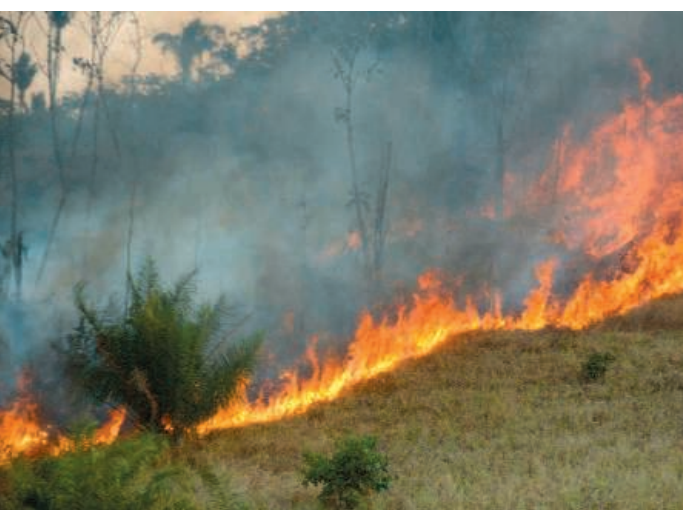
LETTERS

edited by Jennifer Sills

Biofuels: Effects on Land and Fire

IN THEIR REPORTS IN THE 29 FEBRUARY ISSUE ("LAND CLEARING AND THE BIOFUEL CARBON debt," J. Fargione *et al*., p. 1235, and "Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change," T. Searchinger *et al.*, p. 1238), the authors do not provide adequate support for their claim that biofuels cause high emissions due to land-use change. The conclusions of both papers depend on the misleading premise that biofuel production causes forests and grasslands to be converted to agriculture. However, field research, including a meta-analysis of 152 case studies, consistently finds that land-use change and associated carbon emissions are driven by interactions among cultural, technological, biophysical, political, economic, and demographic forces within a spatial and temporal context rather than by a single crop market (*1*–*3*).



Fired up. Biofuel production may have indirect effects on the use of fire as a land-management tool in the Amazon.

Searchinger *et al*. assert that soybean prices accelerate clearing of rainforest based on a single citation (*4*) for a study not designed to identify the causal factors of land clearing. The study (*4*) analyzed satellite imagery from a single state in Brazil over a 4-year period and focused on land classification after deforestation. Satellite imagery can measure what changed but does little to tell us why. Similarly, Fargione *et al*. do not rely on primary empirical studies of causes of land-use change.

Furthermore, neither fire nor soil carbon sequestration was properly considered in the Reports. Fire's escalating contribution to global climate change is largely a result of burning in tropical savannas and forests (*5*, *6*). Searchinger *et al*. postulate that 10.8 million hectares could be needed for future biofuel, a fraction of the 250 to 400 million hectares burned each year between 2000 and 2005 (*5*, *6*). By offering enhanced employment and incomes, biofuels can help establish economic stability and thus reduce the recurring use of fire on previously cleared land as well as pressures to clear more land (*7*–*9*). Neither Searchinger *et al.* nor Fargione *et al.* consider fire as an ongoing land-management tool. In addition, deep-rooted perennial biofuel feedstocks in the tropics could enhance soil carbon storage by 0.5 to 1 metric ton per hectare per year (*10*). An improved understanding of the forces behind land-use change leads to more favorable conclusions regarding the potential for biofuels to reduce greenhouse gas emissions.

KEITH L. KLINE AND VIRGINIA H. DALE

Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831–6038, USA.

CREDIT: VIRGINIA H. DALE

References

1. E. Lambin *et al*., *Annu. Rev. Env. Res*. **28**, 205 (2003).
2. H. J. Geist, E. F. Lambin, *BioScience* **52**, 143 (2002).
3. P. E. Kauppi *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **103**, 17574 (2006).
4. D. C. Morton *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **103**, 14637 (2006).
5. F. Mouillot *et al*., *Geophys. Res. Lett.* **33**, L01801 (2006).
6. L. Giglio *et al*., *Atmos. Chem. Phys*. **6**, 957 (2006).
7. A. S. Mather, *Int. For. Rev*. **9**, 491 (2007).
8. D. Nepstad *et al*., *For. Ecol. Management* **154**, 395 (2001).
9. P. Tschakert *et al*., *Ecol. Econ*. **60**, 807 (2007).
10. M. J. Fisher *et al*., *Nature* **371**, 236 (1994).

