four different water drainage systems were compared in a rice field in central Thailand including: (1) continuous flooding, (2) mid-season drainage, (3) multiple drainage and (4) a local method (drainage was done according to local cultural practice) in order to find a system of drainage that would optimize yields while simultaneously limiting methane and nitrous oxide emissions. Methane and nitrous oxide emission were observed and compared with rice yield and physical changes of rice plants. It was found that drainage during the flowering period could reduce methane emission. Interestingly, nitrous oxide emission was related to number of drain days rather than the frequency of draining. Fewer drain days can help reduce nitrous oxide emission. The mid-season drainage and the multiple drainage, with 6.9% and 11.4% reduction in rice yield, respectively, had an average methane emission per crop 27% and 35% lower when compared to the local method. Draining with fewer drain days during the flowering period was recommended as a compromise between emissions and yield. The field drainage can be used as an option to reduce methane and nitrous oxide emissions from rice

fields with acceptable yield reduction. Mid-season drainage during the rice flowering period, with a shortened drainage period (3 days), is suggested as a compromise between the need to reduce global warming and current socio-economic realities.

Tuskan, G. A. and M. E. Walsh (2001). "Short-rotation woody crop systems, atmospheric carbon dioxide and carbon management: A U.S. case study." Forestry Chronicle **77**(2): 259–264.

Atmospheric concentrations of carbon dioxide (CO2) are increasing along with global use of fossil fuels and worldwide rates of deforestation. These trends have led international panels and organizations to devise carbon management strategies in an effort to curb increases in CO2. The goal of this paper is to explore the potential role of short-rotation woody crops (SRWC) in the U.S. as one option in a carbon-managed future economy. On a scale of 40 × 106 ha, and at an average productivity rate of 21 Mg oven-dry biomass ha−1 yr−1, SRWC systems could account for an average of 0.30 Pg of C yr−1 when prorated over the 50-year deployment life of a typical SRWC system. Most of the accounted carbon (76%) would come from fossil fuel displacement as opposed to direct carbon sequestration. The proportion of accounted carbon associated with fossil fuel displacement increases with longer time frames due to the relatively rapid saturation of the carbon sequestration pool.

U.S. DOE (2007). Technical Guidelines: Voluntary Reporting of Greenhouse Gases (1605(b)) Program. Washington, DC, Office of Policy and International Affairs, United States Department of Energy.

On February 14, 2002, the President directed the Secretary of Energy, in consultation with the Secretary of Commerce, the Secretary of Agriculture, and the Administrator of the Environmental Protection Agency, to propose improvements to the voluntary emission reduction registration program under section 1605(b) of the 1992 Energy Policy Act. The improvements were to enhance measurement accuracy, reliability and verifiability, working with and taking into account emerging domestic and international approaches.In response to this charge, the Department of Energy (DOE), in consultation with the other agencies, has revised the reporting Guidelines for the Voluntary Reporting Program in two parts:• General Guidelines• Technical Guidelines (calculating emissions and reductions)

U.S. EPA (2006). Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990–2020. Washington, DC, U.S. Environmental Protection Agency.

U.S. EPA (2009). Inventory of U.S. greenhouse gas emissions and sinks: 1990–2007. Washington, DC, U.S. Environmental Protection Agency.

The United States Environmental Protection Agency (EPA) prepares the oficial U.S. Inventory of Greenhouse Gas Emissions and Sinks to comply with existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC). This chapter summarizes the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 2007. In 2007, total U.S. greenhouse gas emissions were 7,150.1 Tg CO2 Eq. Overall, total U.S. emissions have risen by 17 percent from 1990 to 2007. Emissions rose from 2006 to 2007, increasing by 1.4 percent (99.0 Tg CO2 Eq.). The following factors were primary contributors to this increase: (1) cooler winter and warmer summer conditions in 2007 than in 2006 increased the demand for heating fuels and contributed to the increase in the demand for electricity, (2) increased consumption of fossil fuels to generate electricity and (3) a significant decrease (14.2 percent) in hydropower generation used to meet this demand.

U.S. EPA (2010). Inventory of U.S. greenhouse gas emissions and sinks: 1990–2008. Washington, DC, U.S. Environmental Protection Agency.

UNCBD (2010). "Article 2. Terms of Use." Retrieved 28 September, 2010, from http://www.cbd.int/convention/articles.shtml?a=cbd-02.

USDA (2007). National Resources Inventory. Ames, IA, U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University**:** 123.

USDA (2008). Conservation Reserve Program: Summary and Enrollment Statistics. Washington, DC, U.S. Department of Agriculture, Farm Service Agency.

USDA (2008). U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990–2005. Washington, DC, U.S. Department of Agriculture, Office of the Chief Economist, Global Change Program Office**:** 161.

Emissions of the three most important long-lived greenhouse gases (GHG) have increased measurably over the past two centuries. Carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) concentrations in the atmosphere have increased by approximately 35%, 155%, and 18%, respectively, since 1750. In the U.S., agriculture accounted for close to 7% of total GHG emissions (7260 Tg CO2 eq.) in 2005. Livestock, poultry, and crop production contributed a total of 481 Tg CO2 eq. to the atmosphere in 2005. This total includes an offset from agricultural soil carbon sequestration of roughly 32 Tg CO2 eq. The primary agricultural sources are N2O emissions from cropped and grazed soils (263 Tg CO2 eq.), CH4 emissions from enteric fermentation (112 Tg CO2 eq.), and CH4 emissions from managed livestock waste (41 Tg CO2 eq.). Forests in the United States contributed a net reduction in atmospheric GHG of approximately 787 Tg CO2 eq. in 2005, which offset total U.S. GHG emissions by approximately 11%. In aggregate, the U.S. agricultural sector (including GHG sources for crop, poultry, and livestock production and GHG removal from the atmosphere via sinks for in) was estimated to be a net sink of 306 Tg CO2 eq. in 2005.

USDA ERS (2009). Manure Use for Fertilizer and for Energy – Report to Congress. Washington, DC, U.S. Department of Agriculture, Economic Research Service.

The Food, Conservation, and Energy Act of 2008 directed the U.S. Department of Agriculture to evaluate the role of animal manure as a source of fertilizer, and its other uses. About 5 percent of all U.S. cropland is currently fertilized with livestock manure, and corn accounts for over half of the acreage to which manure is applied. Expanded environmental regulation through nutrient management plans will likely lead to wider use of manure on cropland, at higher production costs, but with only modest impacts on production costs, commodity demand, or farm structure. There is widespread interest in using manure as a feedstock for energy production. While current use is quite limited, expanded government support, either direct or indirectly, could lead to a substantial increase in manure use as a feedstock. However, current energy processes are unlikely to compete with fertilizer uses of manure, because they leave fertilizer nutrients as residues, in more marketable form, and because manure-to-energy projects will be most profi table in regions where raw manure is in excess supply, with the least value as fertilizer.

