Review Article

Agro-Science Letters
Year 2025, Volume-1, Issue-1 (January – March)

www.acspublisher.com

Soil Carbon Sequestration and Greenhouse Gas Dynamics in Sub-Tropical Farmlands: An Integrative Review

Ratna Sahay[a*], R.C. Maurya[a], Pallavi Srivastava[b], Vijay Kumar Yadav[c], and Sadhvi[d]

[a]Krishi Vigyan Kendra, Dhaura, Unnao-209881, U.P., India.
[b]IU, Lucknow, U.P., India.
[c]Dr. R.M.L. Awadh University, Ayodhya, U.P., India.
[d]VBS Purvanchal University, Jaunpur, U.P., India

ARTICLE INFO

Keywords:
Climate change, Greenhouse gas emissions, Soil carbon sequestration

ABSTRACT

Global atmospheric loading of greenhouse gases (GHGs) is intensifying at measurable annual rates: carbon dioxide (CO_2) at 0.5%, methane (CH_4) at 0.6%, and nitrous oxide (N_2O) at 0.25 ppbv yr^{-1}. Farming operations collectively account for roughly 20% of this emission burden, and land-use transformations—especially forest clearance—add another 14% to the total. Among the practices most responsible for carbon release from managed soils are tillage-based soil disturbance, agrochemical inputs, open field burning of harvest residues, and exportation of crop biomass. Cumulative land degradation since the advent of agriculture has eliminated an estimated 55–100 Pg from the global soil carbon pool and 100–150 Pg from terrestrial biotic stocks. Transitioning to scientifically guided management can restore soil organic carbon (SOC) and rebuild degraded land productivity. Under unmitigated warming scenarios, global crop production could fall by a quarter overall, and rain-fed cropping systems—which sustain the world's most food-insecure populations—could face yield losses approaching 50%. Marginal and smallholder farmers, operating on limited land and capital, face heightened exposure to these disruptions. Concurrent declines in crop yields and freshwater accessibility are anticipated as thermal regimes shift and seasonal precipitation becomes less reliable. This review synthesizes current understanding of SOC behavior under climate pressure and makes the case for scientifically robust policy frameworks that strengthen irrigation systems and safeguard water resources. Decarbonizing the global energy base remains the definitive long-run solution, but soil-based carbon sequestration serves as an indispensable near-term strategy during the transition.

How to cite: Sahay, R., Maurya, R. C., Srivastava, P., Yadav, V. K., & Sadhvi. (2025). Soil carbon sequestration and greenhouse gas dynamics in sub-tropical farmlands: An integrative review. *Agro-Science Letters*, 1(1), 26–32. https://doi.org/10.48165/asl.2025.1.1.5

Corresponding Email- ratnaasahay@gmail.com

DOI: https://doi.org/ 10.48165/asl.2025.1.1.5
Received: 18 December 2024 → Accepted: 22 December 2024
Published by ACS Publishers. This article published under the CC BY-NC license (https://creativecommons.org/licenses/by-nc/4.0/

