Agricultural Pollution
Fertilizer

WORLD BANK GROUP

Figure 1. Green Tides along the Coast of Qingdao, China

Source: © STR / AFP / Getty Images (left). © Dongyan Liu (right).
Note: Since 2007, vast algal blooms (covering nearly 29,000 km2 in 2013) have blanketed the Yellow Sea, bringing annual green tides to China's coast (left). A green tide is seen engulfing an Olympic stadium in 2008 (right).

Why Care about Fertilizer Pollution?

Over the past 50–60 years, unbridled growth in global fertilizer use to boost and maintain crop yields has polluted natural and agricultural systems, leading to a range of harmful outcomes. The abundant and inefficient application of fertilizer is a leading cause of water pollution, as well as a contributor to greenhouse gases and the deterioration of air and soil quality. This, in turn, has adverse consequences for public health, the climate, wildlife, and business—including tourism, agribusiness, commercial fishing, and farming. Although its use, in combination with other Green Revolution technologies, is credited for feeding the world and averting a more dramatic expansion of agriculture into natural landscapes, today's fertilizer use is considered to be pushing the planet's biogeochemical boundaries.

Some nutrient losses are to be expected as the biologically available or "reactive" form of nitrogen in fertilizer is particularly mobile, while fertilizer's phosphorus and potassium minerals travel with the soil particles to which they bind (see Box 1). Yet it is common for some 50–75 percent of fertilizer, that is, the vast majority of it, to volatilize, gasify, leach into the soil, or wash away unused by plants after it is applied. Fertilizer is by far the largest anthropogenic source of reactive nitrogen in which the world is awash; and the same can be said of phosophorus, a mined, nonrenewable resource that is both indispensable for food production and thought to be swiftly approaching peak supply (as early as 2035).

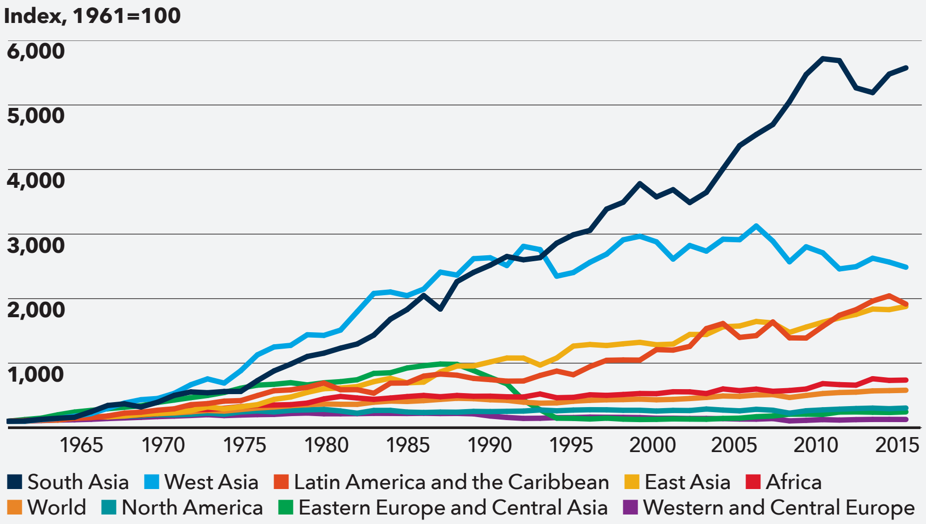
Nature and Magnitude of the Problem

Several practices lie at the heart of this global problem. Fertilizer is often applied in significant excess of what plants can use, and in some instances, the poor timing of fertilizer applications increases the amount that is washed away by irrigation or rainwater. Fertilizer use and losses are notably concentrated in areas where intensive irrigation is practiced. Another problematic practice in certain contexts is the use of the wrong fertilizer blends relative to plant requirements, because the mismatch leaves more fertilizer unmetabolized and free to escape. This has both environmental and economic costs.

