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# Farming pollution

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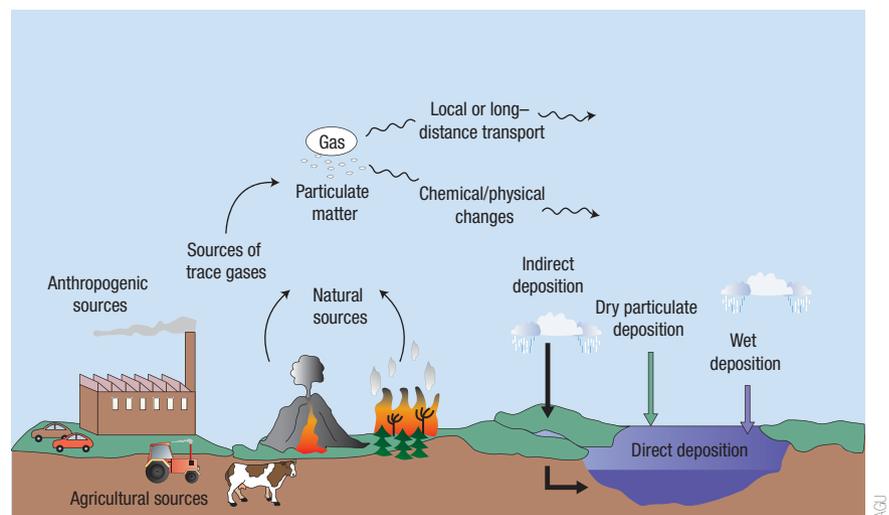
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Modern farms produce particulate matter and gases that affect the environment and human health and add to rising atmospheric greenhouse-gas levels. European policymakers have made progress in controlling these emissions, but US regulations remain inadequate.

The demand for food, feed, fibre and fuel<sup>1</sup> from the Earth's growing human population is expanding. Increasing consumption of animal protein, as opposed to vegetable protein, results in reduced production efficiency of agricultural land per kilogram of food, by a factor of four to six<sup>2</sup>. Because the soils that are suitable for agriculture in the world can expand only marginally, current production must be intensified to fulfil growing needs. Farmers in the United States, Europe and Asia have responded by increasing the intensity of both crop and animal agricultural operations, capitalizing on the greater availability of inexpensive nitrogen fertilizer and innovations in mechanization, pesticides and veterinary medicine. Fertilizer production, the replacement of human farm workers with mechanization, and the transportation of farm products to increasingly distant markets have been facilitated by the abundance of relatively cheap fossil fuels. In addition, cultivation of marginal land and improvements in production efficiency [Author: 'Improvements in production efficiency' doesn't seem like an additional thing. Don't all the things you've already mentioned in the previous couple of sentences improve production efficiency?] have added to global yields over the past 50 years or so.

Agricultural intensification comes with a downside: recognized impacts on air, water and soil have increased over the past decades. In particular, concerns regarding air emissions from agricultural operations and their impacts on human health, climate, environment and ecosystems have arisen. The challenge for both scientists and policymakers, therefore, is to determine how to increase agricultural



**Figure 1** Atmospheric emissions, transport, transformation, and deposition of trace gases. Agricultural emissions of gases and particulate matter meet other anthropogenic and natural emissions in the atmosphere where they can be transported over large distances and transformed in chemical reactions. They enter the Earth's water cycle through wet deposition, dry particulate deposition or indirect deposition (that is, deposition to land, followed by runoff or seepage through groundwater to a body of surface water). Adapted from ref. 1. [Author: OK? The figure needed a little more description.]

production but limit or prevent such damaging emissions.

## AGRICULTURAL EMISSIONS

A number of nitrogen-, sulphur- and carbon-containing compounds, including ammonia, nitrogen oxides, nitrous oxide, hydrogen sulphide, methane, carbon dioxide and volatile organic compounds are emitted through agricultural operations<sup>1-4</sup>. Many of these compounds undergo atmospheric reactions and are transported by winds before they return to the surface through precipitation and dry deposition.