INTRODUCTION

Escalating food commodity prices have triggered global debate over whether established agricultural systems possess adequate capacity to meet the nutritional needs of a continuously growing population (Koning et al., 2008; Swinnen and Squicciarini, 2012; Godfray et al., 2010). The year 2012 served as a watershed moment, as an unprecedented sequence of climatic extremes translated directly into disrupted harvests and heightened vulnerability across major food-producing regions (Parry et al., 2005). At that time, the human population had surpassed 7.2 billion and atmospheric CO_2 had crossed 400 ppmv—both metrics advancing simultaneously, at annual increments of approximately 75 million people and 2.2 ppmv, respectively (GHG Bulletin, 2011). This parallel growth is more than coincidental: demographic expansion is a fundamental driver of fossil-fuel consumption, with each billion-person increment in global population adding roughly 1.4 Pg CO_2-C to annual emission inventories (Lal et al., 2013). Extrapolating these trends to a projected population of 9.6 billion by 2050 and 11 billion by 2100 implies CO_2-C emission trajectories of 13.4 Pg C yr^{-1} and 15.3 Pg C yr^{-1} at those respective milestones, up from 10 Pg C yr^{-1} in 2012. The U.S. Energy Information Authority (EIA, 2013) independently forecast energy-sector CO_2-C outputs of 8.5 Pg in 2010 rising to 9.9 Pg, 11.3 Pg, and 12.4 Pg in 2020, 2030, and 2040, at an average annual growth rate of 1.3%. These emission trajectories unfold against a backdrop of tightening competition for agricultural land, freshwater, and energy (Pimentel, 2011), all of which interact with anthropogenic climate change to undermine the resilience of food production systems. Soil degradation, declining groundwater recharge rates, the waning returns on energy-intensive inputs, and the destabilization of regional agricultural productivity are among the most consequential expressions of this pressure (Swaminathan, 2012). While the nexus linking fossil energy use to climatic instability and food insecurity is broadly acknowledged in scientific literature (Lal et al., 2013), the precise scope of agricultural disruption attributable to a changing climate remains contested, in part because CO_2-driven fertilization effects, nutrient and water limitations, and the stochastic occurrence of extreme weather events interact in non-linear ways (Lovejoy et al., 2012; Zhang, 2011; Godfray et al., 2010).

Climate Change, Soil Carbon Dynamics, and Sequestration in Agroecosystems

Soil systems are exceptionally sensitive to climatic shifts, not merely through altered precipitation volumes but through cascading changes in hydrological, thermal, and biological processes. Temperature and rainfall perturbations reshape overland flow patterns and accelerate erosion, leading to measurable losses in SOC and total nitrogen, elevated soil salinity, and reduced diversity within belowground microbial assemblages—all of which undermine the productive capacity of farmland. The thermal sensitivity of soil carbon was quantified by Kirschbaum (2012), who showed that warming accelerates microbial decomposition of organic substrates and thereby depletes SOC reserves. Paradoxically, elevated atmospheric CO_2 concentrations can stimulate greater plant biomass production and thus increase organic carbon inputs to the soil via root turnover and litter fall. Field evidence reported by Naresh et al. (2013) indicated that chronically low SOC in many cultivated soils stems from a combination of constrained aboveground and belowground biomass production, thermally accelerated organic matter breakdown, and intensified faunal processing of organic residues.

Tillage management exerts one of the most decisive influences on the trajectory of SOC under any given climatic regime. Song et al. (2011) and Naresh et al. (2015) demonstrated through paired field comparisons that zero-tillage and permanent raised bed (PRB) cultivation consistently accumulate more SOC than conventional tillage-based systems. The mechanism is well understood: frequent mechanical soil inversion fractures macroaggregates that ordinarily encapsulate and protect organic carbon, liberating microaggregates and free organic particles that lack structural protection and oxidize rapidly. The net result is a decline in both SOC stocks and aggregate stability. Carbon sequestration in agricultural soils is therefore a potentially powerful, low-cost strategy for partially offsetting the negative effects of atmospheric GHG accumulation on farming systems. This potential is not uniformly distributed, however; intensively managed irrigated rice systems, which demand large quantities of external inputs, tend to generate disproportionately large CO_2 fluxes while contributing relatively little to net soil carbon accumulation (Bhatia et al., 2011). Quantitative evidence from Naresh et al. (2015) showed that SOC concentrations rose from 0.54% under unfertilized controls to 0.82% under combined RDF+FYM treatment, translating to sequestration rates of 0.33 Mg C ha^{-1} yr^{-1} and 0.16 Mg C ha^{-1} yr^{-1} under RDF+FYM and NPK treatments, respectively. National-scale assessments by Lal (1994) put India's SOC sequestration potential through land rehabilitation at 10–14 Tg C yr^{-1}. The organic carbon density of undisturbed vegetation biomass follows a well-characterized gradient: tropical rainforest > temperate forest > temperate deciduous forest > boreal forest > tropical woodland > temperate woodland > tropical grassland > temperate grassland > desert scrub > tundra and alpine meadow (Lal et al., 1999). Projections by Lal (1989) suggested that broad-scale adoption of conservation tillage across 400 million ha of global cropland by 2020 could result in cumulative C sequestration of 1,481–4,913 Tg. For India specifically, agricultural intensification is projected to sequester 12.7–16.5 Tg C yr^{-1}, while carbonate precipitation in irrigated soils may contribute an additional