USDA ERS (2010). Agricultural Resource Management Survey. Washington, DC, U.S. Department of Agriculture, Economic Research Service.

USDA ERS (2010). "Fertilizer Use and Price." Retrieved 2 July, 2010, from http://www.ers.usda.gov/Data/FertilizerUse/.

USDA ERS (2010). U.S. Farm Sector Cash Receipts from Sales of Agricultural Commodities, 2006–2010F. Washington, DC, U.S. Department of Agriculture, Economic Research Service.

USDA NASS (2007). 2007 Census of Agriculture. Washington, DC, U.S. Department of Agriculture, National Agricultural Statistics Service.

USDA NASS (2007). Agricultural Chemical Useage 2006 Vegetables Summary. Washington, DC, U.S. Department of Agriculture, National Agricultural Statistics Service.

USDA NASS (2009). Prospective Plantings. Washington D.C., U.S. Department of Agriculture, National Agricultural Statistics Service**:** 35.

USDA NASS (2009). Specialty Crops. Volume 2. Subject Series. Part 8. 2007 U.S. Census of Agriculture. Washington, DC, U.S. Department of Agriculture, National Agricultural Statistics Service.

USDA NRCS (2010). "National Conservation Practice Standards." Retrieved 18 March, 2010, from http://www.nrcs.usda.gov/Technical/Standards/nhcp.html.

USGS (2009). Ecological Carbon Sequestration Action Inventory. Washington, DC, United States Geological Survey.

Utomo, M., W. W. Frye, et al. (1990). "Sustaining soil nitrogen for corn using hairy vetch cover crop." Agronomy Journal **82**(5): 979–983.

Nitrogen fertility management is often complicated by inadequate supply, low efficiency, high losses, and the potential of polluting water resources. This study was conducted in 1984 and 1985 on a Maury soil (fine, mixed, mesic Typic Paleudalfs) in Kentucky to determine the role of a

hairy vetch (Vicia villosa Roth) cover crop in sustaining soil N for corn (Zea mays L.) under no-tillage and conventional tillage. Winter cover treatments of hairy vetch, rye (Secale cereals L.), and corn residue were combined factorially with N rates of 0, 85, and 170 kg ha'1 in the two tillage systems. Total soil C and N in the 0- to 7.5-cm depth, averaged across treatments and sampling dates, were 21.8 and 2.07 g kg'1, respectively, in no-tillage and 16.6 and 1.70 g kg'1 in conventional tillage. Values were 19.8 and 1.99 g kg'1, respectively, with hairy vetch and 18.8 and 1.80 g kg'1 with rye. Conventional tillage caused rapid mineralization of soil N, as indicated by greater inorganic N approximately 6 wk after plowing. Nitrate apparently leached deeper into the soil under notillage than conventional tillage. Grain yield without N on the vetch treatment was essentially equal to yields with 170 kg N ha'1 on the rye or corn residue treatments—6.75, 6.75, and 6.65 Mg ha'1, respectively. Grain yield with vetch and 170 kg N ha'1 was 7.85 Mg ha'1. Although vetch provided a substantial amount of N, results suggested that to obtain optimum corn yields N fertilization should be reduced little, if any, with a vetch cover crop. Vetch appeared to add grain yield instead of reduce the need for N fertilizer.

van Groenigen, J. W., G. L. Velthof, et al. (2010). "Towards an agronomic assessment of N_2O emissions: a case study for arable crops." European Journal of Soil Science **61**(6): 903–913.

Agricultural soils are the main anthropogenic source of nitrous oxide (N2O), largely because of nitrogen (N) fertilizer use. Commonly, N2O emissions are expressed as a function of N application rate. This suggests that smaller fertilizer applications always lead to smaller N2O emissions. Here we argue that, because of global demand for agricultural products, agronomic conditions should be included when assessing N2O emissions. Expressing N2O emissions in relation to crop productivity (expressed as above-ground N uptake: 'yield-scaled N2O emissions') can express the N2O efficiency of a cropping system. We show how conventional relationships between N application rate, N uptake and N2O emissions can result in minimal yield-scaled N2O emissions at intermediate fertilizer-N rates. Key findings of a meta-analysis on yield-scaled N2O emissions by non-leguminous annual crops (19 independent studies and 147 data points) revealed that yield-scaled N2O emissions were smallest (8.4 g N2O-N kg−1N uptake) at application rates of approximately 180–190 kg Nha−1 and increased sharply after that (26.8 g N2O-N kg−1 N uptake at 301 kg N ha−1). If the above-ground N surplus was equal to or smaller than zero, yield-scaled N2O emissions remained stable and relatively small. At an N surplus of 90 kg N ha−1 yield-scaled emissions increased threefold. Furthermore, a negative relation between N use efficiency and yield-scaled N2O emissions was found. Therefore, we argue that agricultural management practices to reduce N2O emissions should focus on optimizing fertilizer-N use efficiency under median rates of N input, rather than on minimizing N application rates.

VandenBygaart, A. J., E. G. Gregorich, et al. (2003). "Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies." Canadian Journal of Soil Science **83**(4): 363–380.

To fulfill commitments under the Kyoto Protocol, Canada is required to provide verifiable estimates and uncertainties for soil organic carbon (SOC) stocks, and for changes in those stocks over time. Estimates and uncertainties for agricultural soils can be derived from long-term studies that have measured differences in SOC between different management practices. We compiled published data from long-term studies in Canada to assess the effect of agricultural

management on SOC. A total of 62 studies were compiled, in which the difference in SOC was determined for conversion from native land to cropland, and for different tillage, crop rotation and fertilizer management practices. There was a loss of 24 ± 6% of the SOC after native land was converted to agricultural land. No-till (NT) increased the storage of SOC in western Canada by 2.9 ± 1.3 Mg ha–1; however, in eastern Canada conversion to NT did not increase SOC. In general, the potential to store SOC when NT was adopted decreased with increasing background levels of SOC. Using no-tillage, reducing summer fallow, including hay in rotation with wheat (Triticum aestivum L.), plowing green manures into the soil, and applying N and organic fertilizers were the practices that tended to show the most consistent increases in SOC storage. By relating treatment SOC levels to those in the control treatments, SOC stock change factors and their levels of uncertainty were derived for use in empirical models, such as the United Nations Intergovernmental Panel on Climate Change (IPCC) Guidelines model for C stock changes. However, we must be careful when attempting to extrapolate research plot data to farmers' fields since the history of soil and crop management has a significant influence on existing and future SOC stocks.

Varvel, G. E. (2006). "Soil organic carbon changes in diversified rotations of the western corn belt." Soil Science Society of America Journal **70**(2): 426–433.

