LEAVES | Leveraging Agricultural Value Chains to Enhance Tropical Tree Cover and Slow Deforestation

BACKGROUND PAPER

PROFOR
INNOVATION AND ACTION FOR FORESTS

Agriculture, Globalization, and the Demand for Land in the Tropics

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Introduction

There has been recent speculation that the world has reached 'peak cropland' (Ausebel et al. 2013). Indeed, at the global level, cropland area expanded at the very modest rate of 0.12% annually from 1991 to 2015. However, a decline in cropland in high income countries in temperate areas has been more than matched by a sharp increase in cropland area in tropical low and middle-income countries. Cropland in low and middle-income countries nearly doubled from 1991 to 2015 to almost 250 million hectares (Mha). As much as 75% of this expansion has been at the expense of tropical forests (Gibbs et al. 2010).

During much of history, the expansion of cropland in the tropics has been driven by population growth and the need for additional land for food production. However, Nepstad et al. (2006) and others identified an important shift. Since around 1990, a handful of commodities to serve world markets have accounted for the bulk of expansion of cropland was well as pasture land in the tropics. It is widely agreed that the most important of these commodities are beef cattle, soybean for animal feed, and palm oil for food and other uses (Nepstad et al. 2006; Seymour and Busch 2016).

This paper reviews the role of global commodities in the expansion of agricultural land use in three dimensions. First, the paper aims to understand the major drivers in the demand for agricultural commodities in the recent past. Second, it projects each of these drivers forward to provide demand estimates to 2050. Finally, it estimates the likely contribution of intensification and area expansion to supplying the demand for beef, soybeans, and palm oil to 2050.

The policy brief focuses on soybeans and palm oil, where it shows that the five major drivers of tropical land use in the past 25 years have entered a new phase that will sharply slow demand for these commodities. The brief also reviews the outlook for beef which has expanded only modestly in recent years and notes considerable uncertainty with respect to future global trade in beef. However, in the case of beef production, there are also major untapped opportunities for intensification that provide a window for meeting future beef demand without deforestation, provided that appropriate land and forest policies are in place.

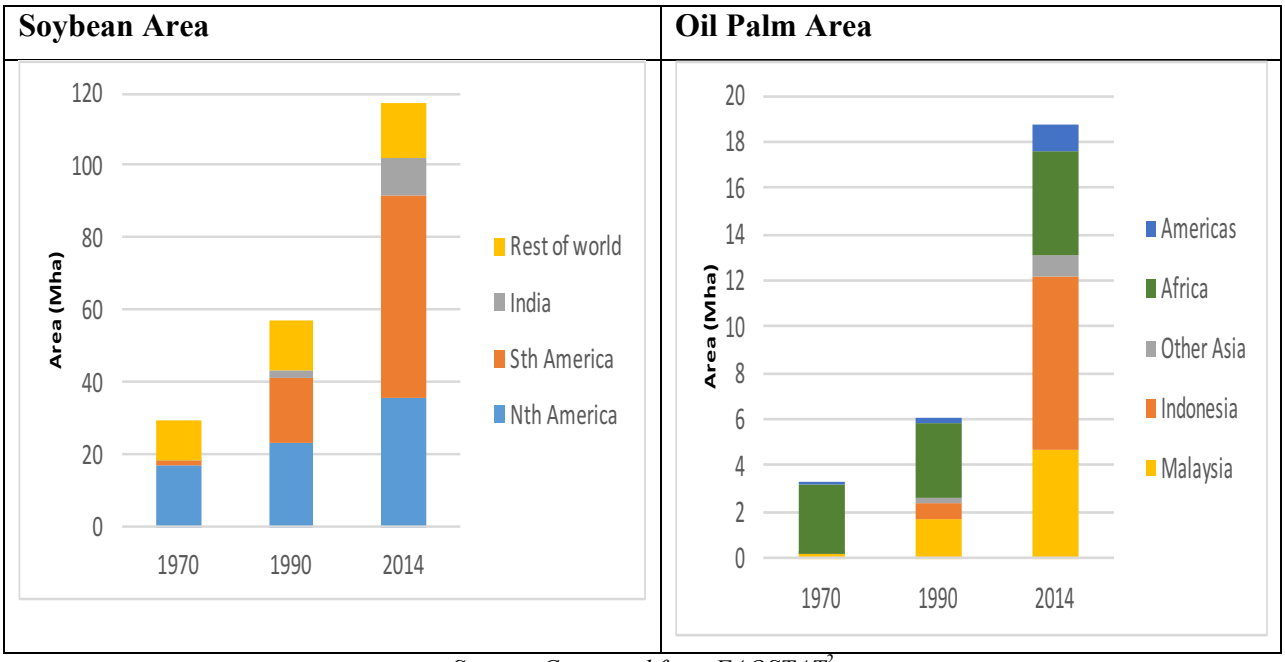
The Big Three Commodities, Land Use Change, and Deforestation

Rapid expansion in area for soybeans and oil palm was highly concentrated in a few countries. (Figure 1) Soybeans were largely provided by expansion in South America, especially in Brazil's vast Cerrado savanna and woodland biome that has been converted into a 'soy basket' for the world. Together with the forests in the Amazon biome, the Cerrado also provided much of the increase in pasture area to produce beef. Over the period from 2001 to 2013, 17% of the new cropland and 37% of the new pasture land replaced land previously under forests in South America (Graesser et al. 2015).

Growth in palm oil demand has largely been supplied by expansion in Indonesia and the eastern states of Malaysia. In Indonesia, an estimated 33% of newly established oil palm was on land provided by clearing forests (Gunarso et al. 2013). However, oil palm directly accounted for 10% -18% of total deforestation in Indonesia in the early 2000s, suggesting there were other important drivers of deforestation as well (Busch et al. 2014; Gunarso et al. 2013).[1]

[1] Some of the forest clearing attributed to logging may have been motivated by the objective of planting oil palm.

Figure 1. Expansion of Soybean and Oil Palm Area, 1970-2014*



Source: Computed from FAOSTAT[2]

**: The Y-axis scale for soybeans is 6 times that for oil palm.*

The most important agricultural commodity in tropical deforestation has been conversion of forests into pastures for beef cattle, especially in South America where the average rate of conversion was 2.7 Mha per year for 2000-2011 out of an estimated total global rate of tropical deforestation of about 8 Mha (Henders et al. 2015; Busch et al. 2017). Pasture land has also expanded into the savanna areas where it is often a first step toward the conversion to more intensive and profitable soybeans. Some evidence suggests that soybean expansion in the savanna displaces pastures into the Amazon and indirectly causes deforestation (Richards et al. 2014).

Various estimates of greenhouse gas emissions from land use change support these data. Henders et al. (2015) estimated that beef, soybeans, and oil palm, respectively, accounted for 1.0, 0.1, and 0.2 Gt of CO_2 emissions per year in 2000-2011 out of total emissions from land use change of 3.7 Gt CO_2 /y. However, these numbers for soybeans and oil palm are certainly underestimated as they do not take account peatlands (for oil palm), soil carbon, and indirect effects (for soybeans).

