Agricultural Waste and Rising CO_2

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Agriculture and climate change

Agriculture both contributes to, and is affected by climate change. The EU needs to reduce its greenhouse-gas emissions from agriculture and adapt its food-production system to cope. But, climate change is only one of many pressures on agriculture, The European Environment Agency explains further…

Faced with growing global demand and competition for resources, the EU's food production and consumption need to be seen in a broader context, linking agriculture, energy, and food security.

Food is a basic human need, and a healthy diet is a key component of our health and wellbeing. A complex and increasingly globalised system of production and delivery has developed over time to meet our need for food and for different flavours. In today's world, a fish caught in the Atlantic might be served within days in a restaurant in Prague alongside rice imported from India. Similarly, European food products are sold and consumed in the rest of the world.

Agriculture contributes to climate change
Before reaching our plates, our food is produced, stored, processed, packaged, transported, prepared, and served. At every stage, food provisioning releases greenhouse gases into the atmosphere. Farming in particular releases significant amounts of methane and nitrous oxide, 2 powerful greenhouse gases. Methane is produced by livestock during digestion due to enteric fermentation and is released via belches. It can also escape from stored manure and organic waste in landfills. Nitrous oxide emissions are an indirect product of organic and mineral nitrogen fertilisers.

Agriculture accounted for 10% of the EU's total

greenhouse gas emissions in 2012. A significant decline in livestock numbers, more efficient application of fertilisers, and better manure management reduced the EU's emissions from agriculture by 24% between 1990 and 2012.

However, agriculture in the rest of the world is moving in the opposite direction. Between 2001 and 2011, global emissions from crop and livestock production grew by 14%. The increase occurred mainly in developing countries, due to a rise in total agricultural output. This was driven by increased global food demand and changes in food-consumption patterns due to rising incomes in some developing countries. Emissions from enteric fermentation increased 11% in this period and accounted for 39% of the sector's total greenhouse-gas outputs in 2011.

Given the central importance of food in our lives, a further reduction of greenhouse gas emissions from agriculture remains quite challenging. Nevertheless, there is still potential to further reduce the greenhouse gas emissions linked to food production in the EU. A better integration of innovative techniques into production methods, such as capturing methane from manure, more efficient use of fertilisers, and greater efficiency in meat and dairy production (i.e. reducing emissions per unit of food produced) can help.

In addition to such efficiency gains, changes on the consumption side can help to further lower greenhouse gas emissions linked to food. In general, meat and dairy products have the highest global footprint of carbon, raw materials, and water per kilogramme of any food. In terms of greenhouse gas emissions, livestock and fodder production each generate more than 3 billion tonnes of CO_2 equivalent. Post-farm transport and processing account for only a tiny fraction of the emissions linked to food. By reducing food waste and our consumption of emission-intensive food products, we can contribute to cutting the greenhouse-gas emissions of agriculture.

Climate change affects agriculture

Crops need suitable soil, water, sunlight, and heat to grow. Warmer air temperatures have already affected the length of the growing season over large parts of Europe. Flowering and harvest dates for cereal crops are now happening several days earlier in the season. These changes are expected to continue in many regions.

In general, in northern Europe agricultural productivity might increase due to a longer growing season and an extension of the frost-free period. Warmer temperatures and longer growing seasons might also allow new crops to be cultivated. In southern Europe, however, extreme heat events and reductions in precipitation and water availability are expected to hamper crop productivity. Crop yields are also expected to vary increasingly from year to year due to extreme weather events and other factors such as pests and diseases.

In parts of the Mediterranean area, due to extreme heat and water stress in summer months, some summer crops might be cultivated in winter instead. Other areas, such as western France and south-eastern Europe, are expected to face yield reductions due to hot and dry summers without the possibility of shifting crop production into winter.

