International Fertilizer Industry Association

Increasing Agricultural Productivity to Mitigate Greenhouse Gas Emissions

International Fertilizer Industry Association
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Contents

Symbols, units, acronyms and abbreviations

(as used in this report)

AW	Alternative World (sceanrio)
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
FAO	Food and Agriculture Organization of the United Nations
GJ	Gigajoules
Gt	Gigatonnes (= 1 billion tonnes)
GHG	Greenhouse gas
ha	Hectare
IFA	International Fertilizer Industry Association
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
K_2O	Potash
kg	Kilogram
kha	Thousand hectares
M	Million
Mg	Magnesium
Mha	Million hectares
Mt	Million tonnes
N	Nitrogen
N_2O	Nitrous oxide
P	Phosphorus
P_2O_5	Phosphate
RW	Real World (scenario)
S	Sulphur
t	Metric tonne

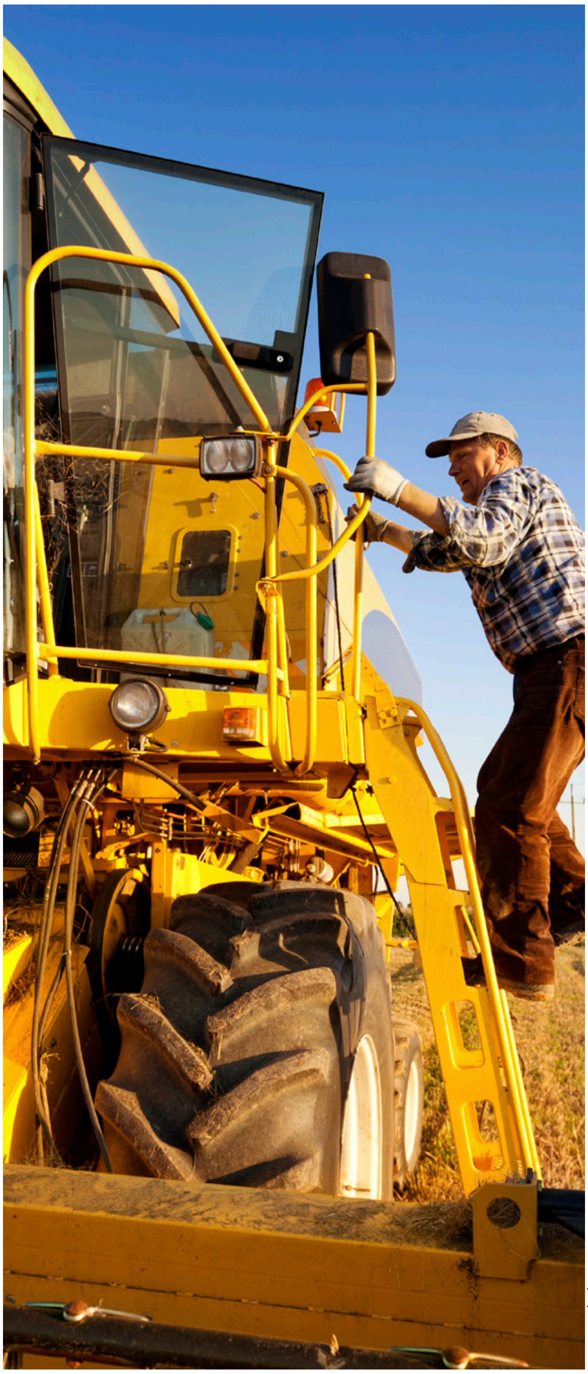
Preamble

Fertilizers are now, and will be in the future, essential to global food production and food security. Without the availability and use of manufactured fertilizers, billions of people would face food shortages or even starvation. The world's producers of nitrogen, phosphate and potash help to feed billions of people. Yet fertilizer production contributes less than 1% of total global greenhouse gas emissions, according to estimates by the International Fertilizer Industry Association (IFA, 2009a).

The focus with regard to agriculture and climate change should be two-fold: first, on helping farmers reduce the total environmental impact of farming through the implementation of best management practices; and, second, on helping them achieve higher yields per hectare to slow the conversion of natural habitats to agriculture.