Many observers who view this rapid expansion of land area in the tropics extrapolate the trend forward and conclude that much of the remaining forests will be destroyed by 2050 (Koh 2007; Malins 2018). However, such dire views do not account for an abnormal series of events that have converged to drive very rapid demand for soybean and palm oil over the past two decades.

[2] FAOSTAT, 2017. www.faostat.fao.org. Accessed online 1 March 2018.

Five Drivers of Global Commodity Demand, 1991-2015

The period from 1991 to 2014 was one of unprecedented growth in the demand for edible oil and oil meal. This growth was greatly underestimated by major international organizations at the time. Projections made around 2000 by the United Nations Food and Agricultural Organization (FAO) and the International Food Policy Research Institute (IFPRI) were compared to the actual outcome in 2014 (Bruinsma 2003; Rosegrant et al. 2001). While the projections were quite accurate for major staples such as wheat and rice, actual consumption of soybeans in 2014 was 25%-40% above projections, a huge margin of error in such a short space of time. Similarly, large underestimation of the consumption for all uses of maize and poultry suggests that the rapid increase in demand for feed grains was not anticipated. Notably, the projections did not include separate estimates for palm oil, now one of the world's most important commodities.

Five factors converged to create a perfect storm that drove demand for oil crops from the early 1990s.

1. Unprecedented income growth in middle-income countries

After relatively slow growth through the 1980s, per capita income growth in middle-income countries led by China exploded in the late 1990s to reach a peak of 6.2% in 2007 before falling to around 3% per year in 2015.[3] With middle-income countries accounting for about three quarters of the world's population, and with income elasticities of about 0.7 for meat and 0.4 for edible oils, income growth rather than population growth drove global commodity demand. In Asia, per capita food consumption of edible oils increased by 35% and meat by 85% from 1991 to 2013, while per capita food consumption of cereals declined slightly.[4]

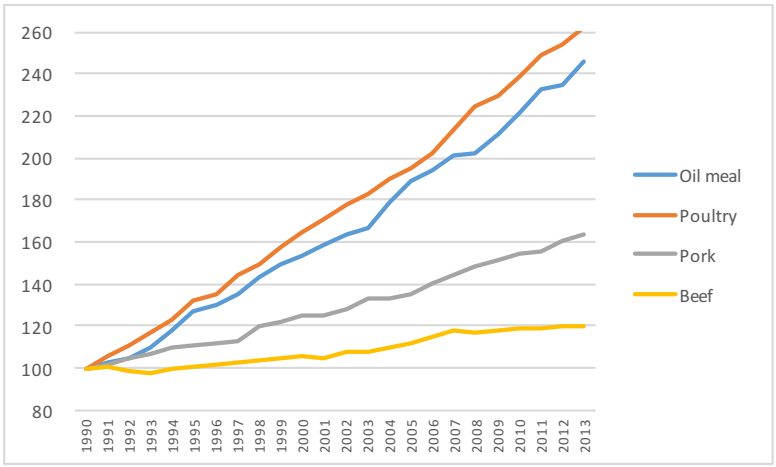
Demand for meat, especially poultry and pork, in turn fuelled a rapid increase in use of feed grains. Poultry was the most dynamic sector based almost entirely on the growth of intensive production systems using prepared feed mixes. Oil meal, a major ingredient in feed mixes, closely tracked the growth of the poultry industry, although a substantial share was also used in the second most dynamic sector, the pig industry, especially in China (Gale 2015). (Figure 2), Soy meal accounts for over 60% of all oil meal.

2. An upsurge in biofuels

A second factor was the rise of the biodiesel sector from the early 2000s following the spike in the price of fossil fuels combined with low prices of agricultural commodities in the early 2000s that made biofuels economically and/or politically attractive. The use of vegetable oils for biodiesel accounted for over one third of the growth of all vegetable oil consumption from 2005 to 2014. The largest biodiesel industry was established in the EU, based on mandates to replace 10% of transport fuel with renewable energy sources. Brazil and the USA also became significant producers of biodiesel. Palm oil and soy oil accounted for 56% of all oil consumed in the biodiesel industry but use of rapeseed another major feedstock likely induced significant substitution by palm and soy oil in food uses of edible oils (Byerlee et al. 2017). Driven by mandates, the use of vegetable oils in biodiesel is insensitive to market forces, and their use for biodiesel has continued to rise despite the falling prices of fossil fuels and rising prices for vegetable oils.

[3] World Bank, https://data.worldbank.org
[4] FAOSTAT, 2017. www.faostat.fao.org. Accessed online 1 March 2018.

Figure 2. Indices of Oil Meal Use for Feed Relative to Poultry, Pork, and Beef Consumption at the Global Level, 1990-2013 (1990 = 100)



Source: Calculated from USDA-PSD (Production, supply, and distribution)[5]

3. Trade liberalization under WTO

Most of the major middle-income countries joined WTO around 2000. China joined in 2001, and India joined in 1995. As a result, trade in vegetable oils and oilseeds was liberalized more than for any other agricultural commodity. Demand for these products grew faster than for cereals, and they were considered less strategic than the major staples, so reliance on imports to meet demand made economic sense and was politically more feasible.

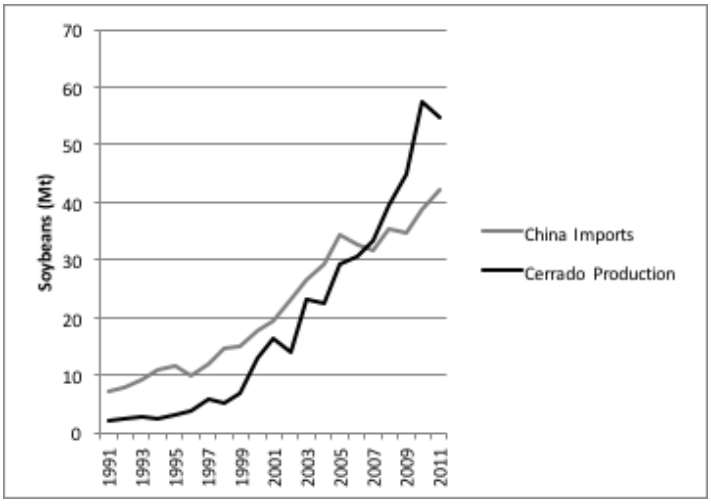
The most spectacular growth in trade was in soybeans to China, which imported almost no soybeans in 1995 and now imports nearly 100 million tons (Mt). This upsurge is without parallel in the world history of agricultural commodity trading. Brazil became a major supplier of soybeans to China, and growth in soybean production in the Cerrado of Brazil closely tracked imports by China.[6] (Figure 3) Similarly, India became the world's largest consumer of palm oil based entirely on imports from Indonesia and Malaysia.