Changes in temperatures and growing seasons might also affect the proliferation and the spreading of some species, such as insects, invasive weeds, or diseases, all of which might in turn affect crop yields. A part of the potential yield losses can be offset by farming practices, such as rotating crops to match water availability, adjusting sowing dates to temperature and rainfall patterns, and using crop varieties better suited to new conditions (e.g. heat- and drought-resilient crops).

Land-based food sources are not the only food sources affected by climate change. The distribution of some fish stocks has already changed in the Northeast Atlantic, affecting the communities relying on these stocks throughout the supply chain. Along with increased maritime shipping, warmer water temperatures can also help facilitate the establishment of invasive marine species, causing local fish stocks to collapse.

Some EU funds, including the European Agricultural Fund for Rural Development, Common Agricultural Policy (CAP), and loans from the European Investment Bank, are available to help farmers and fishing communities to adapt to climate change. There are also other funds under the CAP aimed at helping to reduce greenhouse-gas emissions from agricultural activities.

Global market, global demand, global warming

In line with projected population growth and changes in dietary habits in favour of higher meat consumption, the global demand for food is expected to grow by up to 70% in the coming decades. Agriculture is already one of the economic sectors with the largest environmental impact. This substantial increase in demand will unsurprisingly create additional pressures. How can we meet this increasing global demand while at the same time reducing the impacts of European food production and consumption on the environment?

Reducing the amount of food produced is not a viable solution. The EU is one of the world's largest food producers [1], producing around one eighth of the global cereal output, two thirds of the world's wine, half of its sugar beet, and three quarters of its olive oil. Any reduction in key staples is likely to jeopardise food security in the EU and in the world, and increase global food prices. This would make it harder for many groups around the world to access affordable and nutritious food.

Producing more food out of the land that is already used for agriculture often requires heavier use of nitrogen-based fertilisers, which in turn release nitrous oxide emissions and contribute to climate change. Intensive agriculture and fertiliser use also release nitrates to the soil and to water bodies. Although not directly linked to climate change, high concentrations of nutrients (especially phosphates and nitrates) in water bodies cause eutrophication. Eutrophication promotes algae growth and depletes oxygen in the water, which in turn has severe impacts on aquatic life and water quality.

Whether in Europe or the rest of the world, meeting the growing demand for food by using more land would have serious impacts on the environment and the climate. The area's most suitable to agriculture in Europe are already cultivated to a large extent. Land, especially fertile agricultural land, is a limited resource in Europe and across the world.

Converting forest areas into agricultural land is also not a solution as this process is a source of greenhouse-gas emissions. Similar to many other land-use changes, deforestation (currently occurring mainly outside the European Union) also puts biodiversity at risk, further undermining nature's ability to cope with climate change impacts (such as absorbing heavy rainfall).

Competing demands

It is clear that the world will need to produce more food and that key resources are limited. Agriculture has high impacts on the environment and the climate. Moreover, climate change affects – and will continue to affect – how much food can be produced and where.

Who gets to produce what and where, is a socio-political question and is likely to become more controversial in the future. The global competition for these essential resources, especially with the pending impacts of climate change, is driving developed countries to purchase large patches of agricultural land in less-developed countries. Such land purchases and climate change impacts raise questions about food security in developing countries in particular. Food security is not only a matter of producing sufficient quantities of food, but also of having access to food of sufficient nutritional value.

This complex problem requires a coherent and integrated policy approach to climate change, energy, and food security. Faced with climate change and competition for scarce resources, the entire food system will need to transform itself and be much more resource efficient while continuously reducing its environmental impacts, including its greenhouse-gas emissions. We need to increase yields while reducing our dependence on agrochemicals, to reduce food waste, and to reduce our consumption of resource-intensive and greenhouse gas-intensive foods such as meat.

In doing this, we must also remember that farmers can play a key role in maintaining and managing Europe's biodiversity. They are also a critical component of the rural economy. Therefore, policy measures to tackle this highly complex problem of food and the environment should take into consideration agriculture's impacts on the environment and its socio-economic importance for many communities.