Sequestration and storage of carbon (C) by agricultural soils has been cited as one potential part of the solution to soil degradation and global climate change. However, C sequestration in soils is a slow and dynamic process. The objective of this study was to evaluate the effects of crop rotation and N fertilizer management on soil organic C (SOC) levels at several points in time during 18 yr of a long-term study in the Western Corn Belt. Seven cropping systems (three monoculture, two 2-yr, and two 4-yr rotations) with three levels of N fertilizer were compared. Soil samples were taken in the spring in 1984, 1992, 1998, and 2002 to a depth of 30 cm in 0- to 7.5-, 7.5- to 15-, and 15- to 30-cm increments. No differences were obtained in SOC levels in 1984 at the beginning of the study. After 8 yr, rotation significantly increased SOC 449 kg ha-1 across all cropping systems. From 1992 to 2002, SOC levels in the 0- to 7.5-cm depth decreased by 516 kg ha-1 across all cropping systems. Soil organic C levels in the 7.5- to 15-cm depths in 1992 and 2002 demonstrated similar rotation effects to those in the surface 0- to 7.5-cm, being not significantly affected from 1984 to 1992 but being significantly decreased from 1992 to 2002 (568 kg SOC ha-1 across all cropping systems). Many of the SOC gains in the surface 30 cm measured during the first 8 yr of the study were lost during the next 10 yr in all but the 4-yr cropping systems after 18 yr. The loss of SOC in this latter period occurred when depth of tillage was increased by using a tandem disk with larger-diameter disks. These results demonstrate that more than one point-in-time measurement from long-term experiments is necessary to monitor SOC changes when several management variables, such as cropping system and N fertilizer, are being used. They also indicate that apparent small changes in cultural practices, such as in depth of tillage in this experiment, can significantly change SOC dynamics in the soil. Subtle changes in cultural practices (e.g., tillage depth) can have significant long-term results, but long-term experiments are required to quantify their impact under variable climatic conditions.

Vasquez, S. J., J. M. Hashim-Buckey, et al. (2007). Sample Costs to Establish and Produce Table Grapes (Thompson Seedless), San Joaquin Valley - South. Davis, CA, University of California Cooperative Extension.

Veenstra, J. J., W. R. Horwath, et al. (2007). "Tillage and cover cropping effects on aggregate-protected carbon in cotton and tomato." Soil Science Society of America Journal **71**(2): 362–371.

Conservation tillage (CT) and cover cropping (CC) are agricultural practices that may provide solutions to address water and air quality issues arising from intensive agricultural practices. This study investigated how CT and CC affect soil organic matter dynamics in a cotton(Gossypium hirsutum L.)-tomato (Lycopersicon esculentum Mill.) rotation in California's San Joaquin Valley. There were four treatments: conservation tillage, no cover crop (CTNO); conservation tillage with cover crop (CTCC); standard tillage, no cover crop (STNO); and standard tillage with cover crop (STCC). After 5 yr, the top 30 cm of soil in CTCC had an increase of 4500 kg C ha(-1), compared with an increase of 3800 kg C hat in STCC from initial soil C content in 1999. To enhance our understanding of C dynamics in CT systems, we pulse-labeled cotton with (CO2)-C-13 in the field and followed the decomposition of both the roots and the shoots through three physical fractions: light fraction (LF), which tends to turnover quickly, and two relatively stable C pools-intraaggregate LF (iLF) and mineral-associated carbon (mC). Soil under CT treatments retained more of the cotton-residue-derived C in LF and iLF than ST 3 mo after placement in the field. These differences disappeared after 1 yr, however, with no discernable differences between CT and ST regardless of CC. In California's Mediterranean climate, CT alone does not accumulate or stabilize more C than ST in tomato-cotton rotations, and the addition of cover crop biomass is more important than tillage reduction for total soil C accumulation.

Venterea, R. T., J. M. Baker, et al. (2006). "Carbon and nitrogen storage are greater under biennial tillage in a Minnesota corn-soybean rotation." Soil Science Society of America Journal **70**(5): 1752–1762.

Few studies have examined the impacts of rotational tillage regimes on soil carbon (C) and nitrogen (N). We measured the C and N content of soils managed under corn (Zea mays L.)-soybean (Glycine max L.) rotation following 10 and 15 yr of treatments. A conventional tillage (CT) regime employing moldboard and chisel plowing in alternate years was compared with both continuous no-till (NT) and biennial tillage (BT), which employed chisel plowing before soybean only. While masses of C and N in the upper 0.3 m under both BT and NT were higher than CT, only the BT treatment differed from CT when the entire sampled depth (0.6 m) was considered. Decreased C inputs, as indicated by reduced grain yields, may have limited C storage in the NT system. Thus, while more C was apparently retained under NT per unit of C input, some tillage appears necessary in this climate and cropping system to maximize C storage. Soil carbon dioxide (CO2) fluxes under NT were greater than CT during a drier than normal year, suggesting that C storage may also be partly constrained under NT due to wetter conditions that promote increased soil respiration. Increased temperature sensitivity of soil respiration with increasing soil moisture was also observed. These findings indicate that long-term biennial chisel plowing for corn-soybean in the upper mid-west USA can enhance C storage, reduce tillage-related fuel costs, and maintain yields compared with more intensive annual tillage.

Venterea, R. T., M. Burger, et al. (2005). "Nitrogen oxide and methane emissions under varying tillage and fertilizer management." Journal of Environmental Quality **34**(5): 1467–1477.

Comprehensive assessment of the total greenhouse gas (GHG) budget of reduced tillage agricultural systems must consider emissions of nitrous oxide (N2O) and methane (CH4), each of

which have higher global warming potentials than carbon dioxide (CO2). Tillage intensity may also impact nitric oxide (NO) emissions, which can have various environmental and agronomic impacts. In 2003 and 2004, we used chambers to measure N2O, CH4, and NO fluxes from plots that had been managed under differing tillage intensity since 1991. The effect of tillage on non-CO2 GHG emissions varied, in both magnitude and direction, depending on fertilizer practices. Emissions of N2O following broadcast urea (BU) application were higher under no till (NT) and conservation tillage (CsT) compared to conventional tillage (CT). In contrast, following anhydrous ammonia (AA) injection, N2O emissions were higher under CT and CsT compared to NT. Emissions following surface urea ammonium nitrate (UAN) application did not vary with tillage. Total growing season non-CO2 GHG emissions were equivalent to CO2 emissions of 0.15 to 1.9 Mg CO2 ha-1 yr-1 or 0.04 to 0.53 Mg soil-C ha-1 yr-1. Emissions of N2O from AA-amended plots were two to four times greater than UAN- and BU-amended plots. Total NO + N2O losses in the UAN treatment were approximately 50% lower than AA and BU. This study demonstrates that N2O emissions can represent a substantial component of the total GHG budget of reduced tillage systems, and that interactions between fertilizer and tillage practices can be important in controlling non-CO2 GHG emissions.

