Can corporate supply chain sustainability standards contribute to soil protection?

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Abstract. Companies increasingly view soil degradation in their supply chains as a commercial risk. They have applied sustainability standards to manage environmental risks stemming from suppliers' farming operations. To examine the application of supply chain sustainability standards in soil protection, we conducted a study using global data on existing sustainability standards and their use in the food retail industry, a key sector in agrifood supply chains.

Soil quality is a priority objective in retail sector sustainability efforts: 41% of the investigated companies apply some soil-relevant standard. But the standards lack specific and comprehensive criteria. Compliance typically requires that farmers are aware of soil damage risks and implement some mitigation measures; however, no measurable thresholds are usually assigned. This stands in contrast to some other provisions in a number of standards, such as deforestation criteria. There are two probable causes of this difference: Companies and certification bodies have prioritised other environmental challenges (e.g., pesticide use, biodiversity loss in tropical biomes) over soil degradation. Also, there are practical constraints to the useful standardisation of soil sustainability. Effective soil sustainability provisions will require measurable, controllable, and scalable multidimensional interventions and compliance metrics. Often, these are not yet available. The development of necessary practical tools is a priority for future research.

1. Introduction

1.1 Soils and agricultural intensification

A large majority of food used by humanity depends on soil and its ability to support plant growth (Kopittke et al., 2019). Beside food production, soils provide many other services such as detoxification, drinking water provisioning, regulation of water flow, flood protection, and climate regulation, in addition to many cultural values like heritage and cultural identity (Dominati et al., 2014). Annual value of soil ecosystem services is estimated as high as US$11.4 trillion (McBratney et al., 2017). Without exaggeration, soils are one of the most important resources economies rely upon.

Population growth has been to a large extent associated with agricultural expansion. Human population, counting about 6 million when farming emerged (Livi Bacci, 2017), has since increased dramatically. The great acceleration of the mid-20th century was supported by, among other factors, widespread application of nitrogen fertilisers (Erisman et al., 2008). At the same time, a rising proportion of people has moved into cities. As the number of urban dwellers has been increasing, the share of people working in agriculture has decreased (Satterthwaite et al., 2010; Frouz and Frouzova 2022). Moreover, affluent urban dwellers have become more demanding about food, consuming better-tasting and more expensive food, such as more meat, fat, oil, and dairy products (Satterthwaite et al., 2010; Ericksen, 2008). Furthermore, the mean proportion of income spent on food has been decreasing with rising wealth, in accordance with Engel's law (Engel, 1857; Chai and Moneta, 2010). Intensification and specialisation of agricultural production have contributed to these changes.

Intensification has also been accompanied with an increased influence of large food and retail companies on agricultural practices. This is particularly true for 'lead firms': global buyers who shape sales strategy, price structure, and production systems (Gereffi et al., 2005). Retailers and brand-name food companies typically occupy this position in agrifood value chains. Retailers, processors, and traders that control a major proportion of sales often employ their bargaining power to alter trade conditions to their advantage (Ghosh and Eriksson, 2019; Fearne et al, 2005). They are also able to shape their suppliers' farm management choices. Companies' demand for high-quality produce has been linked to increased pressures on water resources, as buyers make growers follow protocols on quality, consistency, and continuity that effectively require irrigation (Knox et al., 2010). Manufacturers' focus on ultra-processed food contributes to, for example, soil degradation (Monteiro et al., 2018). Processed food producers have been linked to significantly increased input use in agriculture (Moberg et al. 2020). Even environmentally benign practices such as integrated pest management can be driven by contractual requirements of food companies (Codron et al, 2014).