As a result of trade liberalization, soybean became the world's most valuable agricultural commodity in trade in the late 1990s and is now almost double that of wheat, which had held first place in world trade for over a century. Likewise, palm oil is now the third most valuable traded crop commodity and is poised to overtake wheat in the next few years.

These dramatic shifts in world trade can be viewed as trade in 'virtual land' (and water) from land-abundant to land-scarce countries. China 'imports' about 50 Mha of land, mostly due to soybean imports from Latin America (Qiang et al. 2013).[7]

[5] https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQueryAccessed online 1 March, 2018. Accessed online 1 March 2018.
[6] Recent analysis by Godar et al. (2015) provides a subnational breakdown of the origins of traded commodities by destination. Relatively speaking, China sources a higher share of its soybeans from southern Brazil than other importers such as the EU. However, China is still by far the largest sources of soy imports from the Cerrado and Amazon biomes.
[7] Qiang et al. 2013. Updated data from Quiang from 2012 to 2017.

Figure 3. Chinese Imports of Soybeans and Production of Soybeans in the Cerrado, Brazil, 1991-2011



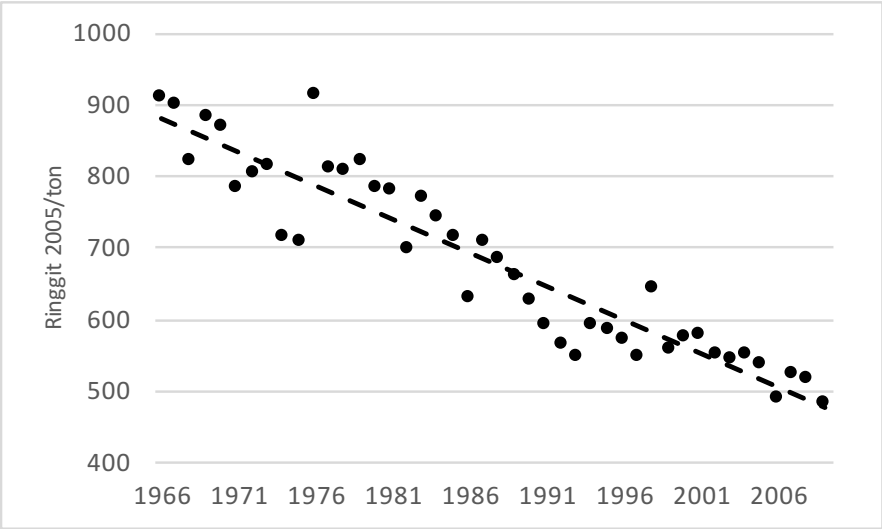
Source: Byerlee et al. 2017

4. Supply-side drivers—technologies and subsidies

On the supply side, both technical progress and subsidies have spurred a decline in the unit costs of production of palm oil and soybean. In the case of palm oil, the unit cost of production declined by about half from 1966 to 2010 due to yield progress, labor saving technologies, and improved efficiency in oil extraction. (Figure 4) Soybeans in Brazil also enjoyed strong technical progress with yield growth of 2.0% annually since 1976 and a dramatic rise in double cropping since 2000. (Figure 5) Along with almost universal adoption of soil amendments and conservation tillage, the development of varieties suited to low latitudes, acid soils, and for double cropping with maize by Embrapa have contributed to this progress. Brazil has had one of the world's fastest rates of growth in total factor productivity of agriculture (USDA 2018). Growth in the state of Mato Grosso, the center of the 'soy basket,' was double the rate for Brazil as a whole (Gasque 2013).

State subsidies that reduced the costs of land and capital reinforced technical progress and accelerated the cost competitiveness of the two major oil crops. In the case of oil palm, Indonesia and the states of Sarawak and Sabah in Malaysia have extensively provided concessions of state-owned land, often forested, at nominal rates as an incentive to private investors. In Brazil, the national development bank, *Banco Nacional de Desenvolvimiento Economico e Social* (BNDES), has financed land development and working capital for soybean expansion at rates significantly below market rates.

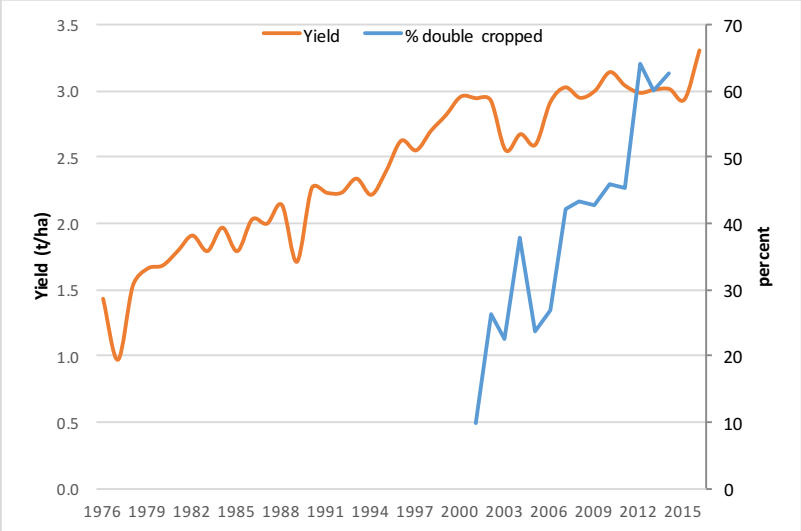
Figure 4. Real Cost of Production of Palm Oil, United Plantations, Malaysia, 1966-2010.



Source: Bruno 2014

The overall result has been a long-run decline in the cost of the production of soybeans and palm oil. Palm oil is the lowest priced oil on world markets and soy meal is one of the lowest cost protein meals for feed.

Figure 5. Intensification of Soybean Production in the Cerrado, Brazil



Source: Data from CONAB[8]

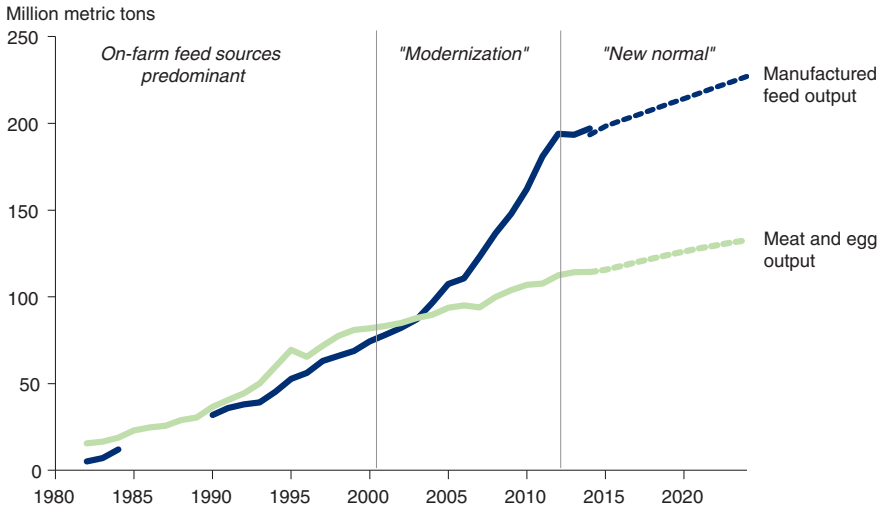
5. Massive substitutions

Finally, highly competitive prices and trade liberalization have resulted in massive substitutions by palm oil in food consumption and soybean meal in feeds. Eighty percent of edible oil consumed in Indonesia was coconut oil in the 1970s. Today, it is nearly 80% palm oil. India did