Alternatively, in the case of greenhouse gases, they can accumulate in the Earth's atmosphere (Fig. 1).

Some agricultural air pollutants (for example, ammonia, hydrogen sulphide, toxic organic compounds, pesticides, insecticides, and particulate matter) can affect human health<sup>5-8</sup> as well as the comfort, health and production efficiency of animals. Hydrogen sulphide, a pungent gas produced by the anaerobic decomposition of manure can cause unconsciousness or death in humans on brief exposure to high concentrations of the gas<sup>9</sup>. Ecosystems can undergo



**Figure 2** Commercial confined animal feeding operations adjacent to agricultural crop land in the US and Europe. **a.** Commercial hog production in North Carolina, United States typically uses lagoon and spray technology for manure management. **b.** Overview of a biomass digestion installation in the Netherlands. Here, commercial cattle producers typically use low-emission housing systems and manure digestion facilities.

eutrophication and acidification as a result of the deposition of reactive nitrogen. In addition, chemical reactions of nitrogen oxides and volatile organic compounds emitted by agricultural operations can lead to the formation of tropospheric ozone, which may adversely impact plant growth in natural and agricultural systems and affect human health and climate.

Nitrogen emissions in various forms (nitrogen oxides ( $\text{NO}_x$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), ammonia ( $\text{NH}_3$ ), and organic nitrogen ( $\text{N}_{\text{org}}$ )) are one of the two main classes of pollutants that are emitted by modern agriculture. Although produced naturally in soils through microbial denitrification and nitrification processes, nitrous oxide — a greenhouse gas that is much more effective than carbon dioxide in trapping heat in the atmosphere — arises from animal production in large quantities, depending on the nitrogen input and management of manure<sup>10</sup>. In order to increase yields, agricultural operations often directly add reactive nitrogen to soils, either through the application of fertilizer or livestock manure to fields, or by growing nitrogen-fixing crops. These measures increase nitrous oxide emissions via microbial reactions, especially enhanced nitrification<sup>11</sup>. Indirect additions of reactive nitrogen exacerbate the problem, for example nitrogen from fertilizer or manure volatilizes as ammonia and oxides of nitrogen, which are redeposited in downwind regions as ammonia, particulate ammonium, nitric acid and nitrate<sup>12</sup>.

A second important pollutant from farming is ambient primary particulate matter, emitted directly from animal housing systems and through practices such as cultivation, harvesting, application of fertilizer and livestock waste to fields, and agricultural field burning. On top of the primary particle output, emissions

of precursor gases (including sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia) lead to the generation of secondary aerosol particles.

Agriculture is a significant source of ammonia and particulate matter: approximately 90% of ammonia emissions in the United States and in many European countries result from animal and crop agriculture<sup>12</sup>. In reactions with sulphuric acid, nitric acid, hydrochloric acid and water these emissions contribute to the formation of ammonium salts, which make up about 20 to 80% of atmospheric fine particulate matter (that is, particles with an aerodynamic diameter of less than 2.5 micrometres)<sup>13,14</sup>. These small particles are transported by winds easily, deposited rather slowly, and therefore have a longer mean residence time in the atmosphere. Aerosols consisting of fine particulate matter affect the Earth's radiation budget and climate through their effects on cloud formation and precipitation<sup>8</sup>. Moreover, fine particulate matter has been associated with adverse health effects, suggesting that reductions in particulate matter and precursor gases will have measurable health benefits<sup>8</sup>.

In addition to direct emissions, a number of ancillary emissions are also related to agricultural production. These include increased emissions of pollutants from the transportation of agricultural goods, emissions from the fertilizer and packing industries, emissions from various forms of agricultural wastes, and pollutant and greenhouse gas emissions associated with the processing of animal feed.

Current scientific understanding is not sufficient to quantify all agricultural emissions and their effects, or to distinguish the roles of various crops, animal housing systems and indirect emissions. However, a growing body of evidence suggests

that agricultural emissions contribute to environmental and human health problems<sup>15</sup>. Therefore, research and management must be focused on increasing production while limiting or preventing air emissions.