Intensification increases crop production but at the same time may often cause substantial environmental impacts (Matson et al., 1997). Agricultural intensification has been shown to reduce the biodiversity of soil organisms (Tsiafouli et al., 2015), limiting their ability to support the provision of ecosystem services (de Vries et al., 2013). Massive use of agricultural machinery enhances soil compaction (Arvidsson and Hakansson, 1991; Kopittke et al., 2019), and together with increasing field sizes it may lead to increased erosion (Stoate et al., 2001). These effects of cultivation, together with unbalanced nutrient supply and reduced organic matter input to the soil, reduce soil organic matter content (Huggins et al., 1998). Compaction, erosion, and loss of organic matter may also feed back as decreasing soil fertility (Quiroga et al. 2006; Oldfield et al. 2019). Unbalanced nutrient use may cause higher nutrient loss from farmland and eutrophication of water bodies, including seas (EU Nitrogen Expert Panel, 2015). Consequently, biogeochemical cycles may be affected (Kopittke et al., 2017). These effects may be further enhanced by on-going climate change, which is expected to increase the stochasticity of farm production (Tigchelaar et al., 2018). But more sustainable agricultural practices can substantially decrease these negative effects of intensification (Pretty and Bharucha 2014). In some instances, for example, when conservation tillage or other soil-saving practices are applied, intensive agriculture may even increase removal of carbon from the atmosphere (Leahy et al., 2020).

1.2 Soil degradation as a business risk

Business attitudes towards the environmental impact of supply chains, including considerations of soil quality, have been changing over the past years from indifference to concern and proactive sustainability interventions. As noted by Hajer et al. (2016), companies approach sustainability in three main ways: as a tool to improve reputation, as a sustainability-oriented business model, or through supply chain risk management. Businesses increasingly view unsustainable practices in their supply chains as a commercial risk. Widespread soil degradation, water scarcity, and biodiversity declines are seen as potential material and, in some cases, reputational hazards. Material risks include market volatility and potential future instability of supply chains. Market shocks facilitated by environmental change have major potential implications for costs (Tigchelaar et al. 2018). Companies fear that deterioration of natural capital may lead to direct cost increases and reduced margins, rising commodity market volatility, and supply chain unpredictability. Soil management is a risk factor due to its critical contribution to crop productivity and consequent impact on market performance (Davies, 2017; Sharman, 2017; Burian et al., 2018; Panagos et al., 2018). Apart from primary producers and their investors, some of the most exposed sectors are the food, beverage, fibre, and biofuel industries (Makower et al. 2021). However, other, especially water-sensitive sectors are impacted as well. Climate change is expected to elevate the relative risk levels.

But companies also need to deal with other actors' concerns. The regulatory environment is increasingly stringent as governments explore effective measures to prevent soil deterioration, and damage contributes to reputational risks as well. Consumers traditionally demand a great deal from the food system: safety, quality, variety, convenience, and service as well as low prices. But they increasingly expect environmentally sustainable production and processing methods. Increasing pressure on companies from various stakeholders such as NGOs has resulted in companies adjusting their strategies to face 'responsible governance' expectations (Fulponi, 2006, Dauvergne and Lister, 2012).

Along with the concerns directly related to soil sustainability, carbon sequestration is an additional motivation to intervene in soil management in supply chains. Better soil management leads to increased soil organic carbon content and is an important contribution to carbon sequestration (Smith et al., 2008; Minasny et al.; 2017; Rumpel et al., 2018; Radley et al. 2021). A growing number of companies aim for net zero greenhouse gas emissions (Hale et al., 2021; Rogelj et al., 2021). While specialist firms and initiatives such as Indigo Ag, Agreena, Soil Capital and Carboneg entered the emerging market with soil carbon credits (Popkin, 2023), many companies see working directly with their own suppliers as a useful contribution to their efforts to reduce their carbon footprint (Vermeulen et al., 2019; Amelung et al., 2020; Bossio et al., 2020).

Business soil conservation efforts are further facilitated by the rapid proliferation of universal sustainability reporting, propelled by regulations such as the EU’s new Corporate Sustainability Reporting Directive and the expanding supply of sustainability data, tools, reporting standards and other infrastructure (Deconinck et al., 2023). Reporting contributes to agri-food companies’ engagement in soil sustainability primarily by focusing their attention on the critical role of supply chains, helping them to understand their complexities and identify the less visible risks.