21.8–25.6 Tg C yr^{-1}. Nationally, total SOC sequestration potential is estimated at 77.9–106.4 Tg yr^{-1} (92.2 ± 20.2 Tg yr^{-1}), with the following breakdown: 12.9% from degraded soil rehabilitation, 45.6% from erosion prevention, 15.8% from agricultural intensification, and 25.7% from carbonate sequestration (Bhattacharya, 2007).

The soil carbon-to-nitrogen (C:N) ratio constitutes a widely recognized indicator of soil organic matter quality and its management trajectory (Lou et al., 2012). Because this ratio is sensitive to the composition of organic inputs and to prevailing climatic conditions, maintaining it within favorable ranges requires management strategies that either augment organic matter additions or retard their mineralization (Al-Kaisi et al., 2005). The SOC and nitrogen responses to tillage intensity are further modulated by rooting depth, cropping sequence, local pedological characteristics, and regional climate (Du et al., 2010; Mishra et al., 2010). Conventional inversion tillage delivers certain short-term agronomic benefits—among them, temporary alleviation of subsoil compaction, burial of surface-applied residues, and mechanical weed control—but these are counterbalanced by accelerated erosion, elevated nutrient runoff, progressive depletion of soil organic matter, and a deteriorating soil structural condition (Lal, 2007).

The net direction and magnitude of SOC change in any field setting reflects the combined influence of numerous interacting drivers: precipitation and temperature regimes, soil texture, the composition and activity of soil microbial communities, tillage frequency and depth, fertilizer regime, irrigation management, residue handling, root architecture, and landscape geomorphology (Derpsch et al., 2014). An illuminating experiment by Grandy and Robertson (2006) revealed that a single tillage intervention in soils that had been undisturbed for years rapidly dismantled the aggregate architecture that had been protecting accumulated organic carbon, restoring decomposition rates to those typical of freshly disturbed mineral soil. Evidence from long-term conservation tillage experiments has further shown that the C gains observed under no-till are principally attributable to physical occlusion within aggregates; accordingly, any departure from the established tillage regime risks rapidly eroding these accumulated stocks (Syswerda et al., 2011). Meta-analytic work by Luo et al. (2010), Virto et al. (2012), and Powlson et al. (2014) synthesized evidence from the Indo-Gangetic Plain (IGP) and confirmed that while SOC accrual rates under reduced or zero tillage average around 0.3 Mg C ha^{-1} yr^{-1}, the actual sequestration benefit at any given location is highly context-dependent. The enhanced sensitivity of surface-applied residues to temperature and moisture fluctuations under conservation agriculture—relative to incorporated residues—means that the pace of decomposition, and therefore the net C balance, varies substantially with local weather patterns (Helgason et al., 2014). In rice–wheat systems of the western IGP, where field burning is the most common alternative to residue retention, any incremental C stored in conservation agriculture plots represents a real displacement of atmospheric emissions that would otherwise result from combustion.