## THE CASE FOR REGULATION

In Europe, effect-based approaches are used to support policy development and regulation of sources. Since the 1970s, several protocols adopted under the Convention on Long Range Transboundary Air Pollution (CLRTAP) issued by the UN Economic Commission for Europe have been developed to protect human health, the environment and ecosystems. They are based on scientific and monitoring programmes as well as integrated assessment modelling<sup>16</sup>. Large scientific programs investigating cause-effect relationships are supported by an extensive monitoring program (the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe) and integrated assessment modelling. The protocols limit the emissions of sulphur oxides, nitrogen oxides and persistent organic pollutants. In 1999 the Gothenburg Protocol was signed by 49 countries of the Northern Hemisphere and has since been successful in implementing the concept of critical loads for ecosystem protection and as a basis for decreasing agricultural emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia (amongst others). Through the actions in the Convention, emissions of sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds were reduced by 65%, 31%, 22% and 40% respectively between 1999 and 2004.

The Netherlands was the first country to set targets for regulating ammonia emissions at the end of the 1980s. Livestock production there must meet stringent ammonia emission targets to reduce atmospheric nitrogen deposition. The introduction of a bookkeeping system in 1998 led to a decrease in fertilizer use. As a result of this strategy, along with regulations to incorporate manure into the soil, modifications to animal housing systems (Fig. 2), and the introduction of water scrubbers in forced ventilation systems, ammonia emissions have decreased by more than 40% since 1995 and particulate emissions have decreased by 43%<sup>3</sup>.

In contrast to Europe<sup>17</sup> (which has 12 air quality standards and objectives: ozone, sulphur dioxide, nitrogen dioxide, lead, carbon monoxide, particulate matter ( $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ ), benzene, arsenic,

cadmium, nickel, and polycyclic aromatic hydrocarbons), US National Ambient Air Quality Standards for national air quality regulations are based on only seven criteria pollutants<sup>18</sup>: ozone, sulphur dioxide, nitrogen dioxide, lead, carbon monoxide, and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>) [Author: OK? As you counted PM<sub>2.5</sub> and PM<sub>10</sub> separately for Europe, shouldn't the same be applied to the US? That makes it seven pollutants.]. US agriculture has adopted modern technologies to maximize productivity without being subjected to the level of environmental regulation that must be obeyed by other modern US industries and by European farmers.

Ammonia emissions from agriculture are particularly problematic in the United States because the US Environmental Protection Agency (EPA) has not applied federal regulations to their control. For example, the US Clean Air Act has been used by the US EPA only to control extreme cases of imminently dangerous ammonia releases. Other compounds, such as hydrogen sulphide, are subject only to regulation at the state level (for example, in California). The enforcement of reporting requirements for releases of ammonia and hydrogen sulphide from animal housings has been controversial, as evidenced by a number of legislative attempts to exempt manure management from the relevant regulations. Some states are implementing mitigation measures for ammonia or hydrogen sulphide; however, at the national level,

both the US Department of Agriculture and the US EPA have expressed a preference for voluntary ammonia mitigation strategies, in line with the wishes of the US farmers.

US policymakers should follow the lead of their counterparts in western Europe. US emissions reduction policy is not limited by technology — effective techniques are already available and include, for example, the reduction of ammonia from swine manure through treatment plants with solid–liquid separation<sup>19,20</sup>, emission-free housing systems, nutrient management systems and precision fertilization. The use of these and other technologies to increase on-farm nutrient efficiencies could be encouraged with policy instruments such as tax incentives, financial grants, targets for nitrogen losses, carbon credits and a cap-and-trade system for greenhouse-gas emissions.

Gaps remain in the scientific understanding of agricultural emissions. Nevertheless, the potential health and environmental risks of intensified modern agriculture require that we develop emission abatement policies based on the best available science — and that we do so without further delay by extending regulations in Europe, introducing them in the US and stimulating their consideration in Asia. Farms need not be a source of air quality problems. They can and should be a source of solutions.

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