In 2015, the world used more than 180 million metric tons of fertilizer, or about six times more than it did 55 years prior (see Figure 2). In developing countries, fertilizer consumption increased by a factor of 34. This growth pattern generally tracks the intensification of agriculture and rise in crop output witnessed over this period, over which global cereal output, for instance, more than tripled. Much of the increase in fertilizer use occurred first in today's high-income countries, and later in parts of South and East Asia, and South America. Today, China is the largest consumer of fertilizer in absolute terms, followed by India, the United States, the European Union,

This note was written by Emilie Cassou. Full references and acknowledgments are available online.

Figure 2: Fertilizer Consumption by Region, 1961–2015



Source: Based on International Fertilizer Industry Association (IFA) data.
Note: Accounts for nitrogen, phosphate, and potash nutrients.

Box 1: What is Fertilizer?

Fertilizers enhance plant growth by providing them nutrients, and in some cases, by improving soil properties (for example, water retention, aeration). The three primary components of fertilizer are the macronutrients nitrogen (N, which promotes leaf growth), phosphorus (P, which promotes root, flower, seed, fruit development), and potassium (K, which aids stem growth, water movement, flowering, and fruiting). Three secondary macronutrients commonly found in fertilizer are calcium (Ca), magnesium (Mg), and sulphur (S). Fertilizer also provides a variety of micronutrients, including copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn), boron (B), and others.

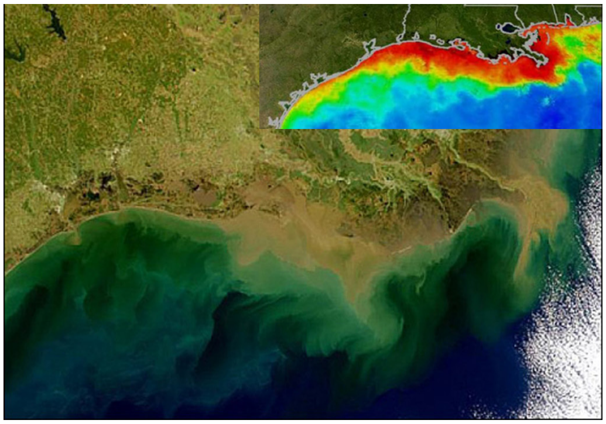
Brazil, and Indonesia. When it comes to per hectare intensity, Gulf countries, New Zealand, Egypt, Ireland, and China have been among the largest users over the past decade. Growth in global fertilizer use shows no signs of slowing, in part due to the high rates of growth projected for Latin America and South Asia, and to a lesser extent in Middle East and North Africa.

Impacts

When an overabundance of fertilizer leaches into the soil, or deposits onto it in the form of ammonia,[1] this can create an imbalance of nutrients that leads to soil acidification, and even to a loss of soil organic carbon, affecting crop yields over time. This, along with the expense of wasted fertilizer, is costly to farmers and can detract from agricultural sector competitiveness. When fertilizer finds its way into surface water, an abundance of nitrogen and phosphorus can fuel an overgrowth of algae and seagrasses, a phenomenon known as eutrophication. This not only mars bodies of water but also depletes dissolved oxygen levels over time, killing native flaura and fauna, and in severe cases, resulting in hypoxic dead zones in which almost nothing can live. Fertilizer runoff has been a leading contributor to vast dead zones, such as those which stretch over tens of thousands of square kilometers in the Gulf of Mexico and the Baltic Sea (see Figure 3). In humans, exposure to toxic algae from recreational water use and the consumption of inadequately treated water can lead to liver damage. And high concentrations of nitrates (plant-available nitrogen) in drinking water are linked to cancers of the digestive track as well as infant methaemoglobinaemia, also known as blue baby syndrome. Cleaning up polluted bodies of water, meanwhile, can be tremendously costly.