Venterea, R. T., M. S. Dolan, et al. (2010). "Urea decreases nitrous oxide emissions compared with anhydrous ammonia in a Minnesota corn cropping system." Soil Science Society of America Journal **74**(2): 407–418.

Quantifying N2O emissions from corn (Zea mays L.) and soybean [Glycine max (L.) Merr.] fields under different fertilizer regimes is essential to developing national inventories of greenhouse gas emissions. The objective of this study was to compare N2O emissions in plots managed for more than 15 yr under continuous corn (C/C) vs. a corn-soybean (C/S) rotation that were fertilized during the corn phase with either anhydrous NH3 (AA) or urea (U). During three growing seasons, N2O emissions from corn following corn were nearly identical to corn following soybean. In both systems, however, N2O emissions with AA were twice the emissions with U. After accounting for N2O emissions during the soybean phase, it was estimated that a shift from C/S to C/C would result in an increase in annual emissions of 0.78 kg N ha-1 (equivalent to 0.11 Mg CO2-C ha-1) when AA was used, compared with only 0.21 kg N ha-1 (0.03 Mg CO2-C ha-1) with U. In light of trends toward increased use of U, these results suggest that fertilizer-induced soil N2O emissions may decline in the future, at least per unit of applied N, although further study is needed in different soils and cropping systems. While soil CO2 emissions were 20% higher under C/C, crop residue from the prior year did not affect soil inorganic N or dissolved organic C during the subsequent season. We also compared different flux-calculation schemes, including a new method for correcting chamber-induced errors, and found that selection of a calculation method altered N2O emissions estimates by as much as 35%.

Venterea, R. T. and D. E. Rolston (2000). "Nitric and nitrous oxide emissions following fertilizer application to agricultural soil: Biotic and abiotic mechanisms and kinetics." Journal of Geophysical Research-Biogeosciences **105**(D12): 15117–15129.

Emissions of nitric and nitrous oxide (NO and N2O) from agricultural soils may have several consequesnces, including impacts on local tropospheris and global stratospheric chemistry. Elevated NO and N2O emissions following application of anhydrous ammonia to an agricultural field in California were driven by the biological generation of nitrite NO2- and subsequesnt abiotic decomposition of nitrous acid (HNO2). Maximum fluzes of >1000ng NO-N cm-2 h-1 and > 400N20-N cm-2 h-1 were observed, and emissions of >100 ng NO-N cm-2 h-1 and >50 N2O-N cm-2 h-1 persisted for >4 weeks. Laboratory experiments were performed to determine rate coefficients and activation energies for HNO2-mediated NO and N2O production. Kinetic parameters describing the conversion of NO to N2O were measures and were found to vary with water-filled pore space (WFPS). Regression models incorporatinf HNO2, WFPS, and temperature accounted for 75-77% or the variability in field fluxes. A previously developed NO emissions model was modified to incorporate a kinetic expression for HNO2- and temperature-dependent production. The model tended to underestimate fluxes under low-flux conditions and overestimate fluxes under high-flux conditions. These data indicate that (1) control of acidity may be qan effective means for minimizing gaseous N losses from fertilized soils and possibly for improving air quality in rural areas, (2) the transformation of HNO2-derived NO may be an important mechanism of N2O production even under relatively aerobic conditions, and (3) mechanistic models which account for spatial heterogeneity and transient conditions may be required to better predict field NO fluxes.

Venterea, R. T. and A. J. Stanenas (2008). "Profile analysis and modeling of reduced tillage effects on soil nitrous oxide flux." Journal of Environmental Quality **37**(4): 1360–1367.

The impact of no-till (NT) and other reduced tillage (RT) practices on soil to atmosphere fluxes of nitrous oxide (N2O) are difficult to predict, and there is limited information regarding strategies for minimizing fluxes from RT systems. We measured vertical distributions of key microbial, chemical, and physical properties in soils from a long-term tillage experiment and used these data as inputs to a process-based model that accounts for N2O production, consumption, and gaseous diffusion. The results demonstrate how differences among tillage systems in the stratification of microbial enzyme activity chemical reactivity, and other properties can control NO fluxes. Under nitrification-dominated conditions, simulated N2O emissions in the presence of nitrite (NO2-) were 2 to 10 times higher in NT soil compared to soil under conventional tillage (CT). Under denitrification-dominated conditions in the presence of nitrate (NO3-), higher bulk density and water content under NT promoted higher denitrification rates than CT. These effects were partially offset by higher soluble organic carbon and/or temperature and lower N2O reduction rates under CT. The NT/CT ratio of N2O fluxes increased as NO2- or NO3- was placed closer to the surface. The highest NT/CT ratios of N2O flux (> 30:1) were predicted for near-surface NO3- placement, while NT/CT ratios < 1 were predicted for NO3- placement below 15 cm. These results suggest that N2O fluxes from RT systems can be minimized by subsurface fertilizer placement and by using a chemical form of fertilizer that does not promote substantial NO2- accumulation.

Verheijen, F. G. A., S. Jeffery, et al. (2009). Biochar application to soils – A critical scientific review of effects on soil properties, processes and functions. Luxembourg, Office for the Official Publications of the European Communities**:** 149.

Biochar application to soils is being considered as a means to sequester carbon (C) while concurrently improving soil functions. The main focus of this report is providing a critical scientific review of the current state of knowledge regarding the effects of biochar application to soils on soil properties, processes and functions. Wider issues, including atmospheric emissions and occupational health and safety associated to biochar production and handling, are put into context. The aim of this review is to provide a sound scientific basis for policy development, to identify gaps in current knowledge, and to recommend further research relating to biochar application to soils. See Table 1 for an overview of the key findings from this report. Biochar research is in its relative infancy and as such substantially more data are required before robust predictions can be made regarding the effects of biochar application to soils, across a range of soil, climatic and land management factors.

Wagner-Riddle, C., A. Furon, et al. (2007). "Intensive measurement of nitrous oxide emissions from a corn-soybean-wheat rotation under two contrasting management systems over 5 years." Global Change Biology **13**(8): 1722–1736.