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1 http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_production_-_crops

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Currently, there are many uncertainties concerning agriculture's role in global environmental change including the effects of rising atmospheric CO_2 concentration. A viable and stable world food supply depends on productive agricultural systems, but environmental concerns within agriculture have to be address if these systems are to be sustainable. Agriculture's role in environmental issues are both large and complex, often contributing to both problems and solutions to the global environment. For example, agricultural practices have the potential to increase soil C storage which can positively influence soil quality and help mitigate the rise in atmospheric CO_2, the leading green house gas (GHG) attributable to potential climate change. At the same time, agriculture is also a major player in the contribution of atmospheric GHG due to the contribution from energy consumption and fertiliser practices. Other environmental concerns such as soil erosion impact on crop productivity and nutrient imbalances in our water systems are also critical concerns that must be addressed to maintain a stable world food supply for the world population while protection the environment.

The USDA National Soil Dynamics Laboratory (NSDL) has been conducting research to improve agriculture sustainability for many years. Originally founded as the Farm Tillage Machinery Laboratory in 1933 on the Auburn University campus in Auburn, Alabama, USA, it was initially charged with researching machines, tractor tire design, and tillage practices (and associated traction) used in cotton production. The lab was instrumental in the development of engineering principles for modern agricultural equipment design. Currently, NSDL's mission is to develop tools, practices, and products to better manage soil for environmentally sustainable and economically profitable agricultural production systems. The research conducted at the laboratory centers around agriculture production

systems found in the Southeastern USA, but the implications of findings clearly have a more global prospective. This is especially true for the research efforts that focus on understanding how agriculture influences global change.

The NSDL research programs focus on solving agricultural problems in three major areas: (1) conservation systems; (2) organic waste management; and (3) global change. Specific objectives include developing conservation systems that reduce drought risk and sequester soil carbon, developing environmentally sound waste management systems, and determining the effects of atmospheric CO_2 levels on above- and below-ground processes that affect crop production, soil carbon storage, and trace gas emissions.

Historically, like in other industries, equipment development resulted in immense changes in agriculture across the world. Vast amounts of native lands were brought under cultivation, especially in the USA. Tillage practices used to prepare seed beds, control weeds, and incorporate manures and other amendments destroyed soil organic matter and soil structure. As a result, in addition to leaving the soil relatively infertile, highly eroded, and easily compacted by rainfall and machine traffic, huge amounts of C were released to the atmosphere. The result of this historical organic matter destruction was that the biosphere acted as a net C source. Due to the conversion of agricultural land back to natural or perennial vegetation, the biosphere now acts as a C sink. But, a stable world food supply also depends on a productive agricultural systems for its cultivated crops. Improved soil management of land under cultivation has enormous potential to increase soil C storage (Potter et al. 1997; Potter et al. 1998). Given that soil structure is dependent on tillage method and frequency, conversion to conservation tillage systems can enhance soil C sequestration through increased production and decreased incorporation of crop residues (Potter et al. 1997; Potter et al. 1998). Increased C storage is not only beneficial to soil health, it also has the potential to help mitigate the rise in atmospheric CO_2. Follett (1993) suggested that agriculture has a great opportunity to help mitigate potential climate change using improved management to 'stash' CO_2 as C in soil and vegetation. For example, Prior et al. (2005) reported that four years of conservation management increased soil C by 67% in the upper soil profile, compared with conventional management. Since agriculture accounts for 10% of all land on earth (Schlesinger 1991), it plays a pivotal role in global C sequestration (Cole et al. 1993; Kern & Johnson 1993; Leavitt et al. 1994; Lal et al. 1998). And, unlike natural vegetation where soil management is unchanging, it is the one part of the land on earth where management decisions can impact the global environment. Research at NSDL develops conservation systems that improve soil quality, conserve natural resources, and increase production efficiency by considering input costs and profitability.