Under any plausible scenario, increased production and well-managed use of fertilizers will be essential to respond to the challenges of providing food security, limiting further land use change, and mitigating greenhouse gas emissions. Research indicates that good farming practices implemented in order to grow more food per hectare, including the optimization of fertilizer application, will result in the lowest possible greenhouse gas emissions per unit of output. Alternative scenarios are highly undesirable, as they require bringing considerably more land into agriculture, resulting in significant deforestation and higher net greenhouse gas emissions in the attempt to meet demand for agricultural products.

This paper addresses the benefits of enhancing agricultural productivity in order to limit further land use change and mitigate agriculture-related greenhouse gas emissions. In doing so, it analyzes the crucial role that fertilizers could play in this connection.



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Background

The world's population increased from 3.1 billion in 1961 to 7 billion in 2011, and it is anticipated to reach 9.1 billion by 2050. Projections by the Food and Agriculture Organization of the United Nations (FAO) show that feeding that many people would require raising overall food production by some 70% between 2005/07 and 2050 (FAO, 2009) unless dramatic changes in agricultural consumption patterns occur. This increase can be achieved through higher yields, larger cultivated area, higher cropping intensity (number of crops per year under tropical conditions), or a combination thereof. Each option will have different environmental impacts, particularly in terms of greenhouse gas emissions, water use efficiency and biodiversity conservation.

In its estimate of the increased food production needed by 2050, FAO (2009) anticipates that 90% of the growth in crop production globally would come from higher yields and greater cropping intensity, with the remainder coming from land expansion. Cereal yield growth would continue to slow down, to some 0.7% per year, and average cereal yield would increase from 3.2 to 4.3 tonnes per hectare (t/ha) during the outlook period. Arable land would expand by some 70 million hectares (Mha) at the global level, with an expansion of about 120 Mha in developing countries partly offset by a decline of some 50 Mha in developed countries. Almost all land expansion in developing countries would take place in Sub-Saharan Africa and Latin America. This could be described as a baseline scenario for planning purposes:

Increasing food production, while limiting both the environmental impact of agriculture and large-scale additional land use requirements.

Agriculture and greenhouse gas emissions

Producing food, feed, fibre and bioenergy to meet the requirements of the world's population generates greenhouse gas emissions. These emissions are predicted to increase as population rises steadily and diets in emerging economies change towards more livestock products. However, through the adoption of improved farm management practices, increased agricultural production can be achieved with the lowest possible environmental impact.

According to the Agriculture chapter of the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (Smith *et al.*, 2007), agriculture contributes 10 to 12% of all global greenhouse gas emissions, for a total of 5.1 to 6.1 gigatonnes (Gt) CO_2-eq[1] per year in 2005, mostly in the form of nitrous oxide (N_2O) and methane (CH_4). The share of greenhouse gas emissions from fertilizer production, distribution and application represents 0.8 to 3.2% of global emissions (0.4 to 1.6 Gt CO_2-eq per year). Deforestation and other one-time land use change due, among their other effects, to agricultural expansion and urbanization account for an estimated 6 to 17% of global emissions (5.9 ± 2.9 Gt CO_2-eq per year). In total, direct and indirect emissions from global agricultural activity and land use change could contribute between 17 and 32% of all greenhouse gas emissions (Bellarby *et al.*, 2008).

Expansion of agricultural land into forests, grasslands or wetlands leads to large carbon emissions. For instance, the conversion of temperate and tropical forests to cropland releases 260 and 590 tonnes of CO_2-eq/ha, respectively. In the case of wetland conversion, greenhouse gas emissions can reach as much as 2,210 tonnes of CO_2-eq/ha (IPCC, 2000).

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In a study using geospatial data, Foley *et al.* (2011) have evaluated how new approaches to agriculture could benefit both food production and environmental sustainability. They estimate that 70% of grasslands, 50% of savannahs, 45% of temperate deciduous forests and 27% of tropical forests worldwide have already been cleared or converted for agriculture. Today agriculture is mainly expanding in the tropics, where it is estimated that about 80% of new cropland is replacing forests.

[1] CO_2-eq: carbon dioxide equivalent in terms of global warming potential, where methane and nitrous oxide are 23 and 296 times more potent, respectively, than carbon dioxide.

Agricultural "intensification" offers opportunities to mitigate greenhouse gas emissions while increasing food security

Although agricultural greenhouse gas flows are complex, best management practices for agricultural systems offer opportunities to mitigate them.