Agricultural Practices as Drivers of GHG Emissions and Crop Vulnerability

Globally, the agricultural sector is responsible for an estimated 30–40% of anthropogenic greenhouse gas emissions, with the bulk of this burden concentrated in developing economies, which generate approximately 75% of agricultural GHGs—a share that may climb above 80% by mid-century (Thornton and Lipper, 2013; Gebreegziabher et al., 2014). The diversity of emission-generating activities within farming systems is considerable: nitrogen-based fertilizer applications, organic amendments, various irrigation regimes, soil tillage, and ruminant livestock management all contribute to the production and release of nitrous oxide, methane, and CO_2 into the atmosphere (IPCC, 2007d). Survey evidence from smallholder farming communities documented by Amdu (2010) reflects a widespread—and self-reinforcing—tendency to increase synthetic fertilizer inputs as an adaptive response to perceived climate-related yield shortfalls, a strategy that amplifies the very emissions driving further climate disruption. Crop production in India faces particularly acute risks: under projected temperature anomalies through 2080–2100, the probability of significant yield declines ranges from 10–40% (Parry et al., 2004; IPCC, 2007b). Wheat production is especially vulnerable; modeling studies by Aggarwal and Mall (2002), Aggarwal (2003), and Samra and Singh (2004) estimated output reductions of 4–5 million tonnes per 1°C of warming in India, coupled with earlier crop maturity by 10–20 days, a development that would compress the growing season and reduce total biomass accumulation. Alongside yield, grain nutritional quality is expected to erode as temperatures rise, with protein concentrations in cereal crops declining partly in response to elevated CO_2 levels and heat-induced metabolic disruption (Hocking and Meyer, 1991). Laboratory and field research by Nagarajan et al. (2010) demonstrated that nighttime temperatures in the 21–32°C range inflict significant damage on key rice production parameters—including harvest index, pollen germinability, spikelet sterility, respiration efficiency, starch quality, and visual grain characteristics. At a broader geographic scale, Ignaciuk and Mason-D'Croz (2014) projected that the ongoing trajectory of climate change will continue to suppress yields of maize, rice, wheat, root vegetables, and horticultural crops well into the second half of this century.

Harnessing Agriculture as a Carbon Sink and Climate Solution

An often underappreciated dimension of the global carbon cycle is the enormous stock of organic carbon residing in cultivated and uncultivated soils: the carbon content of the top meter of soil worldwide is approximately three times the quantity currently present in the atmosphere as CO_2 (Paustian et al., 1997; Lal, 2011). Anthropogenic land conversion—most consequentially the clearing of native vegetation to expand arable area—has historically drained this reservoir, transferring vast quantities of stable soil carbon to the atmosphere. A systematic review by Smith et al. (2008) placed the upper bound of agriculture's technical mitigation potential at 5.5–6 Gt CO_2e yr^{-1}, with the economically feasible range spanning 1.5–4.3 Gt CO_2e yr^{-1} under realistic carbon pricing. Importantly, 36% of this theoretical potential is contingent on converting degraded cropland back to natural vegetation or restoring peat hydrology through re-wetting—interventions that compete directly with the imperative to maintain or expand food production capacity and are therefore only achievable on a limited scale (Smith et al., 2013).

Temperature projections developed within the IPCC Fourth Assessment Report (2007a) foresee global mean warming of 1.8–4.0°C by 2100 relative to pre-industrial baselines. South Asian sub-regional projections derived from the same modeling ensemble suggest temperature increases of 0.5–1.2°C by 2020, 0.88–3.16°C by 2050, and 1.56–5.44°C by 2080, with realized outcomes conditional on future socioeconomic development pathways (IPCC, 2007b). Within the Indian agricultural context, downscaled projections for the Kharif season under the A2 scenario indicate maximum temperature increases of 2.54–3.75°C and minimum temperature rises of 2.34–3.25°C by 2080, with elevated warming concentrated in western and southern production zones (Bandyopadhyay et al., 2008; Aggarwal, 2008). Rabi season projections are similarly concerning, with maximum temperatures projected to exceed current norms by 2.75–3.5°C and minimum temperatures by 3.29–3.6°C across most of the study area, with the exception of the westernmost districts of Etah, Ghaziabad, and Aligarh where the warming signal is more spatially differentiated.