At the same time, nitrogenous fertilizer is volatile and its use contributes to local air pollution in the form of fine particulate matter and ground-level ozone, which are known causes of cardiovascular and respiratory disease. In particular, fertilizer is second only to cattle as a source of emitted ammonia, a form of nitrogen which plays a significant role in particulate matter formation. Meanwhile, by exponentially increasing soil emissions of nitrous oxide, a greenhouse gas 300 times more powerful than carbon dioxide, fertilizer application also contributes to glob-

Figure 3: Dead Zone in the Gulf of Mexico



Source: National Aeronautics and Space Administration (NASA).
Note: Globally, an area roughly the size of the United Kingdom is hypoxic (approximately 240,000 km2 of waterways, of which 30 percent are inland and the remainder along coasts).

1 Emitted ammonia (NH_3) returns to the earth's surface mainly in the form of dry deposition of NH_3 and wet deposition of ammonium NH_4+.

al climate change—and its carbon footprint is larger if one factors in its energy-intensive manufacturing process.

Drivers

While agricultural intensification and the rise in agricultural output provide essential context, they do not fully explain why fertilizer use has risen to the counter-productive levels often observed today. Fertilizer misuse is better understood by examining farmers' economic incentives, and the influences of policy and technology. One factor that is central to today's fertilizer pollution problem is the fact that its market price to farmers does not account for the full environmental and social costs of its use. As a result, the abundant use of fertilizer can simply make economic sense from farmers' perspective, particularly if they highly value near-term results. Farmers may believe that its heavy use is a cost-effective means to overcome low or declining soil fertility, even when fertilizer overuse is part of the problem.[2] In comparison to the perceived benefits of such strategies, the potential for damaging the land and shared water resources over time, or for contributing to climate change, can seem a distant concern.

This proclivity to discount future gains, and to only focus on private ones (real or perceived), is sometimes encouraged by agricultural policies more bent on promoting production than environmental responsibility. Fertilizer subsidies in many countries further insulate farmers from the full cost of fertilizer, leading them to apply it more heavily, and less according to agronomic needs. Similarly, policy incentives that favor the expansion of farmland and irrigation, irrespective of their adverse effects, also invite fertilizer use to expand; and the resulting erosion and runoff exacerbate fertilizer use inefficiency by carrying nutrients off the field. Such scenarios are particularly pronounced where divided administrative responsibilities have led agricultural and environmental policies to be developed separately. This was the case in the European Union, for example, before efforts to reconcile these through Common Agricultural Policy reforms started in the mid-1980s. Meanwhile, the diffuse nature of fertilizer pollution—a form of nonpoint source pollution—has often made it a low priority of environmental policy, hindering attempts to regulate its use.

While the abundant use of fertilizer sometimes works to the advantage of farmers, it is often the case that more judicious use of fertilizer will save them money and enhance their work's profitability. In Vietnam's main coffee growing region, for instance, field studies have estimated that by lessening and better timing their use of fertilizer, especially with respect to irrigation, farmers could improve yields and revenues by 10 percent and 30 percent respectively—fertilizer being one of their largest expenses. In such instances, the heavy use of fertilizer can reflect limitations of knowledge, information, and technology, and result from a lack of tools to understand and provide for plants' specific nutrient needs. Farmers often lack access to or undervalue (at least from a social perspective) aids such as diagnostic tests, agronomic training that would enable them to know when "less is more," well-dosed fertilizer blends (or formula fertilizer), or fertilizer products, planning tools, and irrigation or other technologies designed to deliver fertilizer efficiently. That is not systematically the case, however, and behavioral factors are almost certainly at play where farmer incentives, awareness, and access to information and technology do not fully explain their actions. It may be the case, for instance, that the quantity of fertilizer in a standard package has an influence over the amount that is applied, even though that quantity has no relation to soil-crop needs.

What Can Be Done?

Two major avenues exist to limit fertilizer pollution.

The first involves reducing the amount of fertilizer that farmers use in the first place. Many opportunities exist to curb the use of fertilizer without compromising crop yields or food security. In China, for example, nitrogen use was cut by roughly 4 percent to 14 percent in maize, rice, and wheat system field trials while boosting yields by 18 percent to 35 percent, thanks to a knowledge-intensive approach to farming known as integrated soil-crop system management or ISSM (Chen et al. 2014).

