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Reducing coffee carbon emissions through improved varieties

A critical pathway for slowing emissions growth

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Key takeaways

The objective of this white paper is to describe the potential to decrease the carbon footprint of coffee farming through increased coffee yields achieved using improved varieties. Below are the key takeaways of this paper.

- The development and widespread adoption of higher-performing coffee varieties has the potential to substantially reduce greenhouse gas emissions from coffee agriculture.
- Using higher yielding varieties could reduce the carbon footprint of arabica coffee farming by 32%. This impact is modeled using an improved carbon accounting method for coffee, and real variety performance data coming from the world's largest arabica variety performance trial, with 29 sites in 18 countries.
- The creation of improved, higher-yielding varieties is a critical pathway for slowing GHG emissions growth from coffee agriculture as global demand continues to rise.
- This paper demonstrates the potential carbon emissions savings that could be obtained from higher yielding varieties without changing other inputs (such as fertilizers).

Introduction

Agriculture, forestry, and other land uses are responsible for a quarter of all anthropogenic carbon emissions (IPCC, 2021). Coffee, as one of the world's most widely consumed beverages and a highly exported agricultural commodity (Capa et al. 2015), contributes substantially to global greenhouse gas (GHG) emissions (Killian, 2013).

For coffee roasters and other businesses that rely on coffee, the GHG emissions from coffee farming can make up a major portion of their total carbon footprint as "scope 3" emissions (e.g., indirect emissions associated with a business' activity but not directly emitted by the company itself; other scope 3 emissions include, for example, emissions from dairy products, take-away cups, wastewater, etc.). A desk review and survey led by the Specialty Coffee Association found that, for some companies, "up to 85% or 90% of their emissions are classified as Scope 3" (Burkey et al., 2022). Other studies place the portion of coffee's total carbon footprint coming from cultivation and processing somewhere between 35-55% (Humbert et al, 2009; PCF Pilotprojekt Deutschland, 2008; Killian et al., 2013).

It's safe to assume that emissions from coffee production have grown steadily as both demand and supply have risen over the past decades[1] and that continued demand growth will generate increasing GHG emissions from coffee farming if we continue business-as-usual approaches to coffee farming. GHG emissions at the farm level are contributed primarily by land use conversion (e.g., deforestation, switching away from coffee to more carbon-intensive crops like maize), and to a lesser degree by farm management practices, such as fertilizer use.

In order to meet rising coffee demand without increasing the GHG emissions within coffee management systems or through deforestation, coffee production systems must be radically transformed over the next 10-30 years. There is a large variation in published estimates of GHG emissions from coffee production, partly due to the huge variation

[1] Between 1992 and 2016, global coffee production increased by 61%, from 94.6 million bags (average, 1992-1996) to 152.2 million bags (average, 2012-2016; ICO, 2021).

in agricultural practices followed by farmers worldwide and partly due to variability in emissions calculation methodologies. Overall, however, coffee farms have a lower carbon footprint with the adoption of agroforestry and organic farming systems, and a higher carbon footprint with the adoption of full-sun farming and high use of inorganic fertilizer at the farm level (Archarya & Lal, 2021).

However, changing agronomic management using current technologies (e.g., adopting agroforestry models) is only one pathway to reduce carbon emissions in agriculture. Developing new or improved technologies that increase the efficiency of agriculture, such as more effective nutrition and disease/pest management or better varieties, is a critical pathway for slowing emissions growth from agriculture. Agricultural economists call these total factor productivity gains.[2]

This raises the question: How much potential do more productive coffee varieties have to reduce carbon emissions?

Estimating carbon emissions reductions from improved varieties

Data from the world's largest global coffee variety trial, used together with a revised carbon footprint estimation approach developed for coffee, suggest that using existing higher-yielding varieties could reduce coffee farming GHG emissions by nearly a third.

Calculating the carbon footprint (also called the carbon balance) of coffee farming involves measuring net emissions and dividing the total by green coffee yield. Acharya and Lal's (2021) improved coffee farming carbon balance equation (see Figure 1) predicts that if net carbon sources and carbon sinks are held the same, while yield (GC yield, Mg ha^{-1} year) is increased, the carbon balance of coffee farming will decrease. In other words, the model predicts that higher yields will lower the carbon emissions of coffee farming.

[2] See, for example, Valin et al, 2013.