1.3 Sustainability standards

Government regulations and other public policies are the obvious framework that companies have conventionally followed. However, regulations and subsidies often fail to achieve environmental needs because of weak objectives or unsatisfactory design (Frelih-Larsen et al., 2016; Paleari, 2017; Pe'er et al., 2019; Scown et al., 2020; Amundson, 2020). Since about 2000, numerous predominantly

European and North American food and retail companies have sought to take a private initiative to increase the sustainability of their farm supplies beyond the minimum regulatory requirements. Initially, their focus has been on increased sales of organic food. Organic agriculture enhances soil quality (Gattinger et al. 2012, Tuomisto et al. 2012; Henneron et al., 2014; Seitz et al., 2019), is explicitly defined, and enjoys legislative underpinning and relatively mature markets. However, its scalability remains limited. The organic share of food sales remains at around 10% in even the most advanced European markets and is substantially lower elsewhere (Willer et al., 2021). Therefore, its practical utility as a supply chain sustainability tool is constrained.

Facing the limits of both the regulatory regime and organic segment approach, corporations have explored private pathways to mitigate environmental challenges across their supply chains. Voluntary sustainability standards (VSSs) have been a key tool. They are private norms imposed by companies that require suppliers to follow more or less specific environmental and/or social criteria (Thorlakson et al. 2018, Lambin et al. 2018, Traldi 2021; Meemken et al., 2021). Suppliers' compliance with a standard is secured by a market choice to enter a private contract, as opposed to an obligatory government regulation (Henson and Humphrey 2010). Companies apply two principal approaches to VSSs: (i) third-party controlled certification schemes such as Bonsucro (sugar cane) or the Better Cotton Initiative (Vogt, 2019; Kemper et al., 2023), and (ii) in-house standards.

While companies increasingly view standards as a risk management tool, they also continue to serve as a means of responding to stakeholder expectations, communicating brand differentiation to consumers and managing business-to-business relations. They help companies to ensure product safety or quality attributes, improve market efficiency, strengthen suppliers' liability, or induce innovation in sourcing (Fulponi, 2007; Henson 2008; Chkanikova and Lehner, 2015).

Voluntary sustainability standards are not a straightforward solution. Their geographical focus is uneven. Most of the major VSSs target tropical crops (Tayleur et al., 2017; Kemper et al., 2023). They deal with globally relevant priorities such as deforestation and biodiversity loss that are concentrated in tropical biomes, while local challenges (e.g., soil degradation), more uniformly distributed in world farming, have received less attention so far. Their real-life impact relies critically on their specific design, and some schemes may be less than efficient (Blackman and Rivera, 2011; DeFries et al., 2017; Traldi, 2021). Research suggests a mainstreaming paradox: standard setters face a trade-off between coverage and outcomes (Dietz and Grabs 2021). As the scope of some schemes expands beyond their original focus to cover both environmental and social agendas, parallel generalist standards overlap, their topical distinctions blur, and targeting becomes weaker (Lambin and Thorlakson, 2018). Whether this thematic generalisation impacts standards' specific content, such as environmental criteria, has not yet been sufficiently explored.

Nonetheless, VSSs are potentially an important tool of control over environmental challenges, particularly in the production of so-called soft commodities such as food and fibre. Here we investigate the extent and depth to which corporate voluntary sustainability standards are applied to protect soils, and the potential and constraints of further application of standards in soil quality. We focus on three key research questions: (i) To what extent are companies considering soil sustainability as part of their sustainability strategy? (ii) Do sustainability standards that companies use have a potentially meaningful impact on soil protection, and does that impact affect standards' market penetration? (iii) Are schemes that emphasise the environment more likely to have stronger soil-related impact?

2. Material and methods

To explore the above-described research questions, we integrate three research approaches: (i) In order to gain an insight into the current market uptake of the relevant VSSs in business, we investigate their use in food retail, the key sector of agrifood value chains. (ii) We review the potential impact of soil-related provisions in the existing VSSs, and (iii) examine whether it is linked to the relative environmental specialisation of standards.