Response

ALTHOUGH WE SHARE KLINE AND DALE'S interest in the underlying social, political, and cultural causes of land clearing, the focus of our study was primarily on land clearing's effects. We considered the greenhouse gas impacts of producing various biofuels on newly cleared land or on degraded land that has already been cleared. We found that any newly cleared natural ecosystem used to produce current food-based biofuels releases large amounts of carbon dioxide to the atmosphere. This carbon debt can be minimized or avoided by producing biofuels from some types of waste biomass or from some perennial crops grown on agriculturally degraded land. We showed that a full and accurate accounting of the greenhouse gas impacts of land-use change is needed to determine the extent to which a given biofuel may or may not provide greenhouse gas benefits.

Our analyses explicitly included both carbon release and carbon storage. We reported the potential for perennial crops to store carbon on degraded land with an example of perennial crops grown on U.S. degraded cropland. African grasses grown in South America [(*1*), as cited by Kline and Dale] are an additional example that supports our point, although the magnitude of the effect cited by Kline and Dale is debated (*2*).

The points raised by Kline and Dale do not in any way lead us to draw "more favorable conclusions regarding the potential for biofuels to reduce greenhouse gas emissions." If existing cropland is insufficient to meet imminent food demands, then any dedicated biofuel crop production will necessarily create demand for additional land (*3*–*5*). Some of this land could come from

Published by AAAS

previously degraded land no longer used for food production (*6*). Policies guiding biofuel production toward this land and away from natural ecosystems would offer substantial greenhouse gas and other benefits. As Kline and Dale point out, many factors contribute to land clearing. This observation does not diminish the fact that biofuels also contribute to land clearing if they are produced on existing cropland or on newly cleared lands (*7*–*10*).

JOSEPH FARGIONE,[1,2] JASON HILL,[2,3] DAVID TILMAN,[2]* STEPHEN POLASKY,[2,3] PETER HAWTHORNE[2]

[1]The Nature Conservancy, 1101 West River Parkway, Suite 200, Minneapolis, MN 55415, USA. [2]Department of Ecology, Evolution, and Behavior, University of Minnesota, St. Paul, MN 55108, USA. [3]Department of Applied Economics, University of Minnesota, St. Paul, MN 55108, USA.

*To whom correspondence should be addressed. E-mail: tilman@umn.edu

References

1. M. J. Fisher *et al.*, *Nature* **371**, 236 (1994).
2. E. A. Davidson, D. C. Nepstad, C. Klink, S. E. Trumbore, *Nature* **376**, 472 (1995).
3. D. Tilman *et al.*, *Science* **292**, 281 (2001).
4. N. Alexandratos, *Proc. Natl. Acad. Sci. U.S.A.* **96**, 5908 (1999).
5. A. Balmford, R. E. Green, J. P. W. Scharlemann, *Global Change Biol.* **11**, 1594 (2005).
6. C. B. Field, J. E. Campbell, D. B. Lobell, *Trends Ecol. Evol.* **23**, 65 (2008).
7. D. C. Nepstad, C. M. Stickler, B. Soares-Filho, F. Merry, *Philos. Trans. R. Soc. B Biol. Sci.* **363**, 1737 (2008).
8. G. M. Buchanan *et al.*, *Biol. Conserv.* **141**, 56 (2008).
9. L. M. Curran *et al.*, *Science* **303**, 1000 (2004).
10. D. Rajagopal, S. E. Sexton, D. Roland-Host, D. Zilberman, *Environ. Res. Lett.* **2**, 1 (2007).