No-tillage (NT), a practice that has been shown to increase carbon sequestration in soils, has resulted in contradictory effects on nitrous oxide (N2O) emissions. Moreover, it is not clear how mitigation practices for N2O emission reduction, such as applying nitrogen (N) fertilizer according to soil N reserves and matching the time of application to crop uptake, interact with NT practices. N2O fluxes from two management systems [conventional (CP), and best management practices: NT + reduced fertilizer (BMP)] applied to a corn (Zea mays L.), soybean (Glycine max L.), winter-wheat (Triticum aestivum L.) rotation in Ontario, Canada, were measured from January 2000 to April 2005, using a micrometeorological method. The superimposition of interannual variability of weather and management resulted in mean monthly N2O fluxes ranging from - 1.9 to 61.3 g N ha(-1) day(-1). Mean annual N2O emissions over the 5-year period decreased significantly by 0.79 from 2.19 kg N ha(-1) for CP to 1.41 kg N ha(-1) for BMP. Growing season (May-October) N2O emissions were reduced on average by 0.16 kg N ha(-1) (20% of total reduction), and this decrease only occurred in the corn year of the rotation. Nongrowing season (November-April) emissions, comprised between 30% and 90% of the annual emissions, mostly due to increased N2O fluxes during soil thawing. These emissions were well correlated (r(2) = 0.90) to the accumulated degree-hours below 0 degrees C at 5 cm depth, a measure of duration and intensity of soil freezing. Soil management in BMP (NT) significantly reduced N2O emissions during thaw (80% of total reduction) by reducing soil freezing due to the insulating effects of the larger snow cover plus corn and wheat residue during winter. In conclusion, significant reductions in net greenhouse gas emissions can be obtained when NT is combined with a strategy that matches N application rate and timing to crop needs.

Wassmann, R., M. S. Aulakh, et al. (2002). "Methane emission patterns from rice fields planted to several rice cultivars for nine seasons." Nutrient Cycling in Agroecosystems **64**(1): 111–124.

The presented data set comprises a series of field experiments conducted in the period from 1993 to 1999 at the International Rice Research Institute, Philippines. Methane emissions from different rice cultivars were compared during nine seasons using an automated measuring system. The list of cultivars in this experiment consists of high yielding semi-dwarf cultivars (IR72, IR52, PSBRc20, PSBRc14), traditional tall cultivars (Dular, Intan), hybrid (Magat) as well as plant types with high yield potential that are currently under development (IR65597, IR65600). Seasonal averages in emission rates ranged from 20 to 89 mg CH4 m-2 d-1 under inorganic fertilization and from 129 to 413 mg CH4 m-2 d-1 following organic amendments. However, differences were generally small within a given season and stayed below significance level for the bulk of the inter-cultivar comparisons. Each experiment included IR72 to allow computation of cultivar-specific emission indices in relation to this reference. These indices ranged from 0.57 (PSBRc14) to 1.8 (Magat), but did not reveal consistent ranking for rice genotypes. The similarity in methane emissions was corroborated in a field screening of 19 cultivars using dissolved CH4 in soil solution as a proxy for relative emission rates. Irrespective of cultivars, higher plant density (10*20 cm spacing vs. 20*20 cm spacing of plant hills) stimulated methane production in the soil, but did not result in higher emission rates. This finding was attributed to higher oxygen influx into the soil and subsequent stimulation of methane oxidation when plants hills were more abundant. Over multi-seasonal periods, differences observed between cultivars were inconsistent indicating complex interactions with the environment. These results stress the need for more mechanistic understanding on cultivar effects to exploit the mitigation potential of cultivar selection in rice systems.

Wassmann, R., R. S. Lantin, et al. (2000). "Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs." Nutrient Cycling in Agroecosystems **58**(1): 23–36.

Methane (CH4) emissions from rice fields were determined using automated measurement systems in China, India, Indonesia, Thailand, and the Philippines. Mitigation options were assessed separately for different baseline practices of irrigated rice, rainfed, and deepwater rice. Irrigated rice is the largest source of CH4 and also offers the most options to modify crop management for reducing these emissions. Optimizing irrigation patterns by additional drainage periods in the field or an early timing of midseason drainage accounted for 7–80% of CH4 emissions of the respective baseline practice. In baseline practices with high organic amendments, use of compost (58–63%), biogas residues (10–16%), and direct wet seeding (16–22%) should be considered mitigation options. In baseline practices using prilled urea as sole N source, use of ammonium sulfate could reduce CH4 emission by 10–67%. In all rice ecosystems, CH4 emissions can be reduced by fallow incorporation (11%) and mulching (11%) of rice straw as well as addition of phosphogypsum (9–73%). However, in rainfed and deepwater rice, mitigation options are very limited in both number and potential gains. The assessment of these crop management options includes their total factor productivity and possible adverse effects. Due to higher nitrous oxide (N2O) emissions, changes in water regime are only recommended for rice systems with high baseline emissions of CH4. Key objectives of future research are identifying and characterizing high-emitting rice systems, developing site-specific technology packages, ascertaining synergies with productivity, and accounting for N2O emissions.

Webber, D. F., S. K. Mickelson, et al. (2010). "Livestock grazing and vegetative filter strip buffer effects on runoff sediment, nitrate, and phosphorus losses." Journal of Soil and Water Conservation **65**(1): 34–41.

Livestock grazing in the Midwestern United States can result in significant levels of runoff sediment and nutrient losses to surface water resources. Some of these contaminants can increase stream eutrophication and are suspected of contributing to hypoxic conditions in the Gulf of Mexico. This research quantified effects of livestock grazing management practices and vegetative filter strip buffers on runoff depth and mass losses of total solids, nitrate-nitrogen (NO3-N), and ortho-phosphorus (PO4-P) under natural hydrologic conditions. Runoff data were collected from 12 rainfall events during 2001 to 2003 at an Iowa State University research farm in central Iowa, United States. Three vegetative buffers (paddock area: vegetative buffer area

ratios of 1:0.2, 1:0.1, and 1:0 no buffer [control]) and three grazing management practices (continuous, rotational, and no grazing [control]) comprised nine treatment combinations (vegetative buffer ratio/grazing management practice) replicated in three 1.35 ha (3.34 ac) plot areas. The total 4.05 ha (10.02 ac) study area also included nine 0.4 ha (1.0 ac) paddocks and 27 vegetative buffer runoff collection units distributed in a randomized complete block design. The study site was established on uneven terrain with a maximum of 15% slopes and consisted of approximately 100% cool-season smooth bromegrass. Average paddock and vegetative buffer plant tiller densities estimated during the 2003 project season were approximately 62 million and 93 million tillers ha(-1) (153 million and 230 million tillers ac(-1)), respectively. Runoff sample collection pipe leakage discovered and corrected during 2001 possibly reduced runoff depth and affected runoff contaminant mass losses data values. Consequently, 2001 runoff analysis results were limited to treatment comparisons within the 2001 season and were not compared with 2002 and 2003 data. Analysis results from 2001 showed no significant differences in average losses of runoff, total solids, NO3-N, and PO4-P among the nine vegetative buffer/grazing practice treatment combinations. Results from 2002 indicated significantly higher losses of runoff and total solids from 1:0 no buffer/rotational grazing and 1:0 no buffer/continuous grazing treatment combination plots, respectively, compared among other 2002 season treatment combinations. The 2003 results showed significantly higher runoff and total solids losses from 1:0 no buffer/no grazing treatment combination plots compared among all 2003 treatment combinations and from 1:0.1 vegetative buffer/no grazing treatment combination plots compared among all 2003 treatment combinations and with respective 2002 treatment combinations. However, the 2003 results indicated effective vegetative buffer performance with significantly lower runoff, total solids, and NO3-N losses from the larger 1:0.2 buffer area compared among the smaller 1:0.1 buffer area and 1:0 no buffer treatment combinations. The 2003 results also indicated a highly significant increase in losses of NO3-N from 1:0.1 buffer/no grazing treatment combination plots compared among other 2003 season treatment combinations and with respective 2002 treatment combinations. Overall results from this study suggest a shift from significantly higher 2002 season plot losses Of Continuous and rotational grazing treatment combinations to significantly higher 2003 season losses of no grazing treatment combinations. We speculate this shift to significantly higher runoff and contaminant losses from no grazing treatment combination plots during 2003 reflects the variability inherent to a complex and dynamic soil-water environmental of livestock grazing areas. however, we also hypothesize the environmental conditions that largely consisted of a dense perennial cool-season grass type, high-relief landscape, and relatively high total rainfall depth may not necessarily include livestock grazing activities.

