Global Food Security 3 (2014) 92–98

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Does intensification slow crop land expansion or encourage deforestation?

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form
31 March 2014
Accepted 1 April 2014

Keywords:
Intensification
Crop yields
Global markets
Land use changes
Deforestation

ABSTRACT

The role of intensification in minimizing cropland and slowing deforestation is often disputed. We make a broad distinction between technology-induced and market-induced intensification. We find evidence at the local level that technical progress in a few cases may induce land expansion although much depends on where the technical change occurs (near the forest frontier or away from it) and the type of market (local or global). At a global level, technology-driven intensification is strongly land saving although deforestation in specific regions is likely to continue to occur. Market-driven intensification, however, is often a major cause of land expansion and deforestation especially for export commodities in times of high prices. Beyond land saving, the type of intensification matters a lot for environmental outcomes. Finally, technology-driven intensification by itself is unlikely to arrest deforestation unless accompanied by stronger governance of natural resources.

1. Introduction

Expansion of crop land area to meet the world's growing food, fuel, and fiber needs has received much attention in recent years due to forest encroachment and the resulting loss of carbon sequestration and biodiversity that are critical global public goods (Laurance et al., 2014). A growing body of literature has analyzed options for slowing cropland expansion, especially in light of looming land scarcity and the recent push for a sustainable development goal of zero deforestation by 2030 (UNEP, 2014).

Historically, yield increase rather than area expansion has been the major source of growth in agricultural output allowing rising global demand for food to be supplied largely from existing cropland. From 1961–2000, global population more than doubled and per capita cereal consumption increased by 20%. However, harvested area of cereals grew by only 7% much of it through increased cropping intensity on the same land area.

Although it is intuitive that intensification to raise production on existing cropland is the best way to save natural ecosystems from agricultural encroachment, this is by no means accepted scientifically. An important and influential stream of literature has highlighted that on the agricultural frontier, crop intensification such as the rapid increase of soy production in Brazil and oil palm in Indonesia at the expense of pastures or natural vegetation to supply global markets, has been a major driver of deforestation (Angelsen and Kaimowitz, 2001a; Nepstad and Stickler, 2008). The high profitability of these systems logically increases returns to land and acts as an incentive to expand the crop frontier. Even where intensification does save land, as is evident in the figures in the preceding paragraph, the amount saved is often disputed, given the complexity of interacting effects through product, land and labor markets (Lambin, 2012; Stevenson et al., 2013), and the difficulty of simulating a counterfactual scenario without intensification. A net saving of land at the global level may co-exist with cropland expansion at the local level that incurs significant global environmental costs. Further, intensification even when it saves land may induce other environmental costs, such as off-site impacts of agro-chemicals on natural ecosystems, so that sustainable intensification including landscape approaches is needed (Cunningham et al., 2013).

This paper sets out to reconcile competing hypotheses on intensification as a way to save land, both locally and globally. After briefly summarizing perspectives on global demand and supply of cropland we lay out key concepts on intensification and the various pathways from intensification to land use changes. We then summarize evidence on the effects of intensification on land

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http://dx.doi.org/10.1016/j.gfs.2014.04.001

use, distinguishing the level of innovation (local and global) and the type of intensification (market-driven or technology-driven). We also briefly highlight tradeoffs at the local level about land sharing vs. land sparing. Finally, we note critical policy interventions especially investment in R&D coupled with improved land and forest governance, needed to arrest further land expansion.

2. Whither global demand and supply of cropland?

Many of the concerns about intensification and land use arise from perceptions of a looming scarcity of land suited to crop cultivation combined with rising values being placed on services provided by natural ecosystems. Projections of future demand and supply of land are quite variable. The UN Food and Agricultural Organization (FAO) projects a need to increase arable area by approximately 70 Mha globally from 2005/07 to 2050, an increase of only 5%. However they also project an increase of 107 Mha in developing countries as cropland continues to decline in developed countries (Alexandratos and Bruinsma, 2012). The World Bank projects increases of 6–12 Mha each year from 2010 to 2030 for a total of 120–240 Mha, with the higher estimate from projections that allow a greater role for trade and thereby production by the lowest-cost producers who are often located in land abundant countries (Deininger and Byerlee, 2011). These estimates are broadly in line with a synthesis by Lambin and Meyfroidt (2011) who also include projections of the loss of land due to expansion of urban settlements and infrastructure as well as land degradation. Taking these losses into account, Fischer et al. (2014) provide an estimate of total additional gross cropland demand from 2010 to 2030 of 160–340 Mha. These results are broadly consistent with global models discussed later in this paper, that suggest expansion of cropland to 2050 of about 300 Mha, given projected yield growth (Lobell et al., 2013).