[8] http://www.conab.gov.br/conteudos.php?a=1252&Pagina_objcmsconteudos=3#A_objcmsconteudos. Accessed online 1 March 2018

not consume palm oil until 1995. Today, it accounts for nearly half of consumption and has accounted for two thirds of the growth in consumption of all oils since 1995. Similarly, the Chinese feed industry has undergone a massive structural change by developing a modern feed industry that substituted soy meal for traditional feeds, such as crop by-products, and increased the protein content of feeds. (Figure 6) These substitutions have significantly added to the growth in consumption of palm oil and soybeans above the already high rates due to income growth and biofuels.

Figure 6. Growth of the Prepared Feed industry in China Showing Structural Change, 2000-2012



Source: Gale, 2015

Beef—A Different Set of Drivers

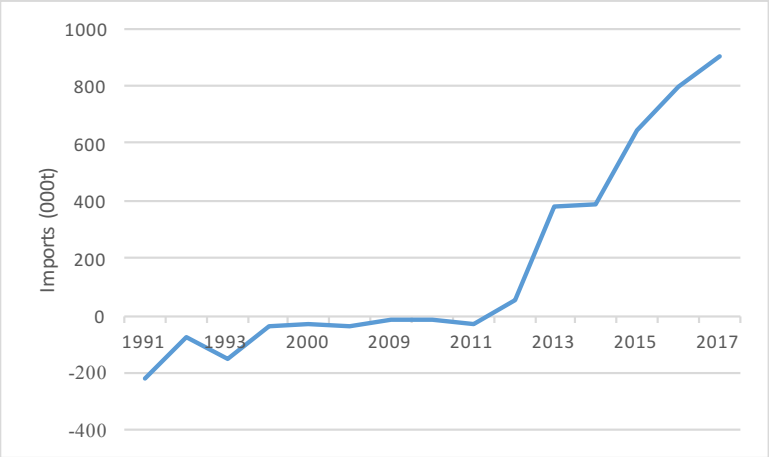
Many, if not all, of the five drivers of the rapid expansion of oil palm and soybeans are relevant for other tropical commodities, especially rubber and cocoa, that have resulted in deforestation in recent decades. However, beef is different in a number of respects.

First, global consumption of beef has expanded slowly at only about 1% annually since 1991, compared to 5% or more for soybeans and palm oil. Second, only about 15% of world beef production is traded. However, because of its high per unit value, this still makes it the third most valuable agricultural commodity in world trade. Third, much of the growth in the demand for beef has been generated by domestic consumption. In Brazil, domestic markets have accounted for two thirds of demand growth since 1991. Higher incomes in Brazil have transformed Brazil into a country with one of the highest per capita consumption of beef (38 kg per year).

At the same time, global demand has played an important role in stimulating beef production, especially in Brazil. In the early 1990s, Brazil was a minor player in world beef markets, but this changed in the early 2000s with the collapse of the Russian livestock sector and the incidence of 'mad cow' disease in the U.S. that limited US beef exports in many markets. Much of the beef for Russia was sourced in the Brazilian Amazon on newly deforested lands (Schierhorn et al. 2013). More recently, China has converted from being an exporter of beef to a major importer, with Brazil a major supplier. (Figure 7) With stagnant demand for beef in Brazil and elsewhere

in tropical Latin America, the growth of the beef industry is increasingly linked to global markets.

Figure 7. Recent Growth in Beef Imports to China in the 2010s



Source. USDA-PSD[9]

Outlook to 2050—A New Normal?

Future demand for edible oils for food use was estimated to 2050 based on income growth, population growth, urbanization, and shifts in diets due to health (Byerlee et al. 2017). To estimate future demand for meat and soybeans, a combination of FAO and IFPRI projections to 2050 were used (Alexandratos and Briunsma 2012; IFPRI 2017). Demand for soymeal was based on FAO projections, but with allowance for increased efficiency in feed conversion and further substitution of soymeal for other protein meals (Byerlee et al. 2017). Finally, demand for feedstocks for biodiesel was estimated by examining mandates and prospects for the eight major biodiesel industries in the EU, USA, Brazil, Argentina, Colombia, Indonesia. Malaysia, and Thailand. (Byerlee et al. 2017). [10]

The main results of this analysis presented in Figure 8 suggest a sharp slowdown in demand for the two major oil crops, palm oil and soybeans, except in sub-Saharan Africa where growth may accelerate due to high population growth combined with positive income growth. (Figure 9) Soybean demand in turn reflects a slowdown in poultry consumption with slower income growth and a falling income elasticity. Projections of FAO and IFPRI to 2050 are very consistent for poultry with an annual growth rate of 1.8% to 2050, only half of the recent growth rate.

For beef, IFPRI projects a slightly higher demand growth at 1.4% annually versus 1.2% projected by FAO. IFPRI also projects changes in net trade to 2050. The major finding of the IFPRI analysis is that the southern cone of Latin America (Brazil, Argentina, Paraguay and Uruguay) will increase its dominance of beef exports rising from 3.8 Mt in 2010 to 11.5 Mt in 2050. On the import side, the largest growth will be in sub-Saharan Africa and South Asia (minus India). Notably, beef imports by China are expected to double by 2030 but then decline, presumably due to negative population growth and a growing domestic beef industry. Export

[9] https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQueryAccessed online 1 March 2018. Accessed online 1 March 2018.
[10] About 6% of edible oil is used for other industrial uses. Demand for these uses was assumed to increase in direct proportion to GDP growth.

growth from Latin America of about 2.8% per year to 2050 will continue pressure to expand into forestland as discussed below.