West, T. O. and G. Marland (2002). "A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States." Agriculture, Ecosystems & Environment **91**(1–3): 217–232.

The atmospheric CO2 concentration is increasing, due primarily to fossil-fuel combustion and deforestation. Sequestering atmospheric C in agricultural soils is being advocated as a possibility to partially offset fossil-fuel emissions. Sequestering C in agriculture requires a change in management practices, i.e. efficient use of pesticides, irrigation, and farm machinery. The C emissions associated with a change in practices have not traditionally been incorporated comprehensively into C sequestration analyses. A full C cycle analysis has been completed for agricultural inputs, resulting in estimates of net C flux for three crop types across three tillage intensities. The full C cycle analysis includes estimates of energy use and C emissions for primary fuels, electricity, fertilizers, lime, pesticides, irrigation, seed production, and farm machinery. Total C emissions values were used in conjunction with C sequestration estimates to model net C flux to the atmosphere over time. Based on US average crop inputs, no-till emitted less CO2 from agricultural operations than did conventional tillage, with 137 and 168 kg C ha(-1) per year, respectively. Changing from conventional tillage to no-till is therefore estimated to both enhance C sequestration and decrease CO2 emissions. While the enhanced C sequestration will continue for a finite time, the reduction in net CO2 flux to the atmosphere, caused by the reduced fossil-fuel use, can continue indefinitely, as long as the alternative practice is continued. Estimates of net C flux, which are based on US average inputs, will vary across crop type and different climate regimes. The C coefficients calculated for agricultural inputs can be used to estimate C emissions and net C flux on a site-specific basis. Published by Elsevier Science B.V.

West, T. O. and W. M. Post (2002). "Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis." Soil Science Society of America Journal **66**(6): 1930–1946.

Changes agricultural management can potentially increase the accumulation rate of soil organic C (SOC), thereby sequestering CO2 from the atmosphere. This study was conducted to quantify potential soil C sequestration rates for different crops in response to decreasing tillage intensity or enhancing rotation complexity, and to estimate the duration of time over which sequestration may occur. Analyses of C sequestration rates were completed using a global database of 67 long-term agricultural experiments, consisting of 276 paired treatments. Results indicate, on average, that a change from conventional tillage (CT) to no-till (NT) can sequester 57 +/- 14 g C m(-2) yr(-1), excluding wheat (Triticum aestivum L.)-fallow systems which may not result in SOC accumulation with a change from CT to NT. Enhancing rotation complexity can sequester an average 20 +/- 12 g C m(-2) yr(-1), excluding a change from continuous corn (Zea mays L.) to corn-soybean (Glycine mar L.) which may not result in a significant accumulation of SOC. Carbon sequestration rates, with a change from CT to NT, can be expected to peak in 5 to 10 yr with SOC reaching a new equilibrium in 15 to 20 yr. Following initiation of an enhancement in rotation complexity, SOC may reach a new equilibrium in approximately 40 to 60 yr. Carbon sequestration rates, estimated for a number of individual crops and crop rotations in this study, can be used in spatial modeling analyses to more accurately predict regional, national, and global C sequestration potentials.

WGA (n.d.). "Statistics on Specialty Crops." Retrieved 25 August, 2010, from http://www.wga.com/public/active/documentLibrary/downloadFile.php?id=230.

White, E. M., C. R. Krueger, et al. (1976). "Changes in total N, organic matter, available P, and bulk densities of a cultivated soil 8 years after tame pastures were established." Agronomy Journal **68**: 581–583.

Cultivated Williams loam (Typic Argiboroll, fine-loamy, mixed) soils in north-central South Dakota were sampled after pastures were established and 8 years later so that the effect of the pastures on soils could be studied from analysis in the laboratory. Pastures were seeded to Russian wildrye (Eiymus]unceus Fisch.), crested wheatgrass (Agropyron desertorum (Fisch.) Schult.), or a mixture smooth bromegrass (B~omus inermis Leyss.),

intermediate wheatgrass (Agropyron intermedium (Host) Beauv.), a pasture alfalfa (Medicago sativa L.). Soil N and bulk densities increased as available P decreased in the 8 years. The soil organic matter increased under all pastures, but it was small. The increases in organic matter, decreases in available P, and increases in saturated-clod bulk densities were different in the various pastures. Total N and organic matter increased about 0.001 and 0.02% per year, respectively, which is slower than the rate of decrease caused by cultivating the original grassland soils.

Wilhelm, W. W., J. W. Doran, et al. (1986). "Corn and soybean yield response to crop residue management under no-tillage production systems." Agronomy Journal **78**: 184–189.

Crop residues (stover) have many potential uses by society: food, feed, shelter, fuel, and soil amendment. Use of residues for purposes other than as a soil amendment may have serious negative consequences on crop productivity. This study was conducted to investigate the yield response of continuous corn (Zea mays L.) and continuous soybean [Glycine max (L.) Merr.) to removal or addition of crop residues under no-tillage management. The study was conducted near Lincoln, NE, on a Crete-Butler silty clay loam (fine, montmorillonitic, mesic Pachic Arguistoll-Abruptic Argiaquoll) with 1 to 2% slope. Crop residue was collected and weighed immediately after harvest in autumn. Quantity of residue to be returned to each treatment (0, 50, 100, or 150% of that produced) was calculated and uniformly spread over the plot area (12.2 by 12.2 m) by hand. Corn and soybean were planted into the established residue levels with no tillage the following spring. Data were collected on soil water, soil temperature, and grain and residue yield. A positive linear response was found between grain and stover yield and amount of residue applied to the soil surface. Each Mg ha-1 of residue removed resulted in about a 0.10 Mg ha"1 reduction in grain yield and a 0.30 Mg ha-1 reduction in residue yield. Quantity of applied residue accounted for 81 and 84% of the variation in grain yield of corn and soybean, respectively, and 88 and 92% of the variation in residue yield. Amounts of stored soil water at planting were closely associated with quantity of residue applied the previous year. Differences in total available water (soil storage at planting plus rainfall) accounted for approximately 70% of the yield variation associated with the residue treatments. Soil temperature (50-mm depth) and total available water accounted for nearly the same amount of variation in yield (80 to 90%) as quantity of residue, emphasizing the importance of these factors in evaluating response of crops to residue-management practices. Residue removal reduced grain and residue yields by amounts equal to 10 and 30%, respectively, of the quantity of residue removed. Residue effects on crop yield were induced mainly through changes in soil water and soil temperature.