Figure 1. Improved coffee carbon balance equation

$$CB_{yr} = \frac{(\Delta C_{bio} + \Delta SOC) - (E_{soil} + GHG + \text{Farm Inputs})}{\text{GC yield}}$$

- CByr: carbon balance
- ΔCbio: change in the above and below-ground biomass
- ΔSOC: change in SOC stock during the study year
- Esoil: carbon loss due to soil erosion,
- GHG: carbon loss due to GHG emission computed as CO2 equivalent
- Farm Inputs: include the use of carbon equivalent in fertilizers, pesticides, and energy production during the study year
- GC yield: is green coffee yield in the particular year

To test the magnitude of the impact of increased yields from improved varieties on coffee carbon emissions, we first established an estimated baseline yield for coffee from a study of 116 farms in Central America (Rikxoort et al., 2014). This study included five Latin American countries in four coffee farming systems, including traditional and commercial polycultures, and shaded and unshaded monocultures (van Rikxoort et al. 2014). Data about the varieties used by farmers in the study were not included in the trial and are assumed to be a mix of available, average varieties in the region (e.g., not the optimal variety). The average yield across these 116 sites was 5.3 Mg/ha in shaded farms and 7.01 Mg/ha in full sun.

Baseline yields were then compared to yields from WCR's International Multilocation Variety Trial (IMLVT). The IMLVT is a global variety trial network that tests growth, yield, coffee leaf rust and CBD resistance, and seed and cup quality of 31 varieties at 29 sites in 18 countries. Within each site, agronomic practices are the same. When yield data are averaged across all sites, the effect of genetic variation on yield can be inferred.

In the IMLVT, the variety with the lowest yield across all sites had a 29% lower yield than the average, while the highest-yielding variety had a 48% higher yield than the average. Using Acharya + Lal's (2021) model with improved yields observed from IMLVT data, in shaded coffee systems the carbon footprint decreases from 1.6 to 1.1 kg CO_2e kg green coffee if a variety as high yielding as the best in the IMLVT was adopted. For unshaded systems, the footprint would decrease from 2.1 to 1.43 kg CO_2e kg green coffee if a variety as high-yielding as the best in the IMLVT was adopted (see Table 1, pg. 8).

Table 1. Total estimated carbon balance and its parameters under shaded and unshaded coffee farming systems
Source: Adapted from: Lal and Acharya, 2021.

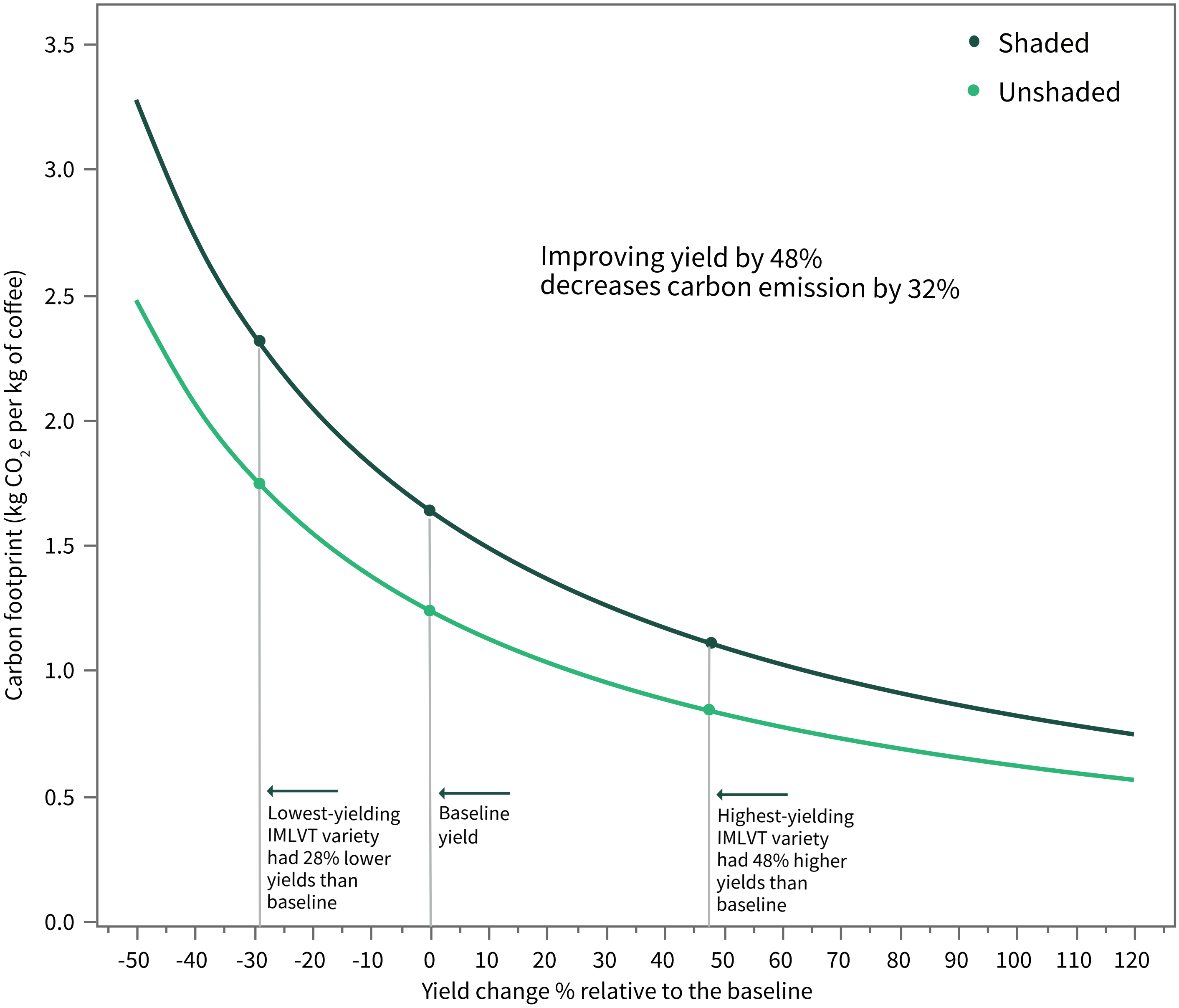
SN	Inputs proposed	Shaded	Unshaded	Reference
1	Fertilizer production (Mg CO_2e ha-1 yr-1)	3.92	6.4	van Rikxoort et al., 2014
2	Pesticide production (Mg CO_2e ha-1 yr-1)	0	0	van Rikxoort et al., 2014
3	Fuel used (Mg CO_2e ha-1 yr-1)	0.14	0.24	van Rikxoort et al., 2014
4	GHG emission (N20, CH4, CO_2) (Mg CO_2e ha-1 yr-1)	9.32	9.96	Hergoualc'h et al., 2008
5	SOC loss due to erosion (Mg CO_2e ha-1 yr-1)	0.009	0.0331	Ataroff and Monasterio, 1997
6	Below and above ground carbon sequestered in the shade trees and coffee plants (Mg CO_2e ha-1 yr-1)	3.62	1.5	Harmand et al., 2007
7	SOC stock (Mg CO_2e ha-1 yr-1)	1.09	0.25	Noponen et al., 2013b
8	Total green coffee harvested (Mg ha-1 yr-1)	5.3	7.01	van Rikxoort et al., 2014
8a	Total green coffee harvested (Mg ha-1 yr-1) using IMLVT highest yielding variety (+48%)	7.8	10.370	World Coffee Research, unpublished
9	Carbon balance per unit green coffee harvested (Mg CO_2e Mg-1 green coffee)	-1.64	-2.12	
	Baseline carbon footprint (kg CO_2e kg green coffee)	1.64	2.12	
	Improved yield carbon footprint (kg CO_2e kg green coffee)	1.11	1.44	
	Percentage improvement over baseline	32.50%	32.30%	

