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Does intensification slow crop land expansion or encourage deforestation?

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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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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