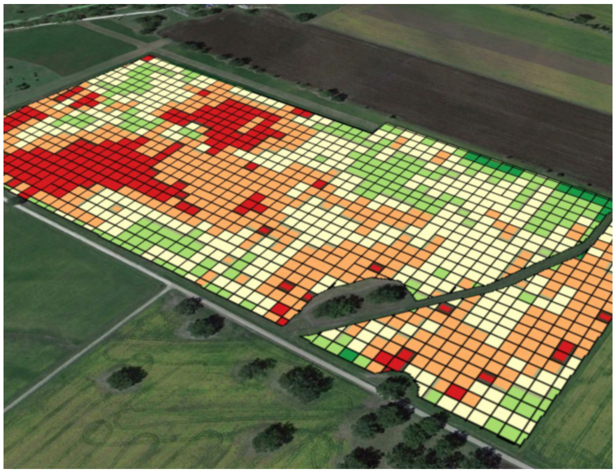
A second avenue to mitigate fertilizer pollution involves limiting the amount that runs off unused by plants, including by recycling nutrients that are already present in the environment. From a technical perspective, this can be achieved through changes in dosing, timing, application methods, and irrigation practices, and through farm management strategies. Examples of the latter include the use of buffer zones, rotational cropping, and aquaculture to absorb excess nutrients. In Bangladesh, what is known as fertilizer deep placement has allowed over 2.5 million farmers to abandon the traditional broadcasting method of applying fertilizer, resulting in notable reductions in fertilizer use (25–40 percent) and losses (up to > 50 percent). The method involves placing fertilizer granules, which stay in place more readily, in the root zone, close to where they are needed.[3] The following are various strategies that can be used to reduce fertilizer use and losses.

Knowledge and information. In general, greater access to agronomic knowledge and data can improve farmers' ability and motivation to apply nutrients more precisely and sparingly. Extension and advisory services, public or private, are one possible conveyor of

2 Farmers may also see it as a way to save time for more lucrative, off-farm work opportunities. In parts of China for instance, the multiplication of such opportunities have led some farmers to apply a full season's dose of fertilizer to their fields before crop planting as a substitute for monitoring and tending to crop needs continuously over the growing season.

3 A third avenue to mitigate fertilizer pollution involves cleaning up, and while various techniques allow this, it can be far

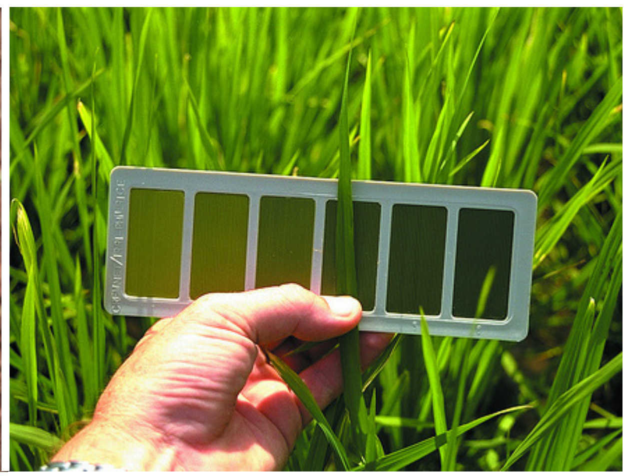
Figure 4: Information-Intensive Farming in Different Contexts



Source: © Agribotix.
Note: Management zone map, created by drone, to measure fertilizer needs.

Source: © Iván Ortiz-Monasterio/CIMMYT.
Note: Handheld N sensor in Yaqui Valley.

Source: © Feed the Future Kenya Innovation Engine.
Note: On-site soil test (Quest Agriculture).