Figure 8. Projected Annual Growth in Global Demand for Soybeans, Palm Oil, Chicken, and Beef to 2050 Relative to Actual Growth from 2000-2013

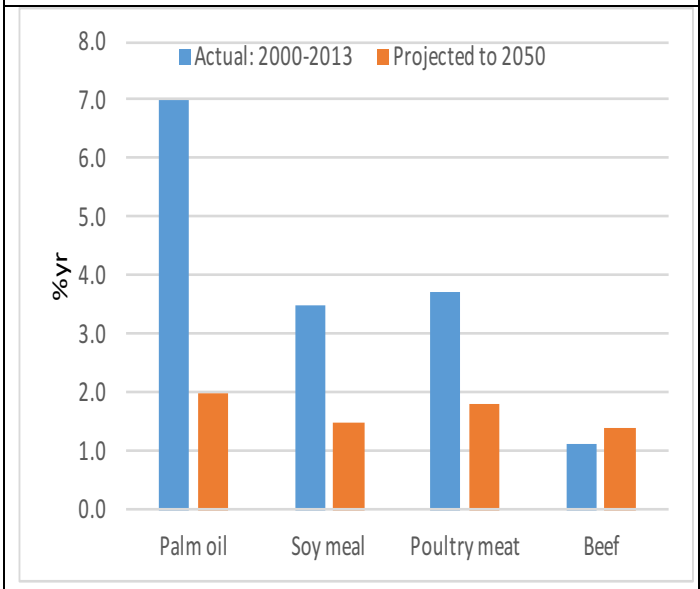
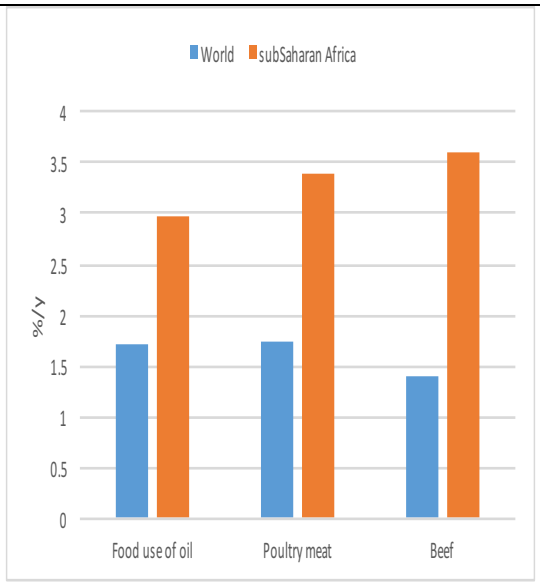


Figure 9. Projected Annual Growth in Demand in Food Use of Vegetable Oils, Poultry Meat, and Beef to 2050 in sub-Saharan Africa Relative to the World



Source: Projections of oils and soy meal from Byerlee et al, 2017 using 2013 as a base. Projections for poultry and beef from IFPRI (2017) using 2010 as a base.

Projections to 2050 are fraught with uncertainty, and these are no exception as summarized in Table 1. One of the big uncertainties is the growth of meat consumption by the 40% of the world's population who still eat less than 20 kg per capita, especially India with its cultural constraints on meat consumption and sub-Saharan Africa where future economic growth is debated. Aquaculture, which is not considered in this analysis, is one of the world's most dynamic industries, and it could become a major producer of soymeal by 2050. On the other hand, in rich countries, mounting concerns about the health, ethical, and environmental impacts of meat consumption may accelerate a trend away from meat, especially beef. This trend may also extend to middle-income countries as evidence by the recent campaign against meat consumption in China.[11] Furthermore, new industries in the form of cultured or synthetic meat and synthetic proteins to substitute for soy meal could come on stream before 2050 (Shapiro 2018).

Finally, while the IFPRI projections consider the impacts of climate change, there is inherently much uncertainty about how climate change together with trade will shift global 'breadbaskets.' For example, oil palm is likely to be negatively affected by longer and more severe dry seasons in many of its current production zones such as. Thailand), while soybean and rapeseed could shift their geographic centres of production toward higher latitudes, especially to Russia and Ukraine that have the available land resources for agricultural expansion. While this would not

[11] https://www.theguardian.com/world/2016/jun/20/chinas-meat-consumption-climate-change

save land as oil palm is a more efficient producer of vegetable oils, it would relieve pressure on remaining tropical forests.

Table 1. Major Drivers of Recent Growth in Demand for Oil Crops and Future Prospects

Driver, 1991-2015	Why the Future is Different	Major Uncertainties
Rising incomes in middle income countries	Sharp slowdown in income growth in the past decade, except for India where meat consumption is very low. Declining income elasticity for edible oils and meat as consumption rises	Meat consumption in the bottom 40%, especially in India with cultural constraints, and in Africa, where future income growth is uncertain. Increasing awareness of health, environmental, and ethical issues in the production and consumption of meat may accelerate a trend away from meat, especially beef, in high and upper middle-income countries.
Biodiesel	EU reaching mandate levels. Bans on the future use of palm oil in EU.	Success of major Indonesian and Brazilian initiatives in biodiesel.
Liberalization of trade	Growing import protection. India has just doubled the tariff on palm oil.	China's policy on protecting its beef industry and investment in the African beef industry.
Supply side	Increasing transactions costs of expanding land area.	Effectiveness of the zero-deforestation initiative in Indonesia and new initiatives to conserve the remaining Cerrado. Impacts of climate change in shifting the competitiveness of different oil crops.
Substitutions	Limited opportunity for further substitutions since the share of soy meal in rations and palm oil in edible oils already high.	Prospects for cultured and synthetic meat and synthetic protein to substitute for soy meal.

Prospects for Intensification and Implications for Land Use

With estimates of demand for the three major commodities implicated in tropical land use change, the next task is to decompose future contributions to supply into components due to likely intensification and a residual due to land use changes. It is important to note that intensification is not a panacea for saving land, and to some extent, it is endogenous to policies on protecting natural land areas. Before making such a decomposition, this paper first discusses the major debates about intensification.

Debates about Intensification and Land Use

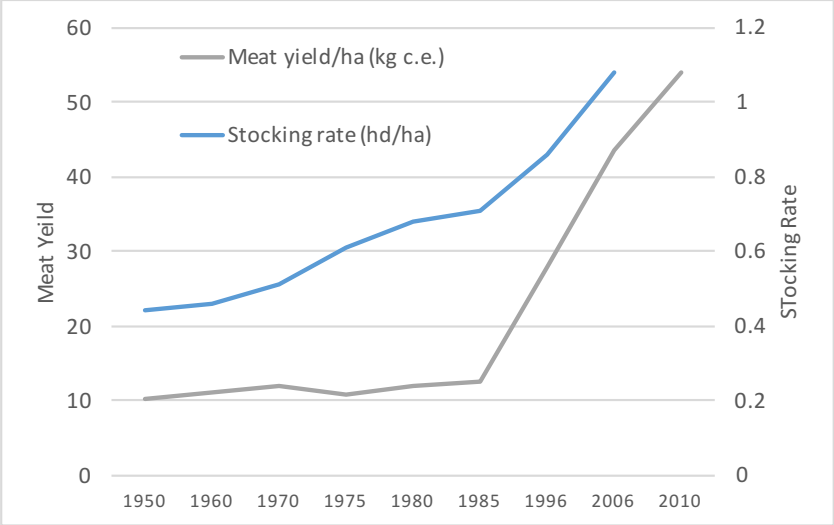
At first sight, intensification of land use seems an obvious strategy for meeting increased demand, slowing farmland expansion, and saving forests. This is commonly known as the Borlaug hypothesis after Norman Borlaug, the Nobel Laureate and "father of the green revolution", who posited that the green revolution saved about 1 billion ha of crop land (Borlaug 2007). More recent analysis using economic models that account for market responses have placed this figure at about 150 Mha (Hertel et al. 2014).

