This brief is based on the paper by Stevenson, J., Byerlee, D., Villoria, N., Kelley, T. and M. Maredia (2011) Agricultural technology, global land use and deforestation: a review and new estimates of the impact of crop research. In: CGIAR Independent Science and Partnership Council. 2011. *Measuring the environmental impacts of agricultural research: Theory and applications to CGIAR research*. Independent Science and Partnership Council Secretariat: Rome, Italy.

INDEPENDENT SCIENCE & PARTNERSHIP COUNCIL
CGIAR

INDEPENDENT SCIENCE & PARTNERSHIP COUNCIL

STANDING PANEL ON IMPACT ASSESSMENT

BRIEF NUMBER 40

Neil Palmer (CIAT)

Nourishing the Future through Scientific Excellence

Does crop improvement reduce agricultural expansion?

The conversion of global forest resources to agricultural land is an issue that is high on the development agenda as a result of climate change and rising commodity and land prices. Land cover change is the third most important human-induced cause of carbon emissions globally and the second most important in developing countries. Agricultural expansion is considered to be one of the most important determinants of tropical deforestation. Between 1980 and 2000, 83% of all new agricultural land in the tropics came from either intact forests (55%) or disturbed forests (28%). In the light of these figures, it is pertinent to ask: what has been the effect of productivity-increasing crop improvement on agricultural expansion and land-use change?

Key messages

- New estimates are presented of the impact of CGIAR crop improvement research between 1965 and 2004 on global land-use change, based on simulations carried out using the Global Trade Analysis Project Agro-Ecological Zone model (GTAP-AEZ).
- The results support Norman Borlaug's hypothesis that increases in cereal yields as a result of widespread adoption of CGIAR-related crop germplasm in developing countries have saved natural ecosystems from conversion to agriculture, but the estimated effect is magnitudes smaller than that proposed by Borlaug.
- The GTAP-AEZ model suggests that the global crop area in 2004 would have been 18–27 million hectares larger without the crop germplasm improvement achieved since 1965. This 'land-saving' effect is dwarfed by the likely impact that higher prices would have had on poverty and malnutrition.

Background

The CGIAR is a major source of improved technologies for food crops, and its impacts on productivity have been well documented. However, the impacts of the CGIAR system on the environment have received little attention. The land-use effects of technological change may represent the single most important source of environmental impacts of the CGIAR's work.

Many have argued that agricultural research to increase yields is critical to saving the world's remaining forests and, in so doing, limiting greenhouse gas (GHG) emissions and losses of biodiversity. Technological change that improves productivity on existing agricultural land is hypothesized to save natural ecosystems (including forests) from being converted to agriculture. This premise is commonly known as the *Borlaug hypothesis* after Norman Borlaug (2007), who claimed that without the technological changes and intensification of agriculture that occurred between 1950 and 2000, an extra 500–600 million hectares of land would have been required to achieve the global harvest seen in 2000.

However, the relationship between adoption of new technologies and land use is more complex than Borlaug's estimates imply. Increases in productivity from new technologies may also increase the profitability of agriculture in comparison with alternative land uses, thereby encouraging expansion of the agricultural frontier. Further, technological change affects food prices, and labor and capital markets, which in turn influence land use.

The global food equation

Logic suggests that, in the long run, global population multiplied by food consumption per person (i.e. total consumption) must equal the total agricultural land area multiplied by average agricultural yields (i.e. total production). The Borlaug hypothesis is based on this global food equation; it suggests that if yields do not change but population and per capita consumption increase, then the global area of agricultural land must increase in proportion to the increased demand. Between 1961 and 2008, global population more than doubled and per capita consumption increased by 20%. The increase in cereal production to meet this increase in demand has overwhelmingly come from an increase in yields, which rose by 140% between 1960 and 2000, while the area harvested increased by only 7%.

