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Plant scientists can't ignore Jevons paradox anymore

Although the 'rebound effect' is well established in environmental economics, the sometimes paradoxical effects of yield increase are rarely questioned within the plant science community. Acknowledging the curse of efficiency can help us to reframe our societal goals from performance at all cost to resilience.

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As concerned scientists, we often take the flag of the environmental crisis in the media to advocate for action. This should also translate in our scientific practice. Beyond laboratory and conference logistics, the environmental crisis should prompt us to critically assess the societal justification of our scientific questions.

In this respect, oil palm (*Elaeis guineensis* (Fig. 1a)) has received considerable attention from plant scientists in recent years. This community acknowledges the threat that increasing palm oil demand poses on forests and biodiversity, and often puts forward yield improvement as a solution. For instance, it was proposed that "the global average yield of 3.5 tons of oil per hectare (t) should be raised to the full yield potential estimated at 11–18 t"[1]. This can be achieved through new micropropagation protocols, assuming that "high-yielding palms by tissue culture could raise yields on existing plantations, reducing the need for further expansion of the cultivated area, which is often associated with negative environmental impacts"[2]. This would involve molecular genetics: the discovery of the corresponding genes "will optimize and ultimately reduce the acreage devoted to oil palm plantations, providing an opportunity for conservation and restoration of dwindling rainforest reserves"[3], "will have important impacts on fruit harvesting practices, to improve oil yields and lead to improved land utilization"[4] and "will facilitate the introduction of higher performing clones and optimize environmentally sensitive land resources"[5].

These predictions are in line with Norman Borlaug's land-sparing hypothesis, which states that higher intensification would reduce the land surface area devoted to agriculture[6]. But are they realistic? Here, I take a detour through environmental economics to explain why this is unlikely to be the case, hoping to raise awareness while highlighting alternative societal goals for our community.

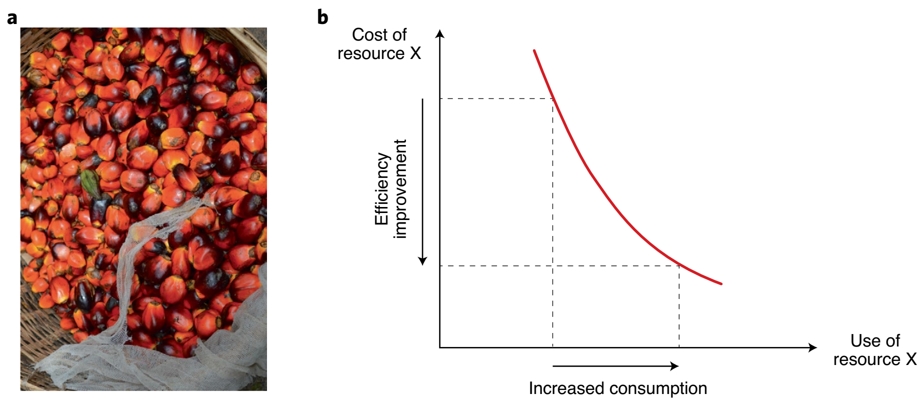

Fig. 1 | Jevons paradox, or the curse of efficiency. a, Fresh oil palm fruits in a food market (Freetown, Sierra Leone). **b**, When the efficiency of a technology increases, the cost in resources decreases, but this also leads to wider acceptance of the technology, and in the end, a larger consumption of resources globally.

The curse of efficiency

Stating that more efficient oil palm would reduce deforestation is problematic for a systemic reason. Jevons paradox, sometimes also called 'rebound effect', states that when a policy or a technology reduces the amount of resources for its use (for example, improve oil yield), that resource becomes more attractive and is thus used at a higher rate (Fig. 1b). This apparent paradox was formulated by Jevons in 1865 when he observed that more efficient use of coal actually led to an overall increase of coal consumption[7]. Why would this paradox apply to oil palm?

Originating from West Africa, oil palm has been a staple crop for at least 5,000 years. With the industrial revolution, the unique quality of its oil attracted substantial interest; for example, to make candle, lubricant, soap and food. When compared to other species, like sunflower or rapeseed, oil palm is more efficient: it requires five-to-eight times less land to produce the same volume of oil. This made this crop very appealing to capitalist economies, which created the conditions under which palm oil production could expand profitably for their industries. Oil palm started to be planted in Southeast Asia as well, in a typical rebound effect. In the 1960s and despite decolonization, this model was maintained and amplified. Countries like Malaysia invested in palm oil through land settlement schemes. This might have initially contributed to poverty alleviation in rural areas, but also had massive social, ecological and cultural consequences.

The last act in this story relates to biofuel policy. The Energy Independence and Security Act was voted in 2007 in the USA to safeguard oil supply through massive biofuel production. The European Union endorsed a similar law in 2009. Such policies triggered a competition for the most biofuel-efficient crops worldwide. Together with a drive towards production-cost reduction and profit increase, this boosted the development of the palm oil industry even further, mostly in Southeast Asia: the production of oil palm has quadrupled between 1995 and 2015, and oil palms now cover 10% of the world's cropland[8,9]. Again,

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increasing oil yield per acre did not reduce oil usage but rather triggered more fuel consumption and thus land clearing, as predicted by Jevons paradox.