Increasing atmospheric carbon dioxide (CO_2) is the primary factor driving climate change. Understanding how elevated CO_2 impacts agricultural systems and investigating how current management practices affect soil carbon (C) sequestration is crucial for developing future mitigation strategies in agriculture. Research at NSDL is also examining the effects of atmospheric CO_2 on both biomass production and soil C sequestration. The rise in atmospheric CO_2 has the potential to alter many aspects of the global environment, including the potential to increase soil C sequestration (Wood et al. 1994; Prior et al. 1997b, 2008; Torbert et al. 1997, 2000).

In addition to increased biomass, elevated CO_2 can alter plant tissue quality. Reduction in tissue nutrient concentration (especially N) has been commonly reported (Norby et al. 2001), which generally results in increased C:N ratio under elevated CO_2 (Mellilo 1983; Cotrufo et al. 1998; Torbert et al. 2000). These changes can impact forage quality (Runion et al. 2009b), decomposition, and C sequestration (Goudriaan & de Ruiter 1983; Torbert et al. 2000; Prior et al., 2004b, 2005, 2006). Other CO_2-induced changes include higher carbohydrate concentration (Runion et al. 1999a; Booker et al. 2000), changes in leaf morphology (Thomas & Harvey 1983) and epicuticular waxes (Graham & Nobel 1996; Prior et al. 1997a), changes in lignin (Runion et al. 1999a; Norby et al. 2001), and increased defense compounds such as tannins and phenolics (Mellilo 1983; Pritchard et al. 1997; Runion et al. 1999a; Booker et al. 2000). Consequently, soil C dynamics can potentially be altered due to changes in plant biomass, physiology, and phytochemistry from increasing levels of CO_2 to the atmospheric. As a results, elevated CO_2 may also alter C storage via changes in soil structure (Schlesinger 1991; Elliott et al. 1993). Research at the NSDL has found that, in addition to increasing soil C, elevated CO_2 decreased soil bulk density and increased soil aggregate stability and saturated hydraulic conductivity (Prior et al. 2004a) as well as providing for a more favorable environment for soil flora and fauna (Runion et al. 2004). Knowledge of how elevated CO_2 alters C dynamics is important to future soil management practices; this will be critical for increasing soil C storage in agricultural systems which will assist in mitigating aspects of climate change.

In addition to elevated CO_2 impacting plant biomass production and quaility, terrestrial ecosystems also return CO_2 to the atmosphere via both autotrophic (plant) and heterotrophic (microbial) respiration. The balance between input and efflux will determine the final C sequestration potential of any soil system (Polglase & Wang 1992). Soil respiration is a significant source of CO_2 flux from terrestrial ecosystems (Schlesinger & Andrews 2000) and small shifts can seriously affect atmospheric CO_2 concentration and its potential impacts on climate (Rustad et al. 2000).

In addition to CO_2, methane (CH_4) and nitrous oxide (N_2O) are important greenhouse gases (GHGs) contributing to global climate change, with each having a different global warming potential (GWP). The GWP is defined as the ratio of radiative forcing from 1 kg of gas to 1 kg of CO_2 over a period of time with the GWP of CO_2 being 1. It has been reported that the GWP of CH_4 is 21 and N_2O is 310 (Lal et al. 1998). Due to the large impact of these gasses relative to CO_2, the contribution to potential global change is very important. Animal and crop production systems accounts for as much as 70% of annual global anthropogenic N_2O emissions and about 33% of global CH_4 emissions, with estimates indicating that they are likely to increase (Mosier et al. 1998a; Mosier 2001).

The NSDL has a multi-disciplinary research team investigating ways that agriculture can help reduce greenhouse gas (GHG) loss through improved practices and fertiliser use in cropping and horticulture systems. This work is evaluating new, innovative application techniques that reduce GHG emissions, including determining fertiliser N use efficiency and fate of fertiliser N in these systems as well as changes in C and N cycling processes. This work showed that soil C storage is sensitive to soil N dynamics and that the decomposition of plant material grown under elevated CO_2 depends on crop species and indigenous soil properties (Torbert et al. 2000). It has also lead to research on the use of microbial inoculations to reduce nitrous oxide emissions (Calvo et al. 2013). In a long-term study at the NSDL, it was found that soil CO_2 efflux was increased by both elevated CO_2 and conservation management (Runion et al. 2009a); despite greater efflux, these treatments still resulted in increased soil C due to greater biomass inputs (Prior et al. 2005). Further, we found that efflux of both N_2O and CH_4 were low and rarely exhibited differences due to either CO_2 or tillage treatment (Smith et al. 2010). These results suggest that adoption of conservation management represents a viable means of reducing agriculture's potential contribution to global climate change.