Over the 30 years from the 1960s to the 1990s, the area under seven CGIAR-mandated crops increased by 75 million hectares. Nelson and Maredia (2001) calculated that, without the yield growth from all sources, land in production would have been about 230 million hectares higher than observed. Attributing one-third of yield growth to crop improvement research, this estimated land saving reduces to 76 million hectares. Applying the same reduction factor, Borlaug's land saving estimate of 500–600 million hectares reduces to 170–200 million hectares.

These studies do not account for the impacts of food price increases on demand, substitution effects on other crops or impacts through factor (labor and capital) markets. More comprehensive economic modeling approaches are needed to account for the full range of market-mediated impacts of technological change on land use.

Alternative models

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), is a multi-market, multi-country model incorporating 17 crop commodities and 35 countries or regions. In IMPACT, crop supply and demand factors determine the market-clearing prices, quantities supplied and consumed, and trade volumes.

Using IMPACT, Evenson and Rosegrant (2003) estimated that crop area in 2000 was 2.8–4.6% less than would be the case if there had been no crop germplasm improvement in developing countries over the period 1965–2000. A range of 3–4% of agricultural land saved between 1965 and 2000 corresponds to 9–12 million hectares in developed countries and 15–20 million hectares in developing countries. These estimates of a total land saving effect from crop germplasm improvement of 24–32 million hectares between 1965 and 2000 are an order of magnitude lower than those produced by Nelson and Maredia (2001) based on the global food equation. However, they are still significant from the perspective of averted deforestation, biodiversity loss and GHG emissions.

The IMPACT model provides a greater degree of economic realism than the estimates based on the global food equation. There are still, however, many restrictive assumptions associated with the model. Because it is a partial equilibrium model for the

agricultural sector only, it misses an entire pathway of impacts via effects on non-farm incomes and their feedback to the agricultural sector via product and factor markets. The model does not include a land market and lacks any explicit link to changes in land uses between crops, pastures, forests and grasslands. This means that it cannot estimate the 'encroachment factor' – the extent to which the additional hectares required in a counterfactual world would have come from forest, rather than from grazing land or other land cover. Modeled using IMPACT, crop germplasm improvement can only ever save land because there is no mechanism for modeling land competition between crop and non-crop uses and, even among crops, the coverage is only partial.

Global Trade Analysis Project (GTAP) model

For a more comprehensive model we turn to the Global Trade Analysis Project (GTAP) model – a multi-commodity, multi-regional, computable general equilibrium (CGE) model based on national or regional input–output tables. Villoria (2011) uses GTAP-AEZ, a version of GTAP that is linked to a global spatially explicit database on land use, to estimate the land-use impacts of crop germplasm improvement since 1965. The model predicts that cropland would have expanded by 18–27 million hectares globally, with 12–18 million hectares of the expansion in developing countries.

Results from GTAP-AEZ demonstrate that for staple food crops, the Borlaug hypothesis prevails: land has been saved as a result of the global crop germplasm improvement and the increases in yield that have taken place since 1965. These estimates are orders of magnitude lower than those predicted by the simple global food equation, because the latter does not take account of feedback loops through prices of products and land. While this may still represent a significant positive impact of agricultural research on the environment, the overall effects on land saving are dwarfed by the effects of crop germplasm improvement on food prices, which both GTAP and IMPACT predict would have increased, with serious implications for poverty and hunger.

It is valid to ask whether the purely economic counterfactuals presented here are ever likely to occur from a political perspective. The counterfactual equilibrium state of increased poverty and hunger without the benefits of crop germplasm improvement research assumes no government policy action is taken to increase food production, especially by clearing land. The inability of the GTAP-AEZ model to account for such policy responses suggests that the land saving effects predicted are lower-bound estimates of the true effect.

Table 1.
Percentage change in land cover assuming no crop germplasm improvement-related productivity gains in CGIAR crops since 1965, GTAP-AEZ estimates

	Cropland	Forests	Pasture
Developing countries	1.52	–0.86	–0.66
Developed countries	0.87	–0.51	–0.36

In order to compare the effects on land use of broad-based productivity improvement in cereals with productivity gains in oilcrops grown at the forest margin, GTAP-AEZ was used to simulate the impact of productivity increases on the rate of soybean expansion in Brazil and oil palm in Indonesia. These simulations demonstrate that, in some circumstances, new technologies can drive greater deforestation at a local level through increased returns to land.