Aggarwal et al. (2010) conducted detailed scenario analyses for the Upper Ganga Basin and found that a package of improved cultivar selection, enhanced nitrogen management, and optimized irrigation scheduling could partially offset projected yield losses for rice under future climate conditions. That said, even with all identified adaptations deployed simultaneously, rice production in the Bulandshahr, Ghaziabad, and Meerut districts retains substantial residual vulnerability that available technologies cannot currently eliminate. The anticipated intensification of nitrogen losses through volatilization in warmer, wetter future climates will necessitate more precise and responsive fertilization strategies, both to prevent economic losses and to realize the yield-enhancing potential of elevated atmospheric CO_2. Lobell et al. (2008) pointed out that not all farming communities are equally positioned to implement adaptive measures; significant disparities in adaptive capacity will persist along lines of income, access to extension services, and institutional support. Effective policy responses must therefore be differentiated, targeting the specific constraints and opportunities of different farming contexts. The adaptation menu encompasses a wide range of interventions: substituting heat-tolerant or early-maturing varieties, adjusting sowing calendars to avoid critical thermal windows, fine-tuning crop nutrition and water delivery, and transitioning to soil management systems that build organic matter and buffer temperature extremes. Yohannes (2016) made the important observation that genuine progress on agricultural climate change requires simultaneous investment in both mitigation and adaptation—neither pathway alone is sufficient—and that conservation agriculture, precision resource management, and integrated agroforestry systems represent the most promising convergence of both goals.

Climate change interacts with food systems through a dual mechanism. Direct or primary effects arise from altered atmospheric chemistry and energy budgets, reshaping photosynthetic efficiency, crop water demand, and carbon allocation within plants. Indirect or secondary effects follow from the reconfiguration of agroclimatic resource availability triggered by primary changes, including northward and altitudinal shifts in cultivation suitability envelopes and modifications to pedological physical and chemical properties that govern root–soil interactions. The aggregate picture is one of mixed consequences: on the positive side, longer frost-free growing seasons, expanded viability of thermophilic crops, and improved biomass productivity from CO_2 enrichment offer genuine opportunity for some producers and regions. On the negative side, accelerated crop maturation under heat stress, deterioration of harvest quality in fruits and grains, escalating pressure from invasive weeds and insects, hastened decomposition of soil organic reserves, and worsening erosion driven by intensified rainfall events collectively erode the productive base of global agriculture (Kim et al., 2009). Because positive and negative impacts are not uniformly distributed geographically or socioeconomically, the net effect for any specific production system is inherently context-specific, and blanket assessments of climate change as uniformly harmful or beneficial are necessarily oversimplified. Building resilient food systems in this environment demands adaptive strategies that are simultaneously scientifically grounded, institutionally supported, and locally appropriate.

CONCLUSION

Climate-resilient agriculture (CRA) provides an organizing framework for embedding both mitigation and adaptation capacities into farming systems, enabling them to withstand, recover from, and transform in response to the mounting pressures of a warming and more variable climate. As thermal anomalies deepen and precipitation regimes become less predictable, concurrent declines in crop yields and accessible freshwater will impose growing hardships on farming communities worldwide, particularly those in tropical and subtropical regions already operating close to biophysical thresholds. Alterations in evapotranspiration dynamics driven by higher temperatures will diminish the efficiency with which crops convert applied water into harvestable biomass, placing a premium on soil conservation and precision irrigation management. Resilience in this context must be operationalized through tangible improvements in the stewardship of soil, water, biodiversity, and genetic resources, guided by best-available scientific evidence and supported by enabling institutional environments. Strategic investments in soil carbon enhancement, aquifer recharge, vegetative cover restoration, and systematic monitoring of GHG flux rates offer a coherent environmental pathway for climate-proofing agricultural landscapes. Evaluating these investments against the dual benchmarks of net carbon balance and global warming mitigation potential ensures that resources are allocated to interventions with the greatest leverage. Ultimately, decoupling agricultural and economic development from fossil fuel combustion—while treating soil carbon sequestration as a viable near-term mitigation bridge—offers the most scientifically defensible and practically achievable route to long-term climatic stability and food security.