2.1 Market uptake of soil-relevant VSSs

We investigated the application of VSSs for soil protection by global food retail. The 250 largest retailers listed in Deloitte's *Global Powers of Retailing 2021* report (Deloitte, 2021) were used as the baseline to determine a sample of relevant companies. Out of this sample, companies labelled 'Grocery Retailers' in the research database Passport operated by Euromonitor International were selected in order to identify those involved in food sales. For these companies (n = 119), we gathered the latest sustainability reports, annual reports, and data from companies' websites available between June and October 2021 and performed content analysis (Krippendorff, 1980) to identify companies' activities in sustainable food sourcing. We focused on standards they use, crops they report as considered in sustainable sourcing, and topics of agricultural sustainability they focus on.

Using binary coding of root word topics, based on Sustainability Consortium's Sustainable Commodity Supply Chains Project's topic classification (The Sustainability Consortium, 2017) with some minor adjustments, and related keywords, we categorised relevant content collected and removed 70 data points due to unavailability of reports and/or relevant data or language barriers. Each report was manually analysed and relevant root words recorded if they appeared; keywords (root word synonyms) were subsequently identified in the equivalent manner. Similarly, any reference to a sustainability standard was also recorded using binary coding in the data sheet. We also recorded any crop when it was mentioned in relation to a standard or a root word/keyword In this way, a binary code matrix was created, recording any instance of a root word/keyword, a standard or a relationship between any of the two variables and a crop.

2.2 Impact of soil provisions in VSSs

Second, we analysed the content of the Standards Map (Fiorini et al., 2018), a global database of 322 VSSs (as of October 2022) operated by the International Trade Centre (https://resources.standardsmap.org/knowledge). Out of 165 standards that cover agriculture, we identified those that explicitly regulate soil management. This was all done using Standard's Map filters. After this we removed organic food standards (because they are irrelevant to supplies from conventional farming) and standards focused on food quality that only marginally mention soil, without further details. We performed content analysis of the remaining standards (*n* = 56), identified 11 sub-categories of criteria that the Standards Map marked as relevant to soil (Fig. 1) and, using the standards' excerpts that the Standard Map indicates as related to each sub-category, identified 400 instances where a particular standard contained one of the 11 sub-categories.

On the basis of the content analysis of the standards, we concocted four categories of ambition level (Table 1), and assigned one to each of these individual instances in order to differentiate between schemes with explicit benchmarks and those confined to general provisions. Content analysis often needs to go beyond simple frequency counts and involve interpretation of the text; however, these approaches increase the risk of researcher's bias (Drisko and Maschi, 2016). We used secondary data (excerpts from the Standard's Map database) and categories that allowed classification with little need of subjective judgement in order to minimise bias (Drisko and Maschi, 2016). The decision criteria were based on the presence of phrases indicating a level of ambition (Table 1).

We extracted from the Standards Map data on crops covered by the 56 soil-related standards to gain an insight about the overlap between supply (existing standards) and demand (reported use by companies for each crop). To examine whether the soil-related criteria are affected by the mainstreaming paradox, we performed Pearson's correlation to test the relationship of the ambition level of each individual standard to the acreage of land certified by the standard. Additionally, Pearson's correlation was calculated to test the relationship of ambition level with the reported use of standards among food retailers (*n* = 18).