Response

KLINE AND DALE CONFUSE THE MUCH-STUDIED question of why some tropical forests are converted in some locations and not others, which depends on multiple factors, with the role of agriculture as an underlying economic driver worldwide. For example, the infrastructure to support agricultural expansion exists in some parts of the Brazilian Amazon, but less in the Peruvian Amazon, which is why our study predicts that biofuels will increase deforestation more in Brazil than in Peru. Some deforestation remains untied to agricultural demand, but as the meta-analysis cited by Kline and Dale actually found, "agricultural expansion is, by far, the leading land use change associated with nearly all deforestation cases" (*1*). Its related report found "economic factors" to be "the most important and robust underlying forces of tropical deforestation" (*2*). Other studies have found that "demand for agricultural commodities appears to be driving substantial increases in deforestation rates" (*3*, *4*).

We cited the study of Mato Grosso, Brazil (*5*), only to highlight proof of the principle that as economic returns for a land use increase, that land use expands. That basic principle of land economics is confirmed by studies showing that agricultural conversion of forests rises with the price of beef (*2*) as well as with access to roads, which reduces shipping costs and increases the effective crop price (*6*). The estimate of land-use change in our study was actually based on a well-established model showing the relationship between price and agricultural production in different countries around the world, and data showing the broad mix of forest and grasslands converted to agriculture in the 1990s. These patterns of conversion by definition reflect the complexity of factors referenced by Kline and Dale that influence where conversion occurs. These factors implicitly explain our average emission of 351 tons of CO_2 per hectare (t/ha), which is closer to grass and savannah conversion of 75 to 300 t/ha than forest conversion of 600 to 1100 t/ha.

Indeed, if farmers did not convert land to replace food diverted to biofuels, corn ethanol would cause fewer greenhouse gas emissions but at the expense of more world hunger.

Kline and Dale also suggest that because large-scale burning already occurs in the tropics, conversion to biofuel production could be good for global warming. But the great bulk of this fire comes from the annual burning of tropical grassland, which only releases aboveground carbon taken up by the grassland that year and therefore does not increase carbon in the atmosphere annually. By contrast, conversion of forest and grassland to cropland adds carbon to the atmosphere.

The assertion that biofuels produced in the developing world can contribute to economic stability and reduce deforestation, which might be true in some circumstances, is irrelevant to our study. It focused on biofuel production in the United States, not the tropics, and the resulting ripple effects in the tropics through food production. More broadly, none of the studies cited by Kline and Dale support the judgment that making deforestation more profitable, through higher crop prices or otherwise, would reduce deforestation—the precise economic effect of many biofuel policies.

TIMOTHY D. SEARCHINGER

Woodrow Wilson School, Princeton University, Princeton, NJ 08544, USA.

CORRECTIONS AND CLARIFICATIONS

News Focus: "Building the tree of life, genome by genome" by E. Pennisi (27 June, p. 1716). The photo identified as a nudibranch is actually a shelled snail, Cyphoma, which is in a different subclass from the nudibranch.

News of the Week: "Heinz Center wants Feds to build ecosystem indicator partnership" by E. Stokstad (20 June, p. 1575). The amount of carbon stored in agricultural soils did not increase by 11 million tons from 1995 to 2005; it increased by 16.5 million tons during the 1990s.

Special Issue on Plant Genomes: Perspectives: "The epigenetic landscape of plants" by X. Zhang (25 April, p. 489). The last sentence in the first paragraph of the Conclusions section should read, "The function(s) of DNA methylation that are enriched in different fractions of the gene space in *Arabidopsis* (3′ half of transcribed regions) and rice (promoter regions), as well as DNA demethylation by the DEMETER (DME) family of DNA glycosylases (*53*), are not yet understood and warrant further functional studies."

Reports: "Wnt5a control of cell polarity and directional movement by polarized redistribution of adhesion receptors" by E. S. Witze *et al*. (18 April, p. 365). In the paragraph beginning "Fz3, a noncanonical Wnt receptor," on p. 368, the mention of Fig. 4, E and F, should be Fig. 3, E and F.