REFERENCES

Aggarwal, P.K. and Mall, R.K. (2002). Climate change and rice yields in diverse agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. Climate Change, 52: 331–343. https://doi.org/10.1023/A:1013714506584

Aggarwal, P.K., Kumar Naresh, S. and Pathak, H. (2010). Impacts of Climate Change on Growth and Yield of Rice and Wheat in the Upper Ganga Basin. IARI, New Delhi.

Al-Kaisi, M.M., Yin, X. and Licht, M.A. (2005). Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agriculture, Ecosystems & Environment, 105: 635–647. https://doi.org/10.1016/j.agee.2004.08.002

Amdu, B. (2010). Analysis of Farmers' Perception and Adaptation to Climate Change and Variability: The Case of Choke Mountain, East Gojjam. MSc thesis, Addis Ababa University.

Bandyopadhyay, A., Bhadra, A., Raghuwanshi, N.S. and Singh, R. (2008). Estimation of monthly solar radiation from measured air temperature extremes. Agricultural and Forest Meteorology, 148(11): 1707–1718. https://doi.org/10.1016/j.agrformet.2008.06.002

Bhatia, A., Aggarwal, P.K., Jain, N. and Pathak, H. (2011). Greenhouse gas emission from rice-wheat growing areas in India: spatial analysis and upscaling. GHG Science & Technology, 2: 115–125. https://doi.org/10.1002/ghg.38

Bhattacharya, T., Chandran, P., Ray, S.K., Pal, K., Venugopalan, M.V., Mandal, C., Wani, S.P., Manna, M.C. and Ramesh, V. (2007). Carbon sequestration in red and black soils of semi-arid tropical India. Agropedology, 17: 26–33.

Derpsch, R., Franzluebbers, A.J., Duiker, S.W., Reicosky, D.C., Koeller, K., Sturny, W.G., Sá, J.C.M. and Weiss, K. (2014). Why do we need to standardize no-tillage research? Soil and Tillage Research, 137: 16–22. https://doi.org/10.1016/j.still.2013.10.002

Du, Z., Ren, T. and Hu, C. (2010). Tillage and residue removal effects on soil carbon and nitrogen storage in the North China Plain. Soil Science Society of America Journal, 74: 196–202. https://doi.org/10.2136/sssaj2009.0048

Gebreegziabher, Z., Mekonnen, A., Deribe, R., Abera, S. and Kassahun, M.M. (2014). Climate change can have significant negative impacts on Ethiopia's agriculture. EfD Discussion Paper 13-14.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L. and Lawrence, D. (2010). Food security: The challenge of feeding 9 billion people. Science, 327: 812–818. https://doi.org/10.1126/science.1185383

Grandy, A.S. and Robertson, G.P. (2006). Aggregation and organic matter protection following tillage of long-term no-till soils. Soil Science Society of America Journal, 70: 1462–1471. https://doi.org/10.2136/sssaj2005.0334

Greenhouse Gas Bulletin (2011). The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2011. World Meteorological Organization (WMO), Geneva, Switzerland.

Helgason, B.L., Gregorich, E.G., Janzen, H.H., Ellert, B.H., Lorenz, N. and Dick, R.P. (2014). Long-term microbial retention of residue is site-specific and depends on residue placement. Soil Biology and Biochemistry, 68: 231–240. https://doi.org/10.1016/j.soilbio.2013.10.002

Hocking, P.I. and Meyer, C.P. (1991). Carbon dioxide enrichment decreases critical nitrate and nitrogen concentrations in wheat. Journal of Plant Nutrition, 14: 571–584. https://doi.org/10.1080/01904169109364224

Ignaciuk, A. and Mason-D'Croz, D. (2014). Modelling Adaptation to Climate Change in Agriculture. OECD Food, Agriculture and Fisheries Papers, 70: 58. https://doi.org/10.1787/5jz2qck2b32d-en

IPCC (2007a). Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Working Group I, Fourth Assessment Report. Cambridge University Press, Cambridge.