Is there enough land to satisfy demand? FAO estimates that some 1.4 billion ha of currently uncultivated land that is not forested or in protected areas is suited to crop agriculture (Alexandratos and Bruinsma, 2012) although they note that this is an optimistic estimate. A more conservative estimate of available land with at least moderate suitability for rainfed cultivation in low-population-density areas – that is, nonforested, nonprotected, and with a population density of less than 25 persons km^{-2} – is approximately 450 Mha (Deininger and Byerlee, 2011).

On first glance, it would thus seem that projected demand for land (even under the scenarios of the higher demand estimates) over the next two decades can be accommodated by available uncultivated land. However, most of this uncultivated land is concentrated in a few countries in sub-Saharan Africa, Latin America, and Eastern Europe and Central Asia and is often far from ports and roads. A global analysis may also miss key constraints at the local level such as human diseases and unrecorded current land use that reduce effective land supply (Lambin et al., 2013). In addition, an expansion of land area of the order of 160 Mha (the lower-bound estimate of the estimated future land needs) could have significant biodiversity costs from conversion of natural ecosystems, even in the nonforested areas considered above (Sawyer, 2008).

Overall then, projections of future land availability for agriculture suggest a growing land scarcity especially when taking into account that demand for commodities will continue to rise with growing affluence in rapidly industrializing countries, the remaining land suited for bringing into cultivation is concentrated in a few countries, and trade from land-abundant to land-scarce countries will increase (Weinzettel et al., 2013). Growing scarcity together with high commodity prices have combined to stimulate global interest in farmland that underlies much of the recent discussion on intensification as a strategy to save land (Smith et al., 2010) and concerns about a global 'landgrab' by investors from land-scarce countries (Deininger and Byerlee, 2011; Zoomers, 2010).

3. Defining intensification and its pathways to land use changes

Intensification is defined in different ways (e.g., Smith, 2013), often adding to confusion in discussing its impacts on land use. We use an economics definition that measures intensification by an increase in the productivity of land measured by the real value of agricultural output per hectare (Hayami and Ruttan, 1971). Along with most of the literature on intensification we emphasize crop production, partly because expansion in cropland has been the major cause of environmental losses such as deforestation, and partly because global statistics on pastureland are very unreliable. Our focus is therefore on crop production per hectare of cropland—that is aggregate crop yields.

We further distinguish two major pathways to intensification – technology driven and market driven. Technology-driven intensification occurs when technical change in a crop allows more output per unit of land for the same level of inputs. Such a shift can come from the introduction of a number of different technologies usually as a result of investment in R&D, such as new varieties of the crop, better crop and resource management practices, and improved crop protection. Market-driven intensification, on the other hand, results from a shift in product mix to higher value crops due to new market opportunities, or a shift in input mix in response to relative price changes, such as the substitution of fertilizer for land in response to rising land prices. Note that since real prices are used to aggregate output across crops for estimating land productivity, market-driven intensification may also reflect an increase in real commodity prices relative to non-agricultural prices.

Improved markets and infrastructure can play a role in intensification without technical change, by lowering the effective cost of inputs to farmers or raising effective output prices. Moreover, technical change and market-driven intensification may go together such as when a new fertilizer-responsive cereal variety is introduced along with more efficient markets for fertilizer that both induce higher levels of input use and yields.