In addition to tillage, fertiliser (including manure) management can also influence GHG emissions. For instance, as N inputs increase N_2O emissions also generally increase. However, the N source used, as well as its soil placement, can greatly impact N_2O loss (Mosier et al. 1982; Eichner 1990). Kaiser and Ruser (2000) reported that soil N_2O emissions were higher in organically fertilised plots. Li et al. (2005) found that reduced tillage enhanced crop residue retention, and farmyard manure application increased C sequestration while increasing N_2O emissions, with little impact on CH_4 emissions. Smith et al. (2012) found that conventional tillage practices and banding of fertiliser (both inorganic and organic) resulted in greater CO_2 and N_2O emissions compared to surface applications of fertiliser, with poultry litter being higher than urea-ammonium nitrate. However, other research reported that subsurface band application of poultry litter reduced N_2O emissions compared to surface or soil incorporation (Nyakatawa et al. 2011), while tillage increased CO_2 emissions from both poultry litter and ammonium nitrate (Nyakatawa et al. 2012).

Virtually no work on GHG emissions has occurred in specialty crop industries such as ornamental horticulture. Earlier work from NSDL examined differing container sizes to establish a baseline between potting media volume and GHG emissions. The CO_2 and N_2O emissions were found to be highest in the largest containers with a positive relationship between container size and flux, but CH_4 emissions were consistently low and unaffected by container size (Marble et al. 2012a). In other work, common fertiliser

placement methods (dibble, incorporated, and topdressed) were evaluated and found that CO_2 emissions were lower with dibbled and N_2O emissions were highest with incorporation, while CH_4 was low and unaffected by placement method (Marble et al. 2012b). Results from these studies begin to address uncertainties regarding the environmental impact of the horticulture industry on climate change, but much more work is required to accurately develop baseline GHG emissions from container production systems to develop future mitigation strategies.

Recent interest in maintaining soil, water, and air quality for a sustainable environment has sparked concerns regarding manure management, primarily centered on improper handling of manure (Harmel et al. 2004). Nutrient loss from improper manure utilisation could potentially contribute to increased hypoxia, eutrophication of surface waters, human health problems, and GHG emissions. Specifically, N and P in manure have been identified as the most critical nutrients posing an environmental threat. In the southeastern U.S. where the poultry industry is steadily increasing, management and disposal of poultry waste is fast becoming a top priority. Historically, the most common disposal practice of poultry litter has been land application to pastures and it is likely this practice will continue to increase as the poultry industry continues to grow. Thus, it is imperative that practices be developed for use of poultry litter which prevent environmental degradation while also providing stable or increased crop yields. Consequently, research is needed to develop new technologies and better manure management practices that can be implemented to increase nutrient retention in soil.

A major focus of research at the NSDL is to evaluate the use of alternative fertiliser sources, such as poultry litter (a poultry manure and bedding material mix), compared to commercial fertiliser in tillage systems designed to enhance soil organic matter accumulation, crop productivity, and grower profitability. Application of poultry litter to soil can improve soil conditions and provide nutrients needed for plant production. Furthermore, using poultry litter in conservation agricultural systems could sequester atmospheric C in soil. Research has shown that the use of poultry litter in long term research plots resulted in increased soil C levels and thus higher atmospheric C sequestration (Watts et al 2010; Watts et al 2011). However, best management practices must be developed for poultry litter application that maximises nutrient uptake and minimises GHG loss.

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