IPCC (2007b). Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for Policymakers. Intergovernmental Panel on Climate Change.

IPCC (2007d). Mitigation of Climate Change. Working Group III, Fourth Assessment Report. Intergovernmental Panel on Climate Change.

Kim, C.G. et al. (2009). Impacts and Countermeasures of Climate Change in Korean Agriculture. Research Report No. 593, Korea Rural Economic Institute.

Kirschbaum, M.U.F. (2012). The temperature dependence of organic-matter decomposition: seasonal temperature variations turn a sharp short-term temperature response into a more moderate annually averaged response. Global Change Biology, 16: 2117–2129. https://doi.org/10.1111/j.1365-2486.2009.02093.x

Koning, N.B.J., van Ittersum, M.K., Becx, G.A., van Boekel, M.A.J.S. and Brandenburg, W.A. (2008). Long-term global availability of food: Continued abundance or new scarcity? Journal of Life Sciences, 55: 229–292. https://doi.org/10.1016/j.njas.2008.07.001

Lal, R. (1989). Conservation tillage for sustainable agriculture. Advances in Agronomy, 42: 85–197. https://doi.org/10.1016/S0065-2113(08)60524-6

Lal, R. (1994). Global overview of soil erosion. In: R.S. Baker (Ed.), Soil and Water Science: Key to Understanding Our Global Environment. Soil Science Society of America Special Publication No. 41, Madison, WI: 39–51.

Lal, R., Hasson, H.M. and Dumanski, J. (1999). Desertification control to sequester C and mitigate the greenhouse effect. In: Proc. St. Michael Conference, 3–5 December 1998, MD: 83–137.

Lal, R. (2007). Implications of climate change on agricultural productivity and food security in South Asia. Key Vulnerable Regions and Climate Change. Springer, Dordrecht.

Lal, R. (2011). In: D. Hillel and C. Rosenzweig (Eds.), Handbook of Climate Change and Agro-ecosystems: Impacts, Adaptation, and Mitigation, pp. 287–305. Imperial College Press.

Lal, R. (2013). The Nexus of Soil, Water and Waste. UNU-FLORES, Dresden, Germany.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D. and Falcon, W.P. et al. (2008). Prioritizing climate change adaptation needs for food security in 2030. Science, 319: 607–610. https://doi.org/10.1126/science.1152339

Lou, Y., Xu, M., Chen, X., He, X. and Zhao, K. (2012). Stratification of soil organic C, N and C:N ratio as affected by conservation tillage in two maize fields of China. Catena, 95: 124–130. https://doi.org/10.1016/j.catena.2012.03.001

Lovejoy, S., Schertzer, D. and Varon, D. (2012). Do GCMs predict the climate or macro-weather? Earth System Dynamics Discussions, 3: 1259–1286. https://doi.org/10.5194/esdd-3-1259-2012

Luo, Z., Wang, E. and Sun, O.J. (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agriculture, Ecosystems & Environment, 139: 224–231. https://doi.org/10.1016/j.agee.2010.08.006

Mishra, U., Ussiri, D.A.N. and Lal, R. (2010). Tillage effects on soil organic carbon storage and dynamics in Corn Belt of Ohio USA. Soil and Tillage Research, 107: 88–96. https://doi.org/10.1016/j.still.2010.02.005

Nagarajan, S., Jagadish, S.V.K., Prasad, A.S.H., Thomar, A.K., Anand, A., Pal, M. and Agarwal, P.K. (2010). Local climate affects growth, yield, and grain quality of aromatic and non-aromatic rice in northwestern India. Agriculture, Ecosystems & Environment, 138: 274–281. https://doi.org/10.1016/j.agee.2010.05.012

Naresh, R.K., Purushottam, Singh, S.P., Arya, V.K., Kumar, V. and Kumar, D. (2013). Enhancing Resource Productivity and Carbon-Based Sustainability Index of Cereal Based Cropping System under Conservation Agriculture in Western Uttar Pradesh. International Journal of Research in Biomedical Biotechnology, 3(1): 30–36.