TECHNICAL COMMENT ABSTRACTS

COMMENT ON "Genetically Determined Differences in Learning from Errors"

Michael Lucht and Dieter Rosskopf

Klein *et al*. (Reports, 7 December 2007, p. 1642) used individuals with a polymorphism adjacent to the dopamine receptor 2 gene as naturally occurring models for reduced brain dopamine receptor density in a probabilistic learning task. We raise the concern that this polymorphism resides in the gene for the kinase ANKK1, where it causes a nonconservative amino acid exchange.

Full text at www.sciencemag.org/cgi/content/full/321/5886/200a

RESPONSE TO COMMENT ON "Genetically Determined Differences in Learning from Errors"

Tilmann A. Klein, Martin Reuter, D. Yves von Cramon, Markus Ullsperger

Since the publication of our findings, further genetic and pharmacological studies have bolstered our conclusion that dopamine D2 receptors are essential for performance monitoring and learning. Although the functionally complex dopamine D2 receptor gene polymorphism DRD2-TAQ-IA may also affect cellular signaling components, the accumulated evidence supports the notion that our findings were mediated by differential D2 receptor density.

Full text at www.sciencemag.org/cgi/content/full/321/5886/200b

References

1. H. J. Geist, E. F. Lambin, *BioScience* **52**, 143 (2002).
2. H. Geist, E. F. Lambin, "What drives tropical deforestation: A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence" (LUCC Report Series No. 4, International Geosphere Biosphere Programme, University of Louvain, Louvain la-Neuve, Belgium, 2001).
3. M. Santilli *et al.*, *Clim. Change* **71**, 267 (2005).
4. K. M. Chomitz *et al*. "At loggerheads? Agricultural expansion, poverty reduction, and environment in the tropical forests" (The World Bank, Washington, DC, 2007).
5. D. C. Morton *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **103**, 14637 (2006).
6. A. S. P. Pfaff, *J. Env. Econ. Management* **37**, 26 (1999).

Biofuels: One of Many Claims to Resources

IN THEIR REPORT, "LAND CLEARING AND THE biofuel carbon debt," (29 February, p. 1235), J. Fargione *et al*. raise the important issue of competing land use needs in the planning of climate change mitigation strategies incorporating biofuel production. Research pointing out probable negative impacts of poorly planned policies is needed, but many recent works simplistically present biofuel as a disturbance in an otherwise optimally functioning system. Fargione *et al*. seem to assume that all land for bioenergy feedstock production either would be taken from the natural resource pool or would drive other land uses directly into it. Contrary to Fargione *et al*.'s thesis, we contend that not all current forms of land use are critical to society. In fact, uses can change without necessarily negatively affecting livelihoods and food security.

Even if current agricultural land use were indeed inelastic, it would be incorrect to attribute all effects of "displacement" to biofuel. Livestock feed mill companies, livestock producers, and consumers themselves have a range of options and should bear some responsibility for the consequences of their choices. Today, the bioenergy sector is the subject of substantial scrutiny, whereas this year the largely unscrutinized feed industry will divert an amount of cereals from humans to animals that is well over 7 times globally that diverted by biofuel use (*1*). Consequently, we question initiatives of specific treatment for biofuel feedstock, as called for by Fargione *et al*. Upon what grounds is it appropriate to enforce sustainability of soy oil imports for biodiesel, while not applying this to soy meal imports for feed?

We suggest that researchers stop presenting bioenergy as an aggressive intruder on an agrarian utopia and instead admit that bioenergy is just one of many agricultural products that use natural resources. Alarmist articles may do more harm than good to current decision-making in the EU and the UN.

TOM WASSENAAR AND SIMON KAY

European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, Agriculture Unit, TP 266, Via E. Fermi 2749, 21027 Ispra (VA), Italy.

Reference

1. Food and Agricultural Organization of the UN, "Crop Prospects and Food Situation" (FAO, Rome, Italy, 2008); www.fao.org/docrep/010/ai465e/ai465e04.htm.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Published by AAAS