Regardless of the sources, intensification affects land use changes through a number of pathways (Fig. 1). At the local level, intensification that raises profitability and returns to land (the top row of Fig. 1) provides incentives to expand land area in what is often called Jevon's paradox (Alcott, 2005; Hertel, 2012). However, a number of market effects mediate this effect, especially when viewing intensification at national and global levels (bottom two rows of Fig. 1). These include:

1. A reduction in market prices for products especially for technology-driven intensification that by definition reduces cost of production per unit of output.
2. Spatial shifts in production and therefore demand for land through increased exports from more efficient innovating regions
3. Effects through labor markets, such as when intensification in lowland areas draws labor away from upland frontier areas.
4. Effects through more rapid agricultural growth on overall economic growth and consequently on agricultural wages and demand for food.

At an extreme when all of these market processes are assumed away so that consumption is fixed, cropland use trades off one for one for increased yields. That is, to meet a given level of consumption a

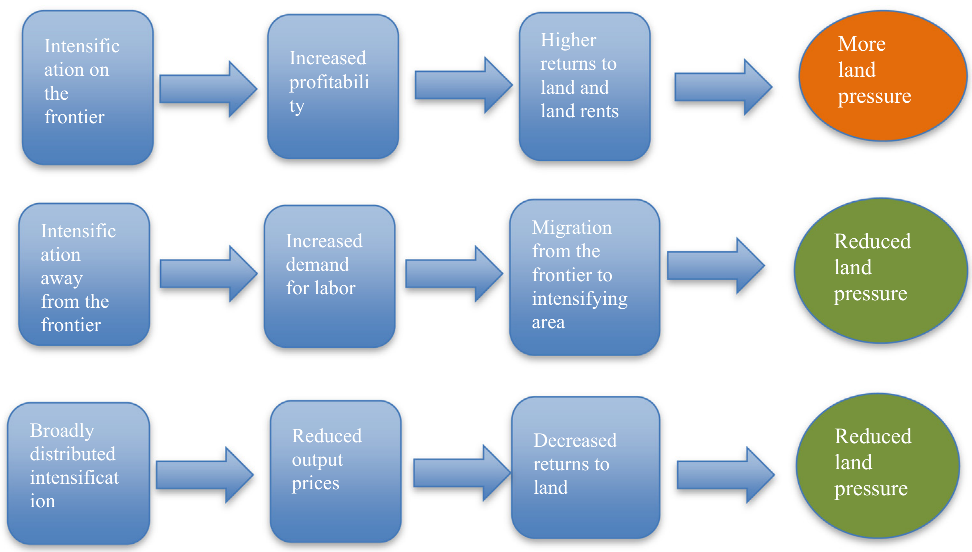

Fig. 1. Examples of pathways from intensification to land use changes.

Table 1
Examples of changes in area, yields and market size associated with periods of major crop growth.
Source: Computed from FAOSTAT.

	Wheat, Sth Asia	Rice, Indonesia	Maize, W. Africa	Soybeans, Brazil	Oil palm, Indonesia
Peak expansion period	1965–84	1965–84	1976–94	1990–2009	1990–2009
Increase in area of crop (%)	61	27	467	169	814
Increase in yield of crop (%)	95	126	55	52	3
Increase in production of crop (%)	213	187	777	310	882
Increase in total arable area (%)	4	0	22	38	49
Extent of increase on the 'frontier'[b]	*	*	**	***	***
Major market for crop[a]	Dom	Dom	Dom	Glob	Glob
Increase in per capita supply in major market (%)	50	67	163	71	181
Average exports as % production	−7	−5	−4	33	73
Likely driver of expansion[b]					
Technology	***	***	**	**	*
Markets	*	*	***	**	***

Notes
[a] Dom—Domestic, Glob—Global.
[b] No of asterisks denote importance

1 percent increase yields reduces demand for cropland by 1 percent. This is generally known as the Borlaug hypothesis (Angelson and Kaimowitz, 2001a; Borlaug, 2007).

Some indication of the relative roles of these intensification processes is provided by a summary of major crop 'revolutions' in the recent past in Table 1. The green revolution in rice and wheat was clearly technology driven but was closely associated with higher input use (fertilizer and irrigation) that substituted for rising land scarcity in Asia. By contrast, West Africa maize revolution was largely based on domestic market expansion (through substitution of maize for traditional staples) and area growth, although new varieties and fertilizer strongly facilitated this change (Smith et al., 1997). Finally, global markets, including exchange rate regimes, are likely to have been the major driver of expansion of soybeans in Brazil and oil palm in Indonesia, although technology also played a significant role in Brazilian soybeans (World Bank, 2009).