Source: International Rice Research Institute.
Note: Leaf color chart for rice.

these, as are various information and communication technologies. In Uruguay, for example, the public sector has developed a public agricultural information system that combines data from farmers (including soil tests) and other sources (for example, weather and satellite-detected farm data) to inform farmer decision-support tools and services. Across a number of countries, farms are increasingly turning to tools such as sensors, global positioning systems, satellite imagery, and data interpretation software to monitor agricultural fields with precision (though resulting gains in fertilizer efficiency can sometimes encourage its use). While this development has predominantly occurred in large industrial farms, precision technologies and service models are also emerging for small- to mid-size commercial farms. Illustratively, in Mexico's intensively cultivated Yaqui Valley, wheat farmers have experimented with a private service model involving the use of handheld infrared devices to determine the mid-season fertilizer needs of crops. In this particular context, the simple diffusion of images showing wide-scale algal blooms in the Gulf of California downstream helped to raise awareness and set the stage for dialogue and change. In West Africa, several nongovernmental organizations are working with entrepreneurs to promote the use of mobile soil test kits—while working with fertilizer suppliers—to provide farmers with information about soil properties and crop aptness even where laboratory testing is inaccessible. Another example of a low-cost information tool is the leaf color chart that has been developed to allow farmers in Asia to visually estimate the nitrogen needs of high-yielding rice varieties at different critical growth stages (see Figure 4).

Inclusive innovation and technology. Just as tech-

less effective and costly than acting preventively, and is not discussed further here.

nological innovations can enhance farmers' access to information as illustrated above, so can they make it easier for farmers to control inputs, thus improving farmers' ability to act on information. These can involve the development of fertilizer products (e.g., custom blended formula fertilizer, slow release, enhanced-efficiency nitrogen fertilizers), irrigation systems (e.g., drip), fertilizer delivery mechanisms (e.g., variable rate application technologies), farming techniques (e.g., irrigation management, fertilizer application methods), and planning tools (e.g., management zone mapping site-specific nutrient management). Vietnamese coffee growers who have switched to drip irrigation to save water and associated labor costs, for example, are finding that they can significantly cut back on the amount of fertilizer they use, often by 50 percent or more. This example being no exception, the diffusion of such technologies often depends on government- or donor-supported programs (e.g., access to finance, business development) as well as on the development of private sector service models that enhance access to these. Most critically, the uptake of new technologies depends on how responsive these are to farmers' existing needs, highlighting the role of inclusive innovation systems that cater to and actively involve a wide variety of actors.

Government incentives. One set of strategies involves realigning fertilizer prices with their true cost, and generally restructuring policies to encourage farmers to use fertilizer more sparingly. The removal of most agricultural subsidies in New Zealand during the 1980s, for example, led to a stark decline in fertilizer use and environmentally beneficial changes in land use—not to mention fiscal gains. The European Union, in 2003, instituted a policy known as cross-compliance under which farm subsidies are contingent on contributions to ecosystem services and compliance with environmental law—including that which governs nitrate pollution. In the United States, the state of Virginia offers cost sharing and tax credits for the adoption of recognized best management practices, such as planting trees, shrubs and grasses, and constructing wetlands around fields, especially those that border water bodies, increasing the land's capacity to absorb runaway nutrients.

Market-based incentives. In some cases, the public sector can influence incentives indirectly, by creating context in which market signals take over (for example, by supporting private sector capacity or developing a legal framework for ecosystem payments). In the aforementioned case of fertilizer deep placement, while the technology's development and demonstration were made possible by donor support, the economic benefits it offers have helped to carry it forward; in Bangladesh, it has generally improved yields (15–35 percent), margins (15–30 percent),[4] and soil quality. In various parts of Latin America, payment for ecosystem service laws have allowed beverage, utility and other companies, and environmental nonprofits, to compensate farmers for adopting practices that keep nutrients out of water sources that these payers would otherwise need to treat at greater expense. In multiple countries including the United States, Tunisia, China, and India, government-authored and administered organic standards have, together with the development of quality assurance infrastructure, enabled markets to reward producers for avoiding the use of most synthetic agro-chemicals among other practices.

Figure 5: Precision Farming

Sources: Drone over maize field: © Precision Drone LLC; microirrigation: DoneRight Irrigation.

4 These are rough orders or magnitude based on various reports for different crops, including but not limited to rice.