Global Crop Intensification Lessens Greenhouse Gas Emissions

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The global population increased from 3.08 billion in 1961 to over 6.51 billion in 2005 (111% increase), and is expected to reach almost 9 billion by 2050. This growth of the human family will result in a 70% rise in food demand. Can such food production increases be met, and if so, what will the impacts be on greenhouse gas (GHG) emissions and climate change? A recently published scientific journal article (Burney et al., 2010) has provided some answers to these questions.

From 1961 to 2005, global crop production increased through the expansion of cropland area (*extensification*) and by increased yields on land already under cultivation (*intensification*). Land area in crop production grew from 960 to 1,208 million hectares (M ha), a 27% increase. Meanwhile, crop yields, weighted by production across crop groups, increased from 1.84 to 3.96 t/ha (135% increase). These yield improvements were made possible through farmer adoption of improved higher-yielding crop varieties and hybrids, increased fertilizer use, improved pest management, greater access to irrigation, increased soil conservation practices, and greater agricultural mechanization.

It has been estimated that agricultural production accounted for 10 to 12% of the total global GHG emissions in 2005. These emissions are comprised mainly of nitrous oxide (N_2O) and methane (CH_4), and sum to the equivalent of 5 to 6 gigatons (GT) of carbon dioxide equivalents (CO_2e). Approximately 60% of the global total N_2O emissions and 50% of the global CH_4 emissions have been attributed to agriculture (Flynn and Smith, 2010). Land use change, resulting from the clearing of forests and conversion of native lands for agricultural production, accounts for between 6 and 17% of the global total GHG emissions.

Our atmosphere experienced N_2O concentration increases from 270 parts per billion (ppb) from pre-industrial times to 319 ppb in 2005, or about a 0.26% per year increase (Davidson, 2009); and rises in carbon dioxide (CO_2) concentration from 318 parts per million (ppm) in 1961 to 380 ppm in 2005 (ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt), or about a 0.44% per year increase. These increases in GHG concentrations are increasingly thought to aggravate global warming and result in climate change issues.

The world's fertilizer N use was approximately 93 million metric tons (M t) in 2005. Using the Intergovernmental Panel on Climate Change (IPCC, 2006) Tier 1 N_2O emission factor of 1% (1 kg of N_2O-N emitted per 100 kg of N applied), this N use is estimated to cause the emission of 1.46 M t of N_2O or about 433 M t of CO_2e. Putting this in perspective, global fertilizer N consumption in 2005 may have accounted for 7.0 to 8.6% of the global GHG emissions in 2005 (Flynn and Smith, 2010).

Abbreviations and notes: N = nitrogen.

1 gigaton (Gt) = 10^9 tonnes = 10^{12} kg = 1,000 Tg
CO_2e = carbon dioxide equivalent in radiative forcing or global warming potential
CO_2e is 296 for N_2O and 23 for CH_4 (IPCC, 2006)

Investments in agronomic research have helped avoid GHG emissions.

Modern agricultural production relies heavily on fertilizer consumption. To help answer questions about the net GHG impacts, scientists at Stanford University in the U.S. (Burney et al., 2010) compared two alternative world (AW) scenarios with the real world (actual; RW) global GHG emissions from 1961 to 2005. In the AW1 scenario, cropland area is expanded, yields are constant as per 1961 levels, but the standard of living improves as in the RW scenario. The AW2 scenario also has cropland area expansion, but the standard of living is kept at the 1961 scenario level. Some of their assumptions and the estimated global GHG outcomes are shown in **Table 1**.

In the AW1 scenario, assuming fertilizer rates and crop yields constant at 1961 levels, much greater (> 7 times more) expansion of cropland area and encroachment upon natural areas was required to meet global food demands, compared to what actually happened in the real world. The AW2 scenario had similar assumptions, but also held per capita grain production (standard of living) constant. Nevertheless, AW2 still required a large expansion of cropland area (4.5 times more) to meet global food demands. In both the AW1 and AW2 scenarios, global CO_2e emissions increased markedly compared to the RW GHG outcome.

Although GHG emissions per hectare from crop production have increased, the net effect of intensification has been a large avoidance of emissions **(Table 1)**. At the same time, the increase in fertilizer production and consumption has made possible about 40 to 60% of the contemporary global crop and food production (Stewart et al., 2005; Erisman et al., 2008).

Expressing the benefits of intensive crop production a different way, 13.1 Gt of CO_2e emissions per year have been avoided, and each dollar invested in agricultural crop yields has resulted in 249 kg fewer CO_2e emissions, relative to technologies employed in 1961 (Burney et al., 2010).

Table 1. Comparison of real versus alternative world scenarios in meeting global food demands for 1961 to 2005, and their GHG emissions (prepared from data in Burney et al., 2010).

	Real World (RW)		Alternative World (AW1)	Alternative World (AW2)
	Crop production intensification		Crop production extensificiation	
	1961	2005	2005	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, M t	1,776	4,784	4,784	3,811
Agricultural tractors, M	11.3	28.5	28.5[1]	23.7
Irrigated area, M ha	139	284	284[1]	298
Fertilizer (N-P_2O_5-K_2O) application rates, kg/ha	32	136	32	32
Global fertilizer consumed, M t	31	165	88	67
Cropland area expansion since 1961, M ha	–	248	1,761	1,111
Net increase in GHG emissions compared to RW, Gt CO_2e	–	–	590	317

[1] AW1 conservatively assumes machinery use and irrigation area remained the same as in the RW.

Important Implications

Two important points can be drawn from this study. First, investments in improving crop productivity are a cost-effective way to prevent increases in GHG emissions. Second, mitigation efforts must ensure that whole-system impacts of strategies to reduce GHG emissions be accounted for. While increasing efficiency of input use in crop production is a viable strategy, input reductions that limit yield increases are not.

Providing the needs of 9 billion people while protecting our planet and its landscape resilience may be the biggest challenge ever faced by humanity (Foley et al., 2005). To meet our food production needs while sustaining the planet and preserving significant parts of its natural ecosystems, ecologically intensive production systems (Cassman, 1999), improved nutrient use efficiency (Dobermann, 2007) through best management practices (BMPs), and better nutrient stewardship to achieve economic, environmental, and social goals have been advocated and advanced by members of the fertilizer industry and the agricultural community (Bruulsema et al., 2008; IFA, 2009; Snyder et al., 2009).

As a global society, are we ready to meet the challenges? BC

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Photo courtesy of Roger Elmore at Iowa State University

Increasing efficiency of input use is a viable strategy.

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