A recent study by Burney *et al.* (2010) analyzes the evolution of greenhouse gas emissions from agriculture between 1961 and 2005 under three different agricultural scenarios: a "Real World (RW) Scenario" and two alternative scenarios in which growing food needs have been met by land expansion ("extensification") rather than yield increases ("intensification"). In the "First Alternative World (AW1) Scenario" it is assumed that population, the global economy and socio-politics have evolved exactly as in the RW scenario, but that agricultural technology and farm practices have remained as they were in 1961. In the "Second Alternative World (AW2) Scenario" agricultural production has increased only enough to maintain 1961 standards of living through 2005.

Between 1961 and 2005, crop production increased from 1,776 million tonnes (Mt) to 4,784 Mt (+169%). Most of this gain was achieved through rising yields (+115%), largely due to higher fertilizer application rates, which increased on average from 32 to 136 kg/ha, and to better management of fertilizers. Improved varieties, better pest and water management, and mechanization also contributed to the yield gain. Nevertheless, an additional area of 248 Mha was converted to cropland during that period, with the global cropland area reaching 1,208 Mha in 2005. In the AW1 scenario, in order to achieve the same crop output in 2005 with 1961 yields, 1,514 Mha more land area than in the RW scenario would have had to be converted to cropping. In the AW2 scenario a more moderate production increase would be necessary, but the conversion of an additional 863 Mha would still be required compared to the RW scenario. In the AW scenarios, the global cropland area in 2005 would have been considerably larger than in the RW scenario: 2.2 and 1.7 times larger under the AW1 and AW2 scenarios, respectively. Such large-scale land use change, if at all possible, would have had huge undesirable environmental impacts.

Comparision of the RW and AW scenarios

	Real World (RW)		Alternative World (AW1)	Alternative World (AW2)
	1961	2005		
Standard of living		Improved	Same as RW	Same as 1961
Crop yield (t/ha)	1.84	3.96	1.84	1.84
Crop production (Mt)	1,776	4,784	4,784	3,811
Agricultural tractors (M)	11.3	28.5	28.5[1]	23.7
Irrigated area (Mha)	139	284	284[1]	298
Fertilizer (N-P_2O_5-K_2O) application rates (kg/ha)	32	136	32	32
Global fertilizer consumed (Mt)	31	165	88	67
Cropland area expansion since 1961 (Mha)	-	248	1,761	1,111
Net increase in GHG emissions compared to RW (Gt CO_2-eq)	-	-	590	317

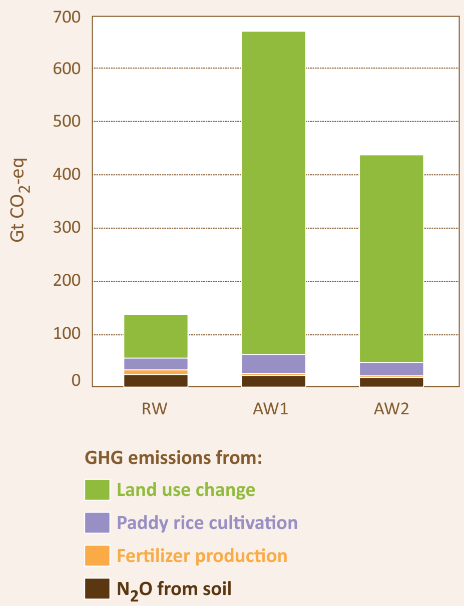
[1] The AW1 scenario conservatively assumes that machinery use and the irrigated area have remained the same as in the RW scenario.

Source: Snyder *et al.*, 2010 (adapted from Burney *et al.*, 2010)

Analysis of the data confirms the positive role of enhanced agricultural productivity in reducing total greenhouse gas emissions. Increased emissions from rising fertilizer production and use have largely been offset by lower emissions associated with cropland expansion. Compared to the RW scenario, an additional 317 Gt CO_2-eq would have been emitted between 1961 and 2005 in the AW2 scenario, and emissions would have increased by as much as 590 Gt CO_2-eq in the AW1 scenario. All the increase would have been caused by massive CO_2 emissions resulting from the conversion of forests, savannahs, wetlands and other natural habitats to cropland.

The study emphasizes the need to continuously improve productivity to meet the soaring world demand for agricultural products. This requires investments in agricultural research, development, and knowledge transfer in order to enhance yield potential, improve yield stability, and, where productivity is well below its potential, bridge the yield gap.