However, there is a rich literature that suggests a more nuanced story. Angelsen and Kaimowitz (2001) drew attention to "Jevon's paradox," where the availability of profitable technologies for intensifying farming on the frontier provides incentives for farmers to expand agricultural area at the expense of forests and savannas. One of their most convincing cases is that of soybeans, where new varieties suited to low latitudes, combined with soil improvement technologies, led to rapid gains in yields of soybeans in the Brazilian Cerrado. Together with strong global markets for soybeans, this promoted the rapid expansion of soybeans in the Cerrado (Kaimowitz and Smith 2001; Barretto et al. 2013; Garrett et al. 2013).

Economists have reconciled these conflicting views in terms of the nature of the market facing producers. If farmers on the frontier are selling into a global market and do not affect world prices, as in the early years of soy expansion in Brazil, Jevon's paradox is likely to prevail. However, for major players in world markets, expansion on the forest frontier reduces world prices and slows land expansion. In a global market, land saving in aggregate may still be consistent with land expansion on the frontier. For example, Villoria et al. (2013) modelled the impacts of the closing of the oil palm yield gap in Southeast Asia. This led to a small expansion of oil palm in Indonesia at the expense of forests, but due to lower palm oil prices, the area under oil crops in other parts of the world declined even more. Although Villoria et al. (2013) showed a net reduction of greenhouse gas emissions by raising oil palm yields, they were not able to evaluate net impacts on biodiversity, which could be negative due the higher biodiversity of tropical forests.

Finally, intensification must consider reverse causality when the availability of cheap land to convert to agricultural uses acts as an incentive to 'extensify,' rather than intensify. In Brazil, there is evidence that farmers have rapidly intensified beef cattle through improved pastures and herd improvement and management as the transactions costs of clearing new land rise due to better monitoring and enforcement of conservation requirements and intensified soybeans through adoption of double cropping, mostly soybeans with maize. (Figures 5 and 10). There is also evidence that these innovations have contributed to substantial land saving (e.g., Lapola et al. 2014; Vale 2015; Cohn et al. 2014).

Figure 10. Intensification of Beef Production in Brazil since 1990



Source: Martha 2012. Stocking rates have been updated from FAOSTAT.[12]

Prospects for Further Intensification

The potential for further intensification varies substantially among the three commodities and by region.

Soybeans

For the big producers and exporters of soybeans, yields are already around 3 tons per hectare (t/ha) and the yield gap is the lowest of the world's major crops (Fischer et al. 2014). Modest genetic gains in yield potential should contribute to an overall yield growth of 0.5% per year (Byerlee et al. 2017). The one region where there is a large yield gap is India, which has experienced the second largest expansion in soy area in the past 25 years (10 M ha), but where yields are still less than 1 t/ha. India is a net soy meal exporter but is likely to convert to an importer with continued rapid growth in its poultry industry. Narrowing the yield gap would reduce India's pressure on world markets and help sustain long-run yield growth at a modest 0.7% per year (Byerlee et al. 2017).

Oil palm

Yield gaps in oil palm grown on large plantations are also fairly modest and estimated at about 30% relative to the top yielding plantations (Woittiez et al. 2017; Fischer et al. 2014). Part of this yield gap reflects labor scarcity and rising wages that have reduced the frequency of harvesting. Progress in mechanical or robotic harvesting could significantly reduce this part of the yield gap. In Indonesia, the yield gap is largest for independent smallholders, averaging around 50% relative to attainable yields with suboptimal use of fertilizer as the major contributor (Euler et al. 2017). The gap is even greater for African smallholders who average less than one quarter of

[12] FAOSTAT 2017. www.faostat.fao.org. Accessed online 1 March 2018.

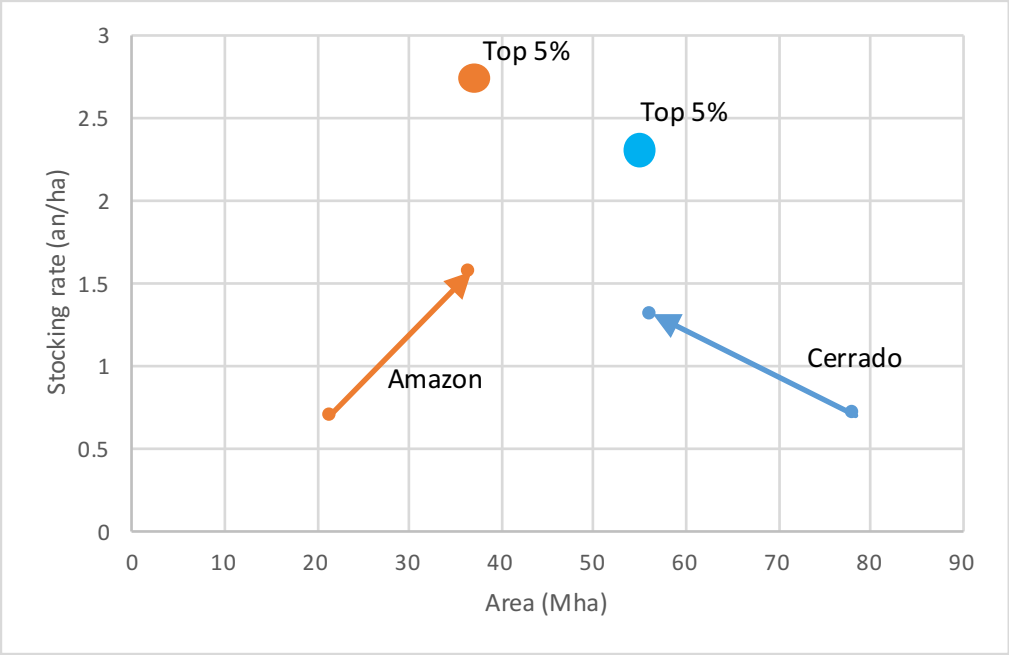
smallholder yields in Asia. A major program of replanting with new varieties and extension advice to improve management, especially among the growing number of independent smallholders, will be needed.

Genetic gains in the yield potential of oil palm have averaged around 1.0% annually, and this should continue or even accelerate with new genomic breeding and tissue culture methods. However, given that trees are replaced only once every 25 years, translation of genetic advances to the field is slow. Still, overall, growth in yields of 1.0% annually should be quite feasible through 2050.

Beef cattle

Although substantial gains have been made in raising the productivity of beef cattle production in Brazil, observers agree that there is much potential for further intensification. One measure of this is the fact that in the Cerrado and Amazon biomes, the average stocking rate per ha is only a bit over half of that achieved by the top 5% of producers (Dias et al. 2018). (Figure 11) Most ranchers now sow improved pastures (mostly *Brachiaria sp*), but these are soon degraded by prevailing management practices. Further gains in beef productivity per head through herd management and genetic upgrading are also possible. Policies such as enforcing regulations on conservation, incentives tied to credit to intensify, payments for environmental services, and improved access to technical advice are needed to continue intensification in the beef industry.