Naresh, R.K., Gupta, R.K., Pal, G., Dhaliwal, S.S., Kumar, D., Kumar, V., Arya, V.K., Raju, Singh, S.P., Basharullah, Singh, O. and Kumar, P. (2015). Tillage Crop Establishment Strategies and Soil Fertility Management: Resource Use Efficiencies and Soil Carbon Sequestration in a Rice-Wheat Cropping System. Ecology, Environment & Conservation, 21: 121–128.

Parry, M., Rosenzweig, C. and Livermore, M. (2005). Climate change, global food supply and risk of hunger. Philosophical Transactions of the Royal Society London B, 360: 2125–2138. https://doi.org/10.1098/rstb.2005.1751

Paustian, K. et al. (1997). Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management, 13: 230–244. https://doi.org/10.1111/j.1475-2743.1997.tb00594.x

Pimentel, D. (2011). Food for thought: A review of the role of energy in current and evolving agriculture. Critical Reviews in Plant Sciences, 30: 35–44. https://doi.org/10.1080/07352689.2011.554316

Powlson, D.S., Stirling, C.M., Jat, M.L., Gerard, B.G., Palm, C.A., Sanchez, P.A. and Cassman, K.G. (2014). Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change, 4: 678–683. https://doi.org/10.1038/nclimate2292

Samra, J.S. and Singh, G. (2004). Heat Wave of March 2004: Impact on Agriculture. Indian Council of Agricultural Research, 32 pp.

Smith, P. et al. (2008). Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B, 363: 789–813. https://doi.org/10.1098/rstb.2007.2184

Smith, P., Haberl, H., Popp, A., Erb, K.H. and Lauk, C. (2013). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? Global Change Biology, 19: 2285–2302. https://doi.

org/10.1111/gcb.12160

Song, M.W., Li, A.Z., Cai, L.Q. and Zhang, R.S. (2011). Effects of different tillage methods on soil organic carbon pool. Journal of Agro-Environment Science, 27(2): 622–626.

Swaminathan, M.S. (2012). Combating hunger. Science, 338: 1009. https://doi.org/10.1126/science.1232350

Swinnen, J. and Squicciarini, P. (2012). Mixed messages on prices and food security. Science, 335: 405–406. https://doi.org/10.1126/science.1210806

Syswerda, S.P., Corbin, A.T., Mokma, D.L., Kravchenko, A.N. and Robertson, G.P. (2011). Agricultural Management and Soil Carbon Storage in Surface vs. Deep Layers. Soil Science Society of America Journal, 75(1): 92. https://doi.org/10.2136/sssaj2009.0414

Thornton, P.K. and Lipper, L. (2013). How Does Climate Change Alter Agricultural Strategies to Support Food Security? IFPRI Discussion Paper 01340.

Virto, I., Burlot, P. and Chenu, C. (2012). Carbon input differences as the main factor explaining the variability in soil organic C storage in no-tilled compared to inversion tilled agrosystems. Biogeochemistry, 108: 17–26. https://doi.org/10.1007/s10533-011-9639-5

Yohannes, H. (2016). A Review on Relationship between Climate Change and Agriculture. Journal of Earth Science and Climatic Change, 7(2). https://doi.org/10.4172/2157-7617.1000335

Zhang, J. (2011). China's success in increasing per capita food production. Journal of Experimental Botany, 62: 3707–3711. https://doi.org/10.1093/jxb/err132