Wilhelm, W. W., J. M. F. Johnson, et al. (2004). "Crop and soil productivity response to corn residue removal: A literature review." Agronomy Journal **96**(1): 1–17.

Society is facing three related issues: overreliance on imported fuel, increasing levels of greenhouse gases in the atmosphere, and producing sufficient food for a growing world population. The U.S. Department of Energy and private enterprise are developing technology necessary to use high-cellulose feedstock, such as crop residues, for ethanol production. Corn (Zea mays L.) residue can provide about 1.7 times more C than barley (Hordeum vulgare L.), oat (Avena sativa L.), sorghum [Sorghum bicolor (L.) Moench], soybean [Glycine max (L.) Merr.], sunflower (Helianthus annuus L.), and wheat (Triticum aestivum L.) residues based on production levels. Removal of crop residue from the field must be balanced against impacting the environment (soil erosion), maintaining soil organic matter levels, and preserving or enhancing productivity. Our objective is to summarize published works for potential impacts of wide-scale, corn stover collection on corn production capacity in Corn Belt soils. We address the issue of crop yield (sustainability) and related soil processes directly. However, scarcity of data requires us to deal with the issue of greenhouse gases indirectly and by inference. All ramifications of new management practices and crop uses must be explored and evaluated fully before an industry is established. Our conclusion is that within limits, corn stover can be harvested for ethanol production to provide a renewable, domestic source of energy that reduces greenhouse gases. Recommendation for removal rates will vary based on regional yield, climatic conditions, and cultural practices. Agronomists are challenged to develop a procedure (tool) for recommending maximum permissible removal rates that ensure sustained soil productivity.

Wilhelm, W. W., J. M. F. Johnson, et al. (2007). "Corn stover to sustain soil organic carbon further constrains biomass supply." Agronomy Journal **99**(6): 1665–1667.

Sustainable aboveground crop biomass harvest estimates for cellulosic ethanol production, to date, have been limited by the need for residue to control erosion. Recently, estimates of the amount of corn (Zea mays L.) stover needed to maintain soil carbon, which is responsible for favorable soil properties, were reported (5.25-12.50 Mg ha-1). These estimates indicate stover needed to maintain soil organic carbon, and thus productivity, are a greater constraint to environmentally sustainable cellulosic feedstock harvest than that needed to control water and wind erosion. An extensive effort is needed to develop advanced cropping systems that greatly expand biomass production to sustainably supply cellulosic feedstock without undermining crop and soil productivity.

Winsten, J. R., C. D. Kerchner, et al. (2010). "Trends in the Northeast dairy industry: Large-scale modern confinement feeding and management-intensive grazing." Journal of Dairy Science **93**(4): 1759–1769.

This paper provides a summary of results from a recent survey of 987 dairy farmers in 4 northeastern US states. The survey results provide descriptive characteristics of the current state of dairy farming in the region, as well as farmer satisfaction levels, concerns, and plans for the future of their farming operations. The paper analyses characteristics of two increasingly important dairy production systems used in the Northeast. Averages from across the survey states (Maryland, Pennsylvania, New York, and Vermont) show that approximately 13% of dairy producers use management-intensive or rotational grazing and 7% use large, modern confinement systems with more than 300 cows. These more specialized production systems show many significant differences in farm and farmer characteristics, satisfaction levels, and plans for the future compared with farms using more traditional production systems. The changing structure of the dairy industry has potentially important implications for environmental quality, rural communities, and the food system.

Wolf, B., X. Zheng, et al. (2010). "Grazing-induced reduction of natural nitrous oxide release from continental steppe." Nature **464**(7290): 881–884.

Atmospheric concentrations of the greenhouse gas nitrous oxide (N2O) have increased significantly since pre-industrial times owing to anthropogenic perturbation of the global nitrogen cycle, with animal production being one of the main contributors. Grasslands cover about 20 per cent of the temperate land surface of the Earth and are widely used as pasture. It has been suggested that high animal stocking rates and the resulting elevated nitrogen input increase N2O emissions. Internationally agreed methods to upscale the effect of increased livestock numbers on N2O emissions are based directly on per capita nitrogen inputs. However, measurements of grassland N2O fluxes are often performed over short time periods, with low time resolution and mostly during the growing season. In consequence, our understanding of the daily and seasonal dynamics of grassland N2O fluxes remains limited. Here we report year-round N2O flux measurements with high and low temporal resolution at ten steppe grassland sites in Inner Mongolia, China. We show that short-lived pulses of N2O emission during spring thaw dominate the annual N2O budget at our study sites. The N2O emission pulses are highest in ungrazed steppe and decrease with increasing stocking rate, suggesting that grazing decreases rather than increases N2O emissions. Our results show that the stimulatory effect of higher stocking rates on nitrogen cycling and, hence, on N2O emission is more than offset by the effects of a parallel reduction in microbial biomass, inorganic nitrogen production and wintertime water retention. By neglecting these freeze–thaw interactions, existing approaches may have systematically overestimated N2O emissions over the last century for semi-arid, cool temperate grasslands by up to 72 per cent.

Wright, L. L. and E. E. Hughes (1993). "U.S. carbon offset potential using biomass energy systems." Water, Air, and Soil Pollution **70**(1): 483–497.

A previous analysis had assumed that about 20% of 1990 U.S. C emissions could be avoided by the substitution of biomass energy technologies for fossil energy technologies at some point in the future. Short-rotation woody crop (SRWC) plantations were found to be the dedicated feedstock supply system (DFSS) offering the greatest C emission reduction potential. High efficiency biomass to electricity systems were found to be the conversion technology offering the greatest C emission reduction potential. This paper evaluates what would be required in terms of rate of technology implementation and time period to reach the 20% reduction goal. On the feedstock supply side, new plantings would have to installed at an average a rate of 1 x 106 ha yr -I while average yields would have to increase by 1.5% annually over the 35-year period. Such yield increases have been observed for high value agricultural crops with large government research support. On the generation side, it requires immediate adoption of available technologies with a net efficiency of 33% or higher (such as the Whole Tree Energy TM technology), installation of approximately 5000 MWe of new capacity each year, and rapid development and deployment of much higher efficiency technologies to result in an average of 42% efficiency by 2030. If these technology changes could be achieved at a linear rate, U.S. C emission reduction could progress at a rate of about 0.6 % yr a over the next 35 years.