The data in Table 1, however, cannot be used to infer that intensification caused land expansion on the frontier even for soybeans and oil palm, due to the multiplicity of pathways from increasing crop production to land use changes. Because of the complexity of these pathways, rigorous econometric methods or models are required to disentangle effects as summarized in the following sections.

4. Technology-driven intensification

Villoria et al. (2014), have recently reviewed the evidence on technical change and land use. Their findings are summarized at three levels, local and country-level, across countries and global.

Most evidence on the effects of technology-driven intensification at the local and national level is based on econometric analysis of household data. These studies show that technological progress at the local or country levels has generally reduced cropland use and deforestation. An important pathway is the link between lowland and upland settings in Southeast Asia that suggest that technologies that employ more labor in the lowlands as was the case for the Green Revolution are likely to discourage forest clearing in the uplands by attracting labor away from the forest margins (Shively and Pagiola, 2004; Maertens et al., 2006). Studies of innovation at the forest margin such as in Mexico

(Deininger and Minten, 1999) and in Malawi (Fisher and Shively, 2007), indicate land saving from technical progress again at least in part through labor market effects. However, at the national level, Villoria et al. (2014) identified two studies that supports Jevons' paradox. One of these was the impact of higher soybean yields on soybean expansion in Brazil that was hypothesized to increase land rents and induce soybean expansion (Garrett et al., 2013).

Many studies have explored statistical relationships between agricultural productivity and land use change by exploiting the variation observed across countries, using national-level data. Barbier (2001), for example, in an analysis of tropical countries for the period 1961–1994, found that agricultural land expansion was significantly and negatively related to cereal yields. More recent evidence suggest a very weak relationship between crop yields and land use (Rudel et al., 2009; Ewers et al., 2009). However, due to methodological issues in identifying causality and defining a counterfactual (i.e. a plausible scenario that models a world in which intensification did not take place), the available evidence from cross-country studies should be taken with extreme caution (Villoria et al., 2014).

There have been many global analyses using economic models of intensification and land use changes including indirect land use changes through trade, in part in response to controversies about biofuels and land use. Several studies have used such models to explicitly quantify the tradeoffs between productivity, cropland use and deforestation.

Two studies of the impact of crop genetic improvement by the Consultative Group on International Agricultural Research (CGIAR) for the period, 1965–2000 suggest that as a result of CGIAR investments in the staple food crops, there was net land-saving of the order of 20–30 Mha (Evenson and Rosegrant, 2003; Stevenson et al., 2013). Although focusing on a restricted subset of yield changes (crop germplasm improvement in developing countries), these estimates of land saving are orders of magnitude lower than predicted by simple estimates that do not take account of feedback loops through prices of products, consumption demand and land-use decisions but nonetheless have been widely cited (e.g., over 1 billion ha by Borlaug (2007)). The net land-saving effects reported by the global modeling of CGIAR impacts still represent a significant positive impact of agricultural research on land use, although dwarfed by the estimated welfare effects of agricultural research on food prices, poverty and malnutrition (Stevenson et al., 2013; Evenson and Rosegrant, 2003).

Most models have focused on alternative scenarios about future land use. For example, Havlik et al. (2013) use GLOBIOM, a partial equilibrium economic model coupled with a grid-cell level biophysical model focused on agriculture and forestry, to quantify the amount of land needed to satisfy the calories needed to feed the projected population in year 2030 if yields are held constant at 2001 levels (the authors cite FAO projections of an increase of 48% and 67% increases in calories from crop and animal products, respectively). They determine that under such circumstances cropland increases by nearly 400 Mha. However, if yields in developing countries would converge with those of developed countries, cropland area expansion by 2030 would be zero.