Figure 11. Average Stocking Rates for Beef Cattle in the Amazon and Cerrado in 1990 (dot) and 2010 (arrow), and Stocking Rates for the Top 5% of Producers in 2010



Source: Dias et al. *2018*

Implications for Future Demand for Land

Given projections of demand and likely gains in intensification, Table 2 provides a summary of the needed expansion in land area to meet demand. (Figure 8) For soybeans, the needed area expansion is very modest compared to the recent past and, with large areas of degraded pasture

land, this rate of expansion can be achieved through the conversion of degraded pastures. In the Cerrado, this can be achieved by maintaining recent successes in intensifying beef cattle while reducing area under pastures. This still leaves two major concerns in the pasture-soybean nexus. First is the continued conversion of biodiverse savannas in the Matopiba area on the eastern edge of the Cerrado, which is now coming under the spotlight of Brazilian and international environmental groups. Second is the need to intensify beef production broadly in the Amazon biome in Brazil and other countries in the region to reverse the continued expansion of pastures at the expense of forests and prevent "leakages" to other countries. This is especially critical since South America is projected to become the major source of beef on world markets in the coming decades (IFPRI 2017).

Table 2. Summary of Projections on Intensification and Area as Components of Future Growth in Major Commodities

	1991-2005	**Projection to 2050**		
	Area expansion, (%/y)	**Yield or stocking rate gap**	**Genetic gain per ha or head**	**Needed area expansion (%/y)**
Soybeans (tropical)	5.0	Low	Med (0.7%/y)	1%
Oil palm	4.7	Med for smallholders	Med (1.0%/y)	1.5%
Beef in Brazil	0.2	High	Med (2.5%?)	- ve (Cerrado) + ve (Amazon)

Source: Soybeans and oil palm expanded and updated from Byerlee et al, 2017. Beef projections constructed by the author.

For oil palm, a growth rate of 1.5% annually in area is a sharp slowdown from the recent past, but still a challenge in terms of reaching zero-deforestation targets in Southeast Asia. Observers agree that there is more than sufficient degraded land available to meet this challenge, but spatial planning of land use is difficult under the complex and often overlapping land laws and tenures at the national, provincial, and local levels in Indonesia. Recent initiatives in provinces such as Central Kalimantan of Indonesia and the state of Sabah of Malaysia that introduce territorial jurisdictions on certification may show the way.

The Special Challenge in Africa

The analysis in this paper has focused on the big three commodities and their hot spots for deforestation in South America and Southeast Asia. Looking to the future, however, emerging trends in Africa deserve much more attention. Already, oil palm companies, many from Asia, are investing in large-scale land acquisition for oil palm in West and Central Africa. Many of these investments threaten tropical forests. One company in the Cameroon has already has had to withdraw after major controversies about deforestation and infringements on land rights. Four major investments in Liberia are stalled. In the savanna areas of Eastern and Southern Africa such as in Mozambique, there have been a number of investments aimed at large-scale production of soybeans, especially along the new growth corridors.

The greatest threat in Africa may be from production of food crops for domestic markets. The population of sub-Saharan Africa reached one billion in 2017 and will more than double by 2050. In addition, after decades of negative economic growth per capita, African economies are growing and urbanizing, sometimes quite rapidly generating increased demand for meat and other higher value commodities. Along with investment in infrastructure in the planned growth corridors, these domestic market demands will increase commercial pressure on the largest remaining tract of intact tropical forests in the Congo basin as well as on the extensive areas of uncultivated savannas that are suited to crop and cattle production. The largest threat may be from the emerging class of medium-sized commercial farmers, often urban based, that are quickly responding to the new market opportunities (Jayne et al. 2016). With weak land rights and poor forest governance, these pressures from domestic markets threaten remaining tropical forests and savannas in the coming decades. At the same time, with low yields of all food crops and minimal use of fertilizer, the imperative and the potential to intensify is greater than for any other region.

Conclusion

This review of demand and supply for the big three commodities (beef, soybeans, and palm oil) driving land use change in the tropics reveals that at least for the oil crops, the simultaneous convergence of five major factors led to a surge in production and area expansion at an unprecedented rate from the early 1990s. In the case of beef, demand was driven more by domestic markets, but the entry of Russia and then China into world beef markets as significant importers also played a role.

The good news is that, looking to the future to 2050, there are strong arguments that the phase of rapid expansion is over and that demand for soybeans and palm oil will slow sharply to perhaps one third of recent growth rates. There are many uncertainties in these projections, but there are already signs that demand has shifted to a new normal. However, the story of beef is more nuanced as import markets are expected to grow steadily at over 2% annually, and the bulk of this demand is expected to be provisioned by South America, especially Brazil.

The slowdown in demand for soybeans and palm oil will make it easier to more sustainably manage future expansion, especially if recent trends in intensification are maintained. For beef, there is still a wide gap between productivity per hectare and that achieved by the top producers. If Brazil can continue to employ a range of tools to intensify production and to conserve remaining forests and savannas, pressure to expand pasture area can be minimized. Similarly, the modest growth expected in oil palm area provides an opportunity for Indonesia to introduce measures to shift this expansion to degraded areas.

The greatest challenge to future land-use expansion in the tropics may lie beyond the big three commodities and even beyond global markets. The high population growth rate, positive income growth, and rapid urbanization in Africa will drive strong growth in domestic markets for food. Commercialization of farming led by small- and medium-scale producers and foreign investors along infrastructural corridors poses major challenges to Africa conserving tropical forests and savannas. Yet the opportunity for intensification is great if appropriate incentives and technologies are put in place.

References

Alexandratos, N., & Bruinsma, J. 2012. *World agriculture towards 2030/2050: the 2012 revision* (Vol. 12, No. 3). FAO, Rome: ESA Working paper.

Angelsen, Arild, and David Kaimowitz, editors. 2001. *Agricultural Technologies and Tropical Deforestation*. Oxon: CABI Publishing.

Ausubel, J.H., Wernick, I.K. and Waggoner, P.E., 2013. Peak farmland and the prospect for land sparing. *Population and development review*, *38*(s1), pp.221-242.

Barretto, A. G., G. Berndes, G. Sparovek, and S. Wirsenius. 2013. "Agricultural Intensification in Brazil and its Effects on Land-Use Patterns: An Analysis of the 1975-2006 Period." *Global Change Biology* 19 (6): 1804-1815.

Borlaug N. 2007. Feeding a hungry world. Science 318(5849):359

Bruno, L. C. 2014. Essays on Technological Progress in East Asia. PhD Dissertation, Norwegian School of Economics, Oslo.

Busch, J., & Engelmann, J. 2017. Cost-effectiveness of reducing emissions from tropical deforestation, 2016–2050. *Environmental Research Letters*, *13*(1), 015001.