Note here that global regulations on biofuels were synergistic with lobbying from the industry to impact the policies of states where palm oil is produced and where it is consumed. This ensured cheap conditions of production and guaranteed a market for their product. In the end, this not only led to more greenhouse gas emissions[10], but it also further justified the existence of infrastructures like refineries, and thus the fossil fuel industry. In fact, in parallel to the rise of biofuels, crude oil consumption continued to increase (+31%) between 1995 and 2015 (ref. [11]). Increasing oil yield further through biotechnology is thus unlikely to reduce fuel consumption and deforestation in the future.

To consolidate this prediction, Jevons paradox has been repeatedly verified for many technological advances. In the last 35 years, refrigerator efficiency has improved by 10%, but their numbers have increased by 20%. Within the same period, fuel consumption per mile has decreased by 40% in planes, but total fuel consumption for planes increased by 150%[12]. Jevons paradox also applies to other types of energy sources. So-called 'smart cities' do not reduce energy consumption: data centres use 10% of the world electricity now and possibly 20% by 2030 (ref. [13]). Variants of Jevons paradox exist outside of the energy sector too: adding lanes to roads can make traffic jams worse because such roads become more attractive[14]. Stating that improving oil palm features would reduce deforestation thus goes against current evidence.

The questionable value of palm oil as food

Beyond biofuel, oil palm is used for many other purposes. In fact, 90% of all palm oil is used by the food industry[2]. Unrefined, red palm oil has many virtues, such as being rich in carotenes (α-carotene, β-carotene and lycopene) and vitamin E. This could provide exciting research questions. However, after refining, none of these added values are kept. Most of the refined palm oil is used today for cosmetics and ultra-processed food. If one includes the low nutritional value and addictive features of ultra-processed food as well as the indirect effect of land clearing by fire on air quality, oil palm has questionable direct and indirect impacts on human health[15]. It actually contributes to two pandemics: obesity (1.9 billion overweight and 650 million obese people globally in 2016, according to WHO) and air pollution (8.8 million premature deaths every year according to WHO). The food industry seems to be aware of the problem: the term 'palm oil' is hidden under 25 different denominations in food products[15].

Many countries now back track on their policies, realizing the damage that oil palm cultivation is causing. However, Malaysia and Indonesia, which produce 84% of all palm oil[2], cannot simply change their agriculture and industry so quickly. Smallholders, who manage 40% of palm oil plantations[15], should be helped in this transition, notably by regulations against the conditions of production imposed by corporate players. Unfortunately, the promise of short-term profits is still contagious: Sierra Leone is now embracing oil palm too[16].

While the cultivation of oil palm needs to recede, stating that gene discovery or more efficient micropropagation protocols will achieve this is too simplistic because increased efficiency usually fuels consumption. This is a typical case where technological improvements in an open trade market can backfire. All authors, reviewers and editors should ban such misleading sentences from their articles. Although I acknowledge that the intention of the authors might be good, ignoring Jevons paradox is problematic if these statements reflect the only societal justifications for working on such a controversial model species.

Revisiting plant biotechnology in the twenty-first century

Some may rightfully say that the impact of soybean plantations on deforestation is much worse than oil palm. The March 2017 report from the European Parliament on the social and environmental impacts of oil palm cultivation states that oil palm is responsible for 8% of world deforestation due to land conversion to agriculture compared with 19% for soybean. Oil palm is not the only crop for which Jevons paradox applies. In fact, this counterintuitive conclusion has been repeatedly verified for most crops[6]. For instance, the improvement of energy-use efficiency in agriculture, with a three-fold increase in yield during the so-called 'green revolution', has actually increased land conversion to agriculture in Africa, Asia, Oceania and Latin America, in contrast to Norman Borlaug's land-sparing hypothesis. Such intensification also led to a 137% increase in energy input (machinery, fuel and fertilizer) per hectare in the past 50 years globally, following Jevons paradox[17].

Of course, this point has to be carefully weighed against the question of food security. Interestingly, global food production exceeds our needs today: there are more overweight individuals than those suffering from hunger. This illustrates again how plant yield cannot be disconnected from its larger economic and historical context: crop production is massively exported, often to the detriment of local food security and sustainability. Thus, should food distribution and waste be the primary targets of food security instead? Could increased food production even worsen the current issues with distribution, waste and obesity in certain places? Again, increasing yield is not necessarily a positive endeavour. At least, its underlined complexity needs to be assessed.

To conclude, Jevons paradox compels us to question efficiency as a societal goal for plant research. In many cases, it might be a valid one, but not always. This is an unprecedented revolution in the 10,000 years of man-made domestication. In our laboratories, this means that we are shifting the societal justification of our research from performance at all cost to resilience[18]. For instance, to address the more long-term issues behind food security, we are developing strategies to make crops more resilient to environmental fluctuations (for example, water stress), to adapt crops to the challenges of polyculture and agroforestry and to explore the potential uses of the Earth's 391,000 plant species[19]. In that respect, cereal mixtures are remarkable responses to the shortcomings of Jevons paradox in agriculture. As they are sown together, these varietal combinations do not favour maximal yield. Instead, they support yield stability through buffering against pests, weeds and disease and through synergistic responses to water deficit[20,21]. Such acquired resilience is attracting considerable interest outside of the laboratory too: wheat varietal mixtures reached 12% of the total area sown to wheat in France in 2019 (it was only 5% in 2017) (http://moulon.inra.fr/optimix/).

As scientists, it is our responsibility to take societal questions for what they are: simple questions with complex answers. The sustainability of our future agriculture and bio-economy will depend on our ability to consider plant resources in a more systemic way. In this respect, Jevons paradox is probably the most basic one to consider, and one we cannot ignore anymore. ❐

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Competing interests

The author declares no competing interests.