The most comprehensive global analysis has been carried out by Lobell et al. (2013) use SIMPLE (a simplified partial equilibrium model) to estimate impacts of investing to completely adapt to the effects of climate change on crop yields for the period 2006–50. In their reference scenario, crop yields increase by 60% (taking account of climate change) but this still leads to expansion of cropland by 23% (over 300 Mha), mostly in Latin America and Subsaharan Africa. With perfect adaptation to climate change, yields are 20% higher than the reference, and cropland expansion is 19% lower. However, adaptation focused only on Latin America and Subsaharan Africa has very small global effects on cropland area, but increases expansion in Latin America and Subsaharan Africa – an illustration of the Jevons' paradox.

Finally, Villoria et al. (2013) estimate that a increase of 59% in oil palm yields in Malaysia and Indonesia (enough to close one third of the yield gap over 25 years) would result in forest conversion to cropland of 0.13 Mha in Indonesia/Malaysia but a global saving in land of 0.3 Mha through increased forestland in other countries such as India, Canada, and Brazil, with an overall net reduction in greenhouse gas emissions. Their counterfactual is static as population and capital growth are kept constant at 2004 levels. These findings highlight that even for a specific locally-targeted technological change, global impacts can outweigh local impacts through international trade, at least for a crop that is largely produced for world markets.

Although the above global modeling analyses support global land savings from technology-induced intensification they indicate that in most cases global land savings coexist with continued deforestation, particularly in forest-rich regions. While some of these studies attempt to measure the net value of the forest saved using GHG emission factors and a price of carbon, it is important to recognize that the location of deforestation matters as well. For some metrics, such as unique biodiversity or protection of water bodies, it is of little consolation to have deforestation in areas of high conservation value even if in the aggregate, forestlands are saved and carbon sequestered.

In addition, global economic models are ‘still in their infancy’ with respect to their ability to analyze changes in land use (Schmitz et al., submitted). In particular, results are very sensitive to the modeling of the transformation of land across different uses in crops, pastures and forests where there are few empirical estimates of key parameters such as the effect of prices on the rate of transformation across uses as well as the productivity of new lands brought into production. In addition, most of the existing studies do not capture likely policy responses over the long term. A more than doubling of world prices of wheat and rice as estimated by Stevenson et al. (2013) in the absence of green revolution research, does not take into account likely policy response induced by changes of such magnitudes, such as increased public investment in agricultural R&D and irrigation, given the political importance of the food system. Likewise, expansion of cropland of the order of 300 Mha in Lobell et al. (2013) and Havlik et al. (2013), much of it at the expense of forests, does not capture likely policy responses induced by concerns about forestland conversion. For example, in the past decade, Brazil has implemented strong measures to protect their forest resources in response to threats from cropland expansion into the Amazon biome (Nepstad et al. 2009; Boucher et al., 2013).

5. Market-driven intensification

A much stronger case may be made that intensification induced by new market opportunities has produced significant land use expansion and deforestation. The general consensus is that since around 1990, commercialization of agriculture to serve growing urban and global markets has been the major cause of cropland expansion, much of it at the expense of natural ecosystems (Rudel, 2007; DeFries et al., 2013; Hosonuma et al., 2012; Meyfroidt et al., 2013). This has become especially apparent as commodity prices have risen over the past decade.

Global integration of commodity markets through trade has been identified in many studies in changing the location of production toward more land-abundant regions (Golub and Hertel, 2008). Growing international trade alone may account for 24% of the global land footprint (Meyfroidt et al., 2013), concentrated in a few countries such as Brazil and Indonesia. Sharply rising incomes in mega-countries such as China have been a major driver of this type of land use change. The recent oil palm expansion in Southeast Asia (Koh and Wilcove, 2008), soybean expansion in Brazil and Argentina (Garrett et al., 2013; Nepstad and Stickler, 2008) and an earlier surge in banana exports in previously forested areas of coastal tropical Latin America (Wunder, 2001) are all examples of market driven intensification, in some cases aided by improved technologies.

From 1999 to 2008, the three most important crops in agricultural expansion in tropical countries were soy, maize and oil palm – all largely to serve global markets or new biofuel markets (Phalan et al., 2013). On a smaller scale, other commodity exports, such as rubber and cocoa, have also expanded rapidly on the forest margins in response to strong global demand and higher prices. Rapid urbanization is also a major driver of commercial agriculture to serve domestic markets that often leads to land expansion (DeFries et al., 2010; Meyfroidt et al., 2013).