Wyland, L. J., L. E. Jackson, et al. (1995). "Soil-plant nitrogen dynamics following incorporation of a mature rye cover crop in a lettuce production system " Journal of Agricultural Science **124**: 17–25.

Winter non-leguminous cover crops are included in crop rotations to decrease nitrate (NO3-N) leaching and increase soil organic matter. This study examined the effect of incorporating a

mature cover crop on subsequent N transformations. A field trial containing a winter cover crop of Merced rye and a fallow control was established in December 1991 in Salinas, California. The rye was grown for 16 weeks, so that plants had headed and were senescing, resulting in residue which was difficult to incorporate and slow to decompose. Frequent sampling of the surface soil (0-15 cm) showed that net mineralizable N (anaerobic incubation) rapidly increased, then decreased shortly after tillage in both treatments, but that sustained increases in net mineralizable N and microbial biomass N in the cover-cropped soils did not occur until after irrigation, 20 days after incorporation. Soil NO3-N was significantly reduced compared to winter-fallow soil at that time. A N-15 experiment examined the fate of N fertilizer, applied in cylinders at a rate of 12 kg N-15/ha at lettuce planting, and measured in the soil, microbial biomass and lettuce plants after 32 days. In the cover-cropped soil, 59% of the N-15 was recovered in the microbial biomass, compared to 21% in the winter-bare soil. The dry weight, total N and N-15 content of the lettuce in the cover-cropped cylinders were significantly lower; 28 v. 39% of applied N-15 was recovered in the lettuce in the cover-cropped and winter-bare soils, respectively. At harvest, the N content of the lettuce in the cover-cropped soil remained lower, and microbial biomass N was higher than in winter-bare soils. These data indicate that delayed cover crop incorporation resulted in net microbial immobilization which extended into the period of high crop demand and reduced N availability to the crop.

Xu, H., Z. C. Cai, et al. (2000). "Effect of land management in winter crop season on CH_4 emission during the following flooded and rice-growing period." <u>Nutrient Cycling in Agroecosystems</u> **58**(1): 327–332.

A greenhouse pot experiment was carried out to study the effect of land management during the winter crop season on methane (CH4) emissions during the following flooded and rice-growing period. Three land management patterns, including water management, cropping system, and rice straw application time were evaluated. Land management in the winter crop season significantly influenced CH4 fluxes during the following flooded and rice-growing period. Methane flux from plots planted to alfalfa (ALE) in the winter crop season was significantly higher than those obtained with treatments involving winter wheat (WWE) or dry fallow (DFE). Mean CH4 fluxes of treatments ALE, WWE, and DFE were 28.6, 4.7, and 4.1 mg CH4 m-2 h-1 in 1996 and 38.2, 5.6, and 3.2 mg CH4 m-2 h-1 in 1997, respectively. The corresponding values noted with continuously flooded fallow (FFE) treatment were 6.1 and 5.2 times higher than that of the dry fallow treatment in 1996 and 1997, respectively. Applying rice straw just before flooding the soil (DFL) significantly enhanced CH4 flux by 386% in 1996 and by 1,017% in 1997 compared with rice straw application before alfalfa seed sowing (DFE). Land management in the winter crop season also affected temporal variation patterns of CH4 fluxes and soil Eh after flooding. A great deal of CH4 was emitted to the atmosphere during the period from flooding to the early stage of the rice-growing season; and CH4 fluxes were still relatively high in the middle and late stages of the rice-growing period for treatments ALE, DFL, and FFE. However, for treatments DFE and WWE, almost no CH4 emission was observed until the middle stage, and CH4 fluxes in the middle and late stages of the rice-growing period were also very small. Soil Eh of treatments ALE and DFL decreased quickly to a low value suitable for CH4 production. Once Eh below -150 mV was established, the small changes in Eh did not correlate to changes in CH4 emissions. The soil Eh of treatments DFE and WWE did not decrease to a negative value until the middle stage of the rice-growing period, and it correlated significantly with the simultaneously measured CH4 fluxes during the flooded and rice-growing period.

Yanai, Y., K. Toyota, et al. (2007). "Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments." Soil Science & Plant Nutrition **53**(2): 181–188.

Laboratory experiments were conducted to examine the effect of charcoal addition on N2O emissions resulting from rewetting of air-dried soil. Rewetting the soil at 73% and 83% of the water-filled pore space (WFPS) caused a N2O emission peak 6 h after the rewetting, and the cumulative N2O emissions throughout the 120-h incubation period were 11 ± 1 and 13 ± 1 mg N m−2 , respectively. However, rewetting at 64% WFPS did not cause detectable N2O emissions (−0.016 ± 0.082 mg N m−2), suggesting a severe sensitivity to soil moisture. When the soils were rewetted at 73% and 78% WFPS, the addition of charcoal to soil at 10 wt% supressed the N2O emissions by 89% . In contrast, the addition of the ash from the charcoal did not suppress the N2O emissions from soil rewetted at 73% WFPS. The addition of charcoal also significantly stimulated the N2O emissions from soil rewetted at 83% WFPS compared with the soil without charcoal addition (P < 0.01). Moreover, the addition of KCl and K2SO4 did not show a clear difference in the N2O emission pattern, although Cl− and $SO4^{2-}$, which were the major anions in the charcoal, had different effects on N2O-reducing activity. These results indicate that the suppression of N2O emissions by the addition of charcoal may not result in stimulation of the N2O-reducing activity in the soil because of changes in soil chemical properties.

Zhang, L., B. K. Wylie, et al. (2010). "Climate-driven interannual variability in net ecosystem exchange in the northern Great Plains grasslands." Rangeland Ecology & Management **63**(1): 40–50.

The Northern Great Plains grasslands respond differently under various climatic conditions; however, there have been no detailed studies investigating the interannual variability in carbon exchange across the entire Northern Great Plains grassland ecosystem. We developed a piecewise regression model to integrate flux tower data with remotely sensed data and mapped the 8-d and 500-m net ecosystem exchange (NEE) for the years from 2000 to 2006. We studied the interannual variability of NEE, characterized the interannual NEE difference in climatically different years, and identified the drought impact on NEE. The results showed that NEE was highly variable in space and time across the 7 yr. Specifically, NEE was consistently low (-35 to 32 g C . m(-2).yr(-1)) with an average annual NEE of -2 +/- 24 g C . m(-2).yr(-1) and a cumulative flux of -15 g C . m(-2). The Northern Great Plains grassland was a weak source for carbon during 2000-2006 because of frequent droughts, which strongly affected the carbon balance, especially in the Western High Plains and Northwestern Great Plains. Comparison of the NEE map with a drought monitor map confirmed a substantial correlation between drought and carbon dynamics. If drought severity or frequency increases in the future, the Northern Great Plains grasslands may become an even greater carbon source.