Increase in greenhouse gas emissions between 1965 and 2005 under three agricultural scenarios



Source: adapted from Burney et al., 2010

Main findings from the study by Burney *et al.* (2010)

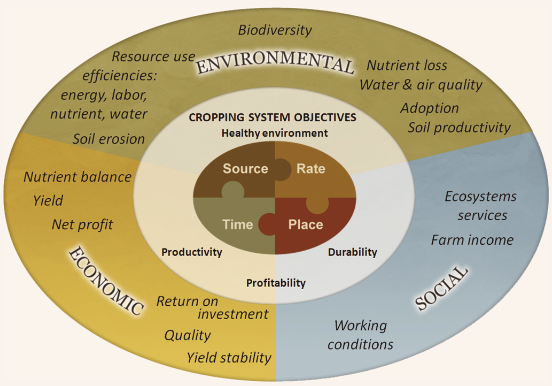
While greenhouse gas emissions from activities such as fertilizer production and application increased, the net effect of higher yields avoided emissions of up to 590 Gt CO_2-eq between 1961 and 2005, or 13.4 Gt CO_2-eq per year.

Investments in yield improvements compare favourably with other commonly proposed climate change mitigation strategies. Further yield improvements should therefore be prominent among efforts to reduce future greenhouse gas emissions.

Fertilization strategies to mitigate greenhouse gas emissions

For planning purposes, the impact of nitrogen (N) fertilizer production and use on total greenhouse gas emissions must be viewed in the correct context. While a small fraction of total global greenhouse gases is emitted during nitrogen fertilizer production, distribution, application and use, the contribution of nitrogen fertilizers to higher yields helps to feed billions of people and reduces the much higher greenhouse gas emissions that would result from land use change. When total greenhouse gas emissions related to crop production are considered, the overall carbon footprint per tonne of agricultural produce is lowest when N fertilizer application rates are close to the economic optimum.

4R Nutrient Stewardship Framework



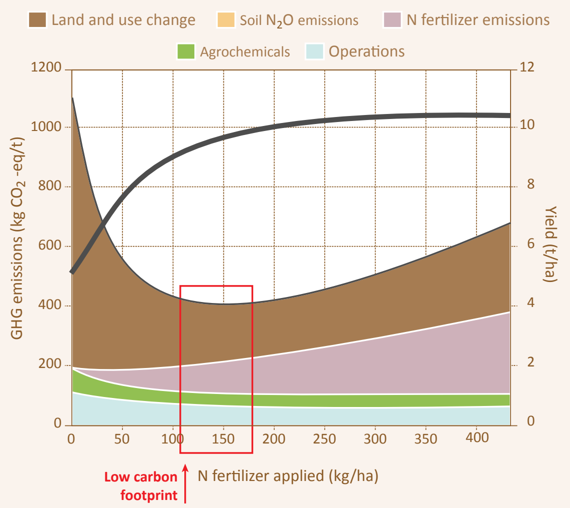
The fertilizer industry supports the "4R" Nutrient Stewardship Framework, which recommends using the Right Source of plant nutrients, at the Right Rate, at the Right Time and in the Right Place to deliver the economic, social and environmental benefits expected by society (Bruulsema *et al.*, 2009; IFA, 2009b).

For more information, go to: ***www.fbmp.org***

In a study on irrigated maize in central Nebraska, USA, Grassini and Cassman (2012) show that achieving high yields, a large positive energy balance, and low greenhouse gas emissions in intensive cropping systems are not conflicting goals in the case of well-managed fields. Irrigated maize in central Nebraska received relatively large energy inputs (about 30 gigajoules per hectare, or GJ/ha), mostly in the form of pumped irrigation water (42%) and N fertilizer (32%). However, there was also, on average, a large positive net energy yield of 159 GJ/ha and a net energy ratio of 6.6. Although the global warming potential per unit area in the studied area was within the upper range of published values for US maize systems, the average global warming potential per unit output was the lowest among published values, at 231 kg CO_2-eq per tonne of grain. If the irrigated maize system in central Nebraska were converted to a rainfed maize system in order to reduce greenhouse gas emissions per unit of land area, a 55% reduction in grain yield would result. According to Cassini and Cassman (2012), offsetting this yield drop would require additional maize plantings of some 124 thousand hectares (kha) in Nebraska or 277 kha in Brazil. They conclude that the most promising way to reduce greenhouse gas emissions without significant impact on productivity appears to be through improvements in input use efficiency.