However, caution is needed interpreting these trends. Contrary to popular perceptions soy in Brazil has largely displaced pastures (Morton et al., 2006; Barona et al., 2010; Pacheco, 2012), although some argue that soy has indirectly caused deforestation by displacing pastures into the Amazon biome (Barona et al., 2010; Pacheco, 2012). The relationship between pasture and cropland is critical to understanding the overall impact on deforestation from agriculture but poor quality data on pasture areas at the global level constrains deeper analysis. In a similar manner, the relationship between the establishment of oil palm plantations and deforestation is often mediated by other drivers of forest loss in Indonesia such as the timber industry. The area planted to oil palm in Indonesia over the period, 1991–2007, of about 5.5 Mha accounts for only a small fraction of forest loss of 30 Mha – much forest land has been allocated to oil palm and other plantation crops in which the timber was extracted and then no oil palm was planted (Sheil et al., 2009).

Considerable evidence suggests that land use expansion is especially responsive to commodity prices. Richards et al (2012) examined historial trends in soybean prices, exchange rates, and cropland dedicated to soybean in Bolivia, Paraguay and Brazil, finding that 8 Mha of soybean production in these countries, or 31% of the current area, was developed as a supply response to the devaluation of local currencies in the late 1990s. All analysts agree that over the past decade, investing in oil palm has been a highly profitable activity (Butler et al., 2009), as vegetable oil prices have risen. Road building, especially in Latin America (Rudel, 2007), has also been implicated in commodity intensification, partly because roads provide better access to markets and higher farm gate prices.

Finally, we note that like technology-driven intensification, market-driven intensification must consider 'leakage effects" through trade. These indirect land use changes have been extensively analyzed in the biofuels literature suggesting that rapid development of new markets for biofuel feedstocks in the USA has led to indirect increases in land use in countries directly connected to world markets, such as Brazil and Argentina (Hertel et al., 2010; Searchinger et al., 2008).

6. What type of intensification?

The recent call for 'sustainable intensification' (Garnett et al., 2013) to minimize tradeoffs with natural ecosystems recognizes that not all intensification experiences are equal. Intensification that degrades the environment including surrounding natural systems through agro-chemical pollution incurs significant environmental costs, even if it saves land (Smith, 2013). Land sharing approaches have also been proposed as a way of minimizing biodiversity losses. Impacts of intensification on biodiversity depend not only on the share of cropland in the landscape but also the contrast between the agricultural production system and the endemic ecosystem (Cunningham et al., 2013). Smallholder rubber agro-forests in Indonesia, for example, conserve 75% of species of natural forests (Geist et al., 2006). Landscape approaches that manage a mosaic of natural vegetation remnants and crop production may support a higher level of natural biodiversity but this is not guaranteed. Such mosaics are more common in smallholder-based systems (Sayer et al., 2012). However, Phalan et al (2011) show that land sparing through a clear separation of intensive agricultural systems and protected wild areas is a more effective strategy for bird species conservation than land sharing in a mixed mosaic of land-use in Ghana.

Sustainable intensification approaches often start from the perspective that there is a free lunch–that "closing the yield gap" through better management of land and water resources can produce win-win outcomes for both agricultural production and the environment. However, the evidence of wide scale adoption of natural resource management technologies by smallholders in developing countries remains either absent or is restricted to small niches (Renkow and Byerlee, 2010). The barriers to adoption are many (Jack, 2013), either in terms of opportunity costs of labor, missing institutions (e.g. secure property rights or land tenure) or simply that at prevailing capital costs for smallholders it is not profitable for farmers to make the changes required to adjust agricultural production towards delivering ecosystem services. In particular, in situations of poor forest governance and ready availability of new land, farmers on the forest frontier have few incentives to intensify.

While this outlook may seem pessimistic, the emerging land-saving literature tells us that episodes of agricultural intensification that may look like win-lose outcomes for agricultural production and the environment when viewed from a local perspective (e.g. Angelsen and Kaimowitz, 2001b) may actually be win-win or net win when analyzed at landscape scale (e.g. Phalan et al. 2011) or globally (e.g. Stevenson et al. 2013). However, the conclusions from these studies are sensitive to the choice of metric used (e.g. hectares of forest or aggregated global GHG emissions). In many cases, important metrics are omitted from the analysis (e.g. relative importance of biodiversity in "lost" and "gained" forests in different parts of the world).