Trends at the agriculture–forest frontier

Satellite imagery shows that the total agricultural area in tropical countries increased by more than 75 million hectares during the 1980s and 1990s. Of this expansion, more than half (55%) occurred by clearing intact, natural forest and a further 28% came from expansion into disturbed forest. Although 'agricultural expansion' may be the proximate cause of deforestation, meta-analyses of over 140 studies have identified three specific factors as the primary drivers: (1) commodity prices, (2) construction of roads, and (3) low wages or high unemployment (Angelsen, 2010). These factors are in turn strongly influenced by property rights and governance of forest resources.

Implications for the CGIAR

Raising the aggregate food supply in the breadbasket regions, through research on CGIAR-mandated crops such as rice, wheat, maize, sorghum and millet, is likely

Table 2.
Factors promoting and limiting expansion of agriculture at the frontier

Factors promoting expansion	Factors limiting expansion
Higher output prices from increased demand or low supply	Lower output prices from lower demand or high supply
Lower wages or opportunity costs of labor	Higher wages or opportunity costs of labor
Lower cost of defending property rights	Higher cost of defending property rights
Reduced access costs	Higher access costs
Lower costs of capital	Higher costs of capital

Source: Adapted from Angelsen and Kaimowitz (2001)

to contribute to reducing agricultural expansion and forest loss. However, the magnitude of the effect – a land saving of 18–27 million hectares between 1965 and 2004 – is probably much lower than that commonly cited, based on the method used by Borlaug. While these figures are significant, the effect is probably relatively small in comparison with the impacts of the same research on lowering food prices and ultimately reducing poverty and hunger.

It is important to recognize that research that improves the profitability of specific crops grown in regions with large areas of remaining forests may promote greater deforestation by raising the returns to land in agricultural uses relative to returns to forest uses. Three critical factors influence whether new agricultural technologies reduce or increase pressure on forests: the location of production; the characteristics of the technological change (in particular, whether it is labor saving); and the demand elasticity for the agricultural product in question.

Technologies that are predominantly adopted at or close to the forest margin, and that apply to commodities with elastic demand on export markets, are likely to add to pressure on forests. Under these criteria, technological change in oil palm is likely to induce further expansion, as oil palm production is located in forest areas and there is potentially unlimited demand. Technological advances in crops with inelastic demand for the crop, and which are predominantly adopted away from the forest margin, are likely to save land. Many of the CGIAR's mandate crops fit this description.

References

Angelsen, A. 2010. Policies for reduced deforestation and their impact on agricultural production. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (46): 19639–19644.

Angelsen, A. and Kaimowitz, D. 2001. *Agricultural Technologies and Tropical Deforestation*. Wallingford, UK: CABI Publishing.

Borlaug, N. 2007. Feeding a hungry world. *Science (New York, N.Y.)*, 318 (5849): 359.

Evenson, R.E. and Rosegrant, M. 2003. The economic consequences of crop genetic improvement programmes. In R. E. Evenson & D. Gollin (Eds.), *Crop variety improvement and its effect on productivity* (pp. 473–497). Wallingford, UK: CABI Publishing.

Nelson, M. and Maredia, M. 2001. Environmental Impacts of the CGIAR: An Assessment. TAC Secretariat Report No: SDR/TAC:IAR/01/11 May 2, 2001. Washington, DC.

Villoria, N. (2011) Online supporting materials – report to the CGIAR Standing Panel on Impact Assessment, February 2011. http://impact.cgiar.org/sites/default/files/images/Villoria%20report.pdf

Independent Science & Partnership Council Secretariat
℅ FAO
Viale delle Terme di Caracalla snc, 00153 Rome, Italy
www.sciencecouncil.cgiar.org
t: 39 06 57056782 f: 39 06 57053298
e: ISPC-Secretariat@fao.org