Greenhouse gas emissions from agriculture are often assessed on a "per unit of cropland area" basis. However, from a climate change mitigation perspective, measurements would be far more meaningful if they were made on a "per unit of crop output" basis. This would help to encourage better production practices on current cropland, and to prevent further undesirable land use change and the conversion of natural habitats.

Relationship between N fertilizer and wheat yield *(bold black line)* **and the effects of the N application rate on estimated greenhouse gas emissions per tonne of wheat** *(top fine black line; coloured areas show contributions plotted cumulatively)* **after accounting for conversion of grasslands to arable land in the United Kingdom**



Source: Adapted from Kindred et al., 2008

To achieve the same yield, agronomic production intensities below the economic optimum require more land and thereby increase total greenhouse gas emissions. In highly "extensive" systems, where nutrient application rates are low, cropland expansion results in surging greenhouse gas emissions per unit of crop output.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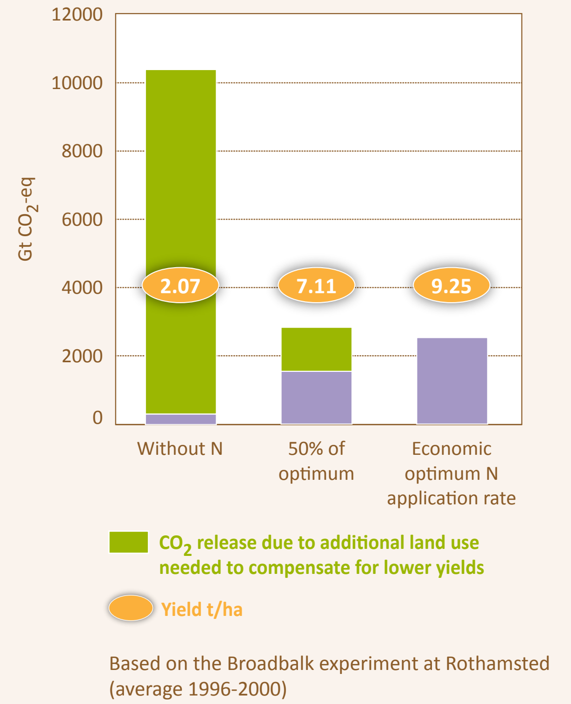
Improving input use efficiency and effectiveness, particularly the efficiency of nitrogen fertilizer use, is desirable from both the environmental and economic perspectives. Because it is imperative to feed the world's fast-growing population, however, this should not be to the detriment of crop yields.

Greenhouse gas emissions (kg CO_2-eq) for producing 9.25 tonnes of winter wheat in the United Kingdom under three different nitrogen fertilization regimes

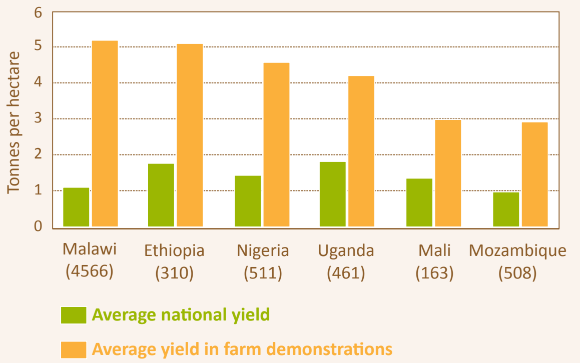


Source: adapted from Brentrup and Pallière, 2008

Balanced fertilization, i.e. the proper supply of all essential nutrients in a balanced ratio throughout the growth of crops, including the use of phosphorus (P), potassium (K), sulphur (S), magnesium (Mg) and micronutrient fertilizers, increases resource use efficiency by crops, particularly the efficiency of nitrogen and water use. With more crop per litre of rain and/or of irrigation water, productive, water-efficient agricultural systems prevent cropland expansion and related greenhouse gas emissions, especially when water resources are limiting.