Using global, mean IMLVT variety performance data therefore allows us to see the isolated impact of improved genetics/varieties on yield, regardless of environment or management practices.

In Figure 2 (pg. 9), it can be seen how the carbon footprint of coffee production changes with yield—emissions are reduced when using higher yielding varieties, and increased when using less productive varieties.

For both shaded and full sun systems, higher-performing varieties create a 32% decline in emissions.

Figure 1. Carbon footprint as a function of yield change. The baseline (0) is taken from van Rikxoort et al. (2014). Arrows point to the differential impact of yield on GHG emissions, using the lowest and highest yielding varieties from the WCR International Multilocation Variety Trial as compared to the mean.



Conclusion

If we adopt the reasonable assumption that worldwide, coffee farmers are cultivating varieties of average performance (e.g., older, unimproved varieties),[3] we can infer the significant potential to reduce global GHG emissions from coffee farming through the adoption of more optimal varieties—the footprint of coffee farming may be reduced by a third. Given that farming practices are a major contributor to most coffee companies' scope 3 emissions, there is significant potential to reduce the carbon footprint of coffee through the development and widespread adoption of higher-yielding coffee varieties. In this white paper, the impacts are modeled based on real variety performance data coming from the world's largest variety performance trial.

The calculations in this paper don't take into account additional gains that could be achieved through continued genetic improvement. As the coffee industry considers how to prioritize investment in coffee agricultural R&D to address coffee's $452 million innovation gap (Maredia and Martinez, 2023), investment in variety development offers a significant return on investment in a portfolio of practices and interventions that seek to reduce GHG emissions. While there is no silver bullet in the quest to reduce the environmental footprint of coffee agriculture, higher-yielding varieties are an important technology in the toolkit for improving production systems and helping the coffee industry meet its global climate goals.

[3] A 2017 study from the USAID Bureau for Food Security found that 4 million hectares (50%) of coffee farmland controlled by smallholder farmers required renovation or rehabilitation, an area equivalent to the entire harvested area of Brazil, Vietnam, Colombia and Ethiopia. The study concluded that total R&R investments to date have met only 5% of farmer need. (USAID, 2017)

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