Busch, Jonah, Kalifi Ferretti-Gallon, Jens Engleman, Max Wright, Kemen G. Austin, Fred Stolle, Svetlana Turubanova, et al. 2014. "Reductions in Emissions from Deforestation from Indonesia's Moratorium on New Oil Palm, Timber and Logging Concessions." *Proceedings of the National Academy of Sciences* 112 (5): 1328-1333.

Bruinsma, J. 2003. World agriculture: towards 2015/2030; An FAO Perspective. Rome.

Byerlee, D., Falcon, W. P., & Naylor, R. L. 2016. *The Tropical Oil Crop Revolution: Food, Feed, Fuel, and Forests*. Oxford University Press.

Cohn, A. S., Mosnier, A., Havlík, P., Valin, H., Herrero, M., Schmid, E., ... & Obersteiner, M. 2014. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proceedings of the National Academy of Sciences*, *111*(20), 7236-7241.

Dias, L. C., Pimenta, F. M., Santos, A. B., Costa, M. H., & Ladle, R. J. 2016. Patterns of land use, extensification, and intensification of Brazilian agriculture. *Global change biology*, *22*(8), 2887-2903.

Euler, M., Hoffmann, M. P., Fathoni, Z., & Schwarze, S. 2016. Exploring yield gaps in smallholder oil palm production systems in eastern Sumatra, Indonesia. *Agricultural Systems*, *146*, 111-119.

Fischer, R. A., Byerlee, D., & Edmeades, G. 2014. *Crop yields and global food security*. ACIAR: Canberra

Gale, F. 2015. Development of China's Feed Industry and Demand for Imported Commodities. US Department of Agriculture, FDS-15K-01. http://www. ers. usda. gov/publications/fdsfeed-outlook/fds-15k-01. aspx.

Garrett, Rachael Devorah. 2013. "Interactions Between Global Supply Chains, Land Use, and Governance: The Case of Soybean Production in South America." PhD diss., Stanford University. http://purl.stanford.edu/vq411gm1873.

Gasques, J., Bastos, E. T., Valdes, C., & Bacchi, M. 2012. Total factor productivity in Brazilian agriculture.In Fuglie, Keith Owen, Sun Ling Wang, and V. Eldon Ball, eds. *Productivity growth in agriculture: an international perspective*. CABI, 2012.

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, 107(38), 16732-16737.

Godar, J., Persson, U. M., Tizado, E. J., & Meyfroidt, P. 2015. Towards more accurate and policy relevant footprint analyses: tracing fine-scale socio-environmental impacts of production to consumption. *Ecological Economics*, 112, 25-35.

Graesser, J., Aide, T. M., Grau, H. R., & Ramankutty, N. 2015. Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environmental Research Letters*, *10*(3), 034017.

Gunarso, Petrus, Manjela Eko Hartoyo, Fahmuddin Agus, and Timothy J. Killeen. 2013. "Oil Palm and Land-use change in Indonesia, Malaysia and Papua New Guinea." Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group Roundtable on Sustainable Palm Oil, Kuala Lumpur, Malaysia.

Henders, S., Persson, U. M., & Kastner, T. 2015. Trading forests: land-use change and carbon emissions embodied in production and exports of forest-risk commodities. *Environmental Research Letters*, *10*(12), 125012.

Hertel, T. W., Ramankutty, N., & Baldos, U. L. C. 2014. Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. *Proceedings of the National Academy of Sciences*, *111*(38), 13799-13804.

International Food Policy Research Institute (IFPRI), 2017, "IMPACT Projections of Food Production, Consumption, and Net Trade to 2050, With and Without Climate Change: Extended Country-level Results for 2017 GFPR Annex Table 7", doi:10.7910/DVN/8GYEHI, Harvard.

Kaimowitz, David and Joyotee Smith. 2001. "Soybean Technology and the Loss of Natural Vegetation in Brazil and Bolivia." In *Agricultural Technologies and Tropical Deforestation,* edited by Arild Angelsen and David Kaimowitz, 195-211. Wallingford: CABI in Association with Center for International Forestry Research.

Koh, Lian Pin. 2007. "Potential Habitat and Biodiversity Losses from Intensified Biodiesel Feedstock Production." *Conservation Biology* 21 (5): 1373-1375.

Lapola, D. M., Martinelli, L. A., Peres, C. A., Ometto, J. P., Ferreira, M. E., Nobre, C. A., ... & Joly, C. A. 2014. Pervasive transition of the Brazilian land-use system. *Nature climate change*, *4*(1), 27.

Malins, C., 2018. Driving deforestation; The impact of expanding palm oil demand through biofuel policy. Rainforest Foundation Norway and Cerulogy.

Martha Jr, G. B., Alves, E., & Contini, E. (2012). Land-saving approaches and beef production growth in Brazil. *Agricultural Systems*, *110*, 173-177.

Nepstad, D. C., Stickler, C. M., & Almeida, O. T. 2006. Globalization of the Amazon soy and beef industries: opportunities for conservation. *Conservation biology*, *20*(6), 1595-1603.

Qiang, W., Liu, A., Cheng, S., Kastner, T., & Xie, G. 2013. Agricultural trade and virtual land use: The case of China's crop trade. *Land Use Policy*, *33*, 141-15

Richards, Peter D., Robert T. Walker, and Eugenio Y. Arima. 2014. "Spatially Complex Land Change: The Indirect Effect of Brazil's Agricultural Sector on Land Use in Amazonia." *Global Environmental Change* 29: 1-9.

Rosegrant, Mark W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. Washington, D. C.: IFPRI.

Schierhorn, F., Meyfroidt, P., Kastner, T., Kuemmerle, T., Prishchepov, A. V., & Müller, D. 2016. The dynamics of beef trade between Brazil and Russia and their environmental implications. *Global Food Security*, *11*, 84-92.

Seymour, F., & Busch, J. 2016. *Why forests? Why now?: The science, economics, and politics of tropical forests and climate change.* Brookings Institution Press.

Shapiro, P. 2018. *Clean Meat: How Growing Meat Without Animals Will Revolutionize Dinner and the World.* New York: Gallery Books.

Trostle, R., & Seeley, R. 2013. Developing countries dominate world demand for agricultural products. *Amber Waves*, https://www.ers.usda.gov/amber-waves/2013/august/developing-countries-dominate-world-demand-for-agricultural-products/

USDA Economic Research Service. 2018. International Agricultural Productivity. https://www.ers.usda.gov/data-products/international-agricultural-productivity/

Vale, P. M. 2014. The conservation versus production trade-off: does livestock intensification increase deforestation? Evidence from the Brazilian Amazon. Centre for Climate Change Economics and Policy the Environment Working paper. London.

Villoria, N. B., Golub, A., Byerlee, D., & Stevenson, J. 2013. Will yield improvements on the forest frontier reduce greenhouse gas emissions? A global analysis of oil palm. *American Journal of Agricultural Economics*, *95*(5), 1301-1308.

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. 2017. Yield gaps in oil palm: A quantitative review of contributing factors. *European journal of agron omy*, *83*, 57-77.

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