"Extensive" farming systems are still widespread globally, particularly in Sub-Saharan Africa, where there is a significant gap between average national yields and the average yields observed in demonstration plots. Closing the yield gaps on underperforming lands has been identified by Foley (2011) as one of five strategies to increase agricultural production while reducing the environmental footprint of farming. They estimate that bringing yields of 16 important food and feed crops to within 75% of their potential could add 1.1 billion tonnes of new production per year, i.e. a 28% increase in global output without cropland expansion. Improving access to inputs, existing technologies and knowledge would make it possible to close the yield gap rapidly in these countries. This would have major environmental, economic and social benefits, as it would prevent the further destruction of natural habitats, which causes large greenhouse gas emissions.

Exploitable maize yield gap in Sub-Saharan Africa



Notes: Number of plots in parentheses. Open pollinated improved varieties in all cases except Nigeria, which uses hybrids.
Data for 2001 for Ethiopia, Mozambique, Nigeria and Uganda; 2002 for Malawi and an average of 2001, 2002 and 2004 for Mali.

Source: adapted from World Bank, 2007

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Conclusions and recommendations

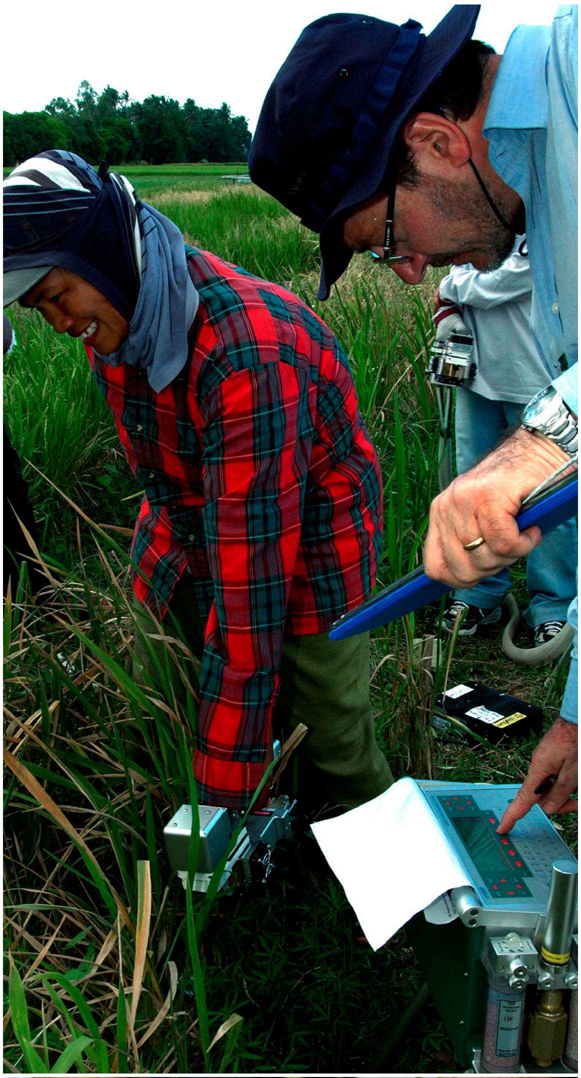
The global fertilizer industry plays a fundamental and essential role in feeding the world's population. It will become even more important as the population grows. While enabling this essential benefit to humankind, the global fertilizer industry contributes a small fraction of global greenhouse gas emissions. At the same time, well-managed fertilizer use is, and will remain, essential to slow the conversion of additional natural habitats to farmland, which is a major source of greenhouse gas emissions and biodiversity loss.

Today, land use change is responsible for 6 to 17% of total global greenhouse gas emissions. Further expansion of agricultural land into forests, grasslands and wetlands is not sustainable.

Future food, feed, fibre and bioenergy demands will require growth rates for crop production that exceed historic and current ones. Agricultural "intensification" through the adoption of best management practices is therefore a desirable and necessary policy goal for governments. The alternative – agricultural "extensification" – means increased conversion of natural habitats to farmland, biodiversity loss, and a significant increase in global greenhouse gas emissions.

The carbon footprint of crop production measured per tonne of crop output is lowest when fertilizer application rates are close to the economic optimum. Improving fertilizer use efficiency is critical, but it must not be pursued to the detriment of agricultural yields.

In order to mitigate agriculture's future contributions to climate change, continuing improvement of crop yields is paramount. This will require continuous public and private investment in agricultural innovation, research, development and knowledge transfer, accompanied by the implementation of best practices in a site-specific manner.



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