7. Policy implications

The evidence briefly summarized above suggests that at a global level, investment in R&D to improve productivity remains one of the best ways to reduce pressure on increasingly scarce land resources and conserve natural ecosystems. Indeed, agricultural R&D to save land may be one of the most cost-effective ways to mitigate climate change from deforestation (Lobell et al., 2013). However, global aggregates often hide important spatial shifts in production that may involve major land use changes in ecologically sensitive areas.

At the local level, intensification, especially that driven by market opportunities, often drives expansion of the crop frontier by providing more profitable opportunities for land use and stimulating rent-seeking behavior of actors that undermines good governance of forest resources. However, the direction and level of land use changes is very location specific, depending on many factors such as land and forest governance and labor markets. In particular, it should not be assumed that investing in R&D will lead to cropland expansion on the frontier (e.g., Phelps et al., 2013), while assumptions that increased yields will save land at the local level may be equally unrealistic (e.g., Gockowski and Sonwa, 2011). In these cases, local effects are often outweighed by effects at higher scales mediated by markets.

At both global and local levels, intensification is only one of many factors driving land-use change and deforestation and improved productivity is unlikely in itself to halt cropland expansion without improved governance and incentives to preserve natural systems. Programs to promote expansion at the intensive margin are unlikely to succeed if it is cheaper for farmers to expand at the extensive margin where forestland is readily available and poorly governed.

Policies to reduce the effects of intensification on land use changes also need to be targeted spatially, especially on the tropical forest margin. An estimated 80% of agricultural expansion in the tropics has been at the expense of primary or secondary forests (Gibbs et al., 2010) (although globally, less than 10% of agricultural area expansion has been from deforestation (Lambin, 2012)).

These policies fall into three groups:

Improving land and forest governance: Better governance of land and forest resources is the most critical area for policy interventions. A range of measures are needed including protection of forests of high conservation value, environmental regulations on forest clearing, land use zoning, and satellite monitoring of forest clearing. A combination of such measures seems to have been effective in sharply slowing deforestation in Brazil (Macedo, et al., 2012; Boucher et al., 2013).

Market certification: The private sector is putting in place standards to certify a range of tropical commodities, such as soy, palm oil, and sugar, to meet minimum social and environmental standards in their production processes, including land use changes. The challenge is to increase the share of certified produce especially in emerging markets that now consume the bulk of these products in order to achieve global impacts. In the case of soy, a moratorium by export companies on purchases from newly cleared forest land seems has been effective in Brazil, though this has possibly led to deforestation being displaced to other Amazon fringe countries (e.g. Bolivia, Peru) where such a moratorium is not in effect. This is example of another type of 'leakage effect' where improved land and forest governance or certification in one area has spillover effects through trade that may increase land expansion in other areas with weaker governance (Lambin and Meyfroidt, 2011).

Payments for environmental services: The value of carbon sequestration in tropical forests and the implementation of REDD should provide incentives for producers to preserve land under natural vegetation by intensifying on existing cropland. However, it is not clear at current prices of carbon whether REDD will give sufficient incentives in times of commodity booms (Butler et al., 2009) and there is little evidence to date of successful implementation of payments for environmental services leading to a reduction in deforestation.

Finally, the available evidence reviewed in this paper suggests that given likely rates of technological progress and future growth in demand for food, the world is still far from "peak cropland" as claimed by Ausubel et al. (2013). Nearly all estimates and models project that considerable expansion of cropland will continue to 2030 or 2050, mostly in the tropical land-abundant countries. Efforts to scale up investments in technological progress, improve governance of forests of high conservation value, and encourage further land expansion in less environmentally sensitive areas can reduce costs of further cropland expansion, but they must be considered globally taking account of 'leakage' effects through trade. These leakage effects combined with the global dimensions of food security and environmental services, provides strong justification for global co-financing of these investments.

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