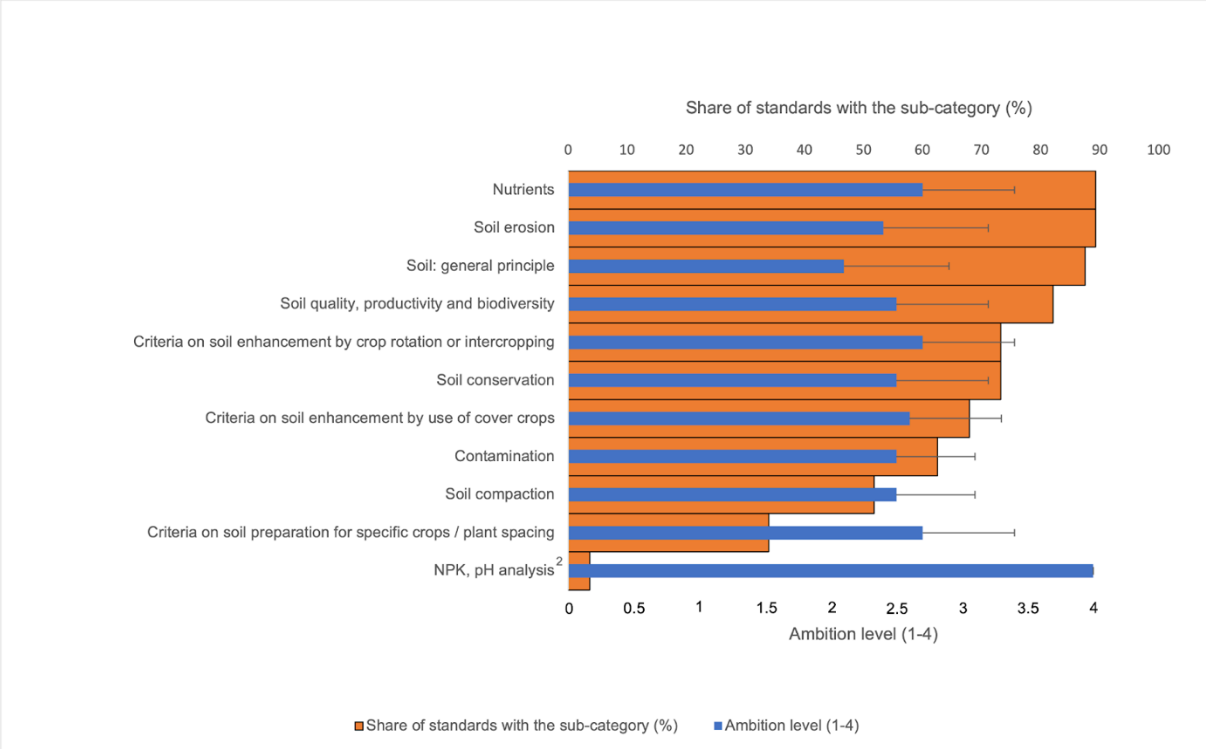

Figure 1: Levels of supply chain sustainability standards' (*n* = 56) soil protection content ambition in individual sub-categories. Level rating criteria are explained in Table 1.

Note:

1. Levels are applied to the sub-categories defined by Standards Map.
2. The category originally called 'Other Criteria on Soil' in the Standards Map is renamed to 'NPK, pH analysis', as this was the only actual topic covered.

Level	Description of category	Example
1	No specific requirements or actions expected.	"If applicable, procedures are in place to measure and reduce soil erosion and compaction and/or improve soil health." Equitable Food Initiative (Criteria on soil conservation)[1]
2	Some knowledge about agricultural sustainability issues is expected and efforts to address them are required.	"Soil Management Plan in place to avoid erosion and maintain and improve soil health Indicator" Bonsucro (Criteria on soil nutrients)[1]

3	An explicit strategy and its demonstration in farm practices are required.	"Indicate pollution caused by the use of fertilisers and pesticides in cotton production. Applying more efficient irrigation practices to optimise water productivity (applicable to irrigated farms only)" Better Cotton Initiative (Criteria on soil contamination)[1]
4	An explicit strategy to deal with the issue in specific measurable rules and interventions is required.	"4.1 Organic matter balance • An organic matter (OM) balance is calculated at company level. The average OM balance (balance is input minus decomposition) for all plots at company level is at least neutral. In case of a perennial crop, the balance at plot level over the entire growing period is neutral." Planet Proof standard (Criteria on soil nutrients)[1]

Table 1: Standard ambition level criteria applied in the analysis

Notes:

1. All quotations taken from ITC (n.d.)

2.3. *Environmental specialisation*

To evaluate the environmental specialisation of individual standards, we used the Standards Map (https://resources.standardsmap.org/knowledge), which indicates the proportion of requirements that are dedicated to five pillars ('Environmental', 'Social', 'Quality and management', 'Economic', and 'Ethics'). As a measure of environmental specialisation, we used the relative share of requirements in each standard dedicated to the environmental pillar extracted from the Standards Map. We applied Pearson's correlation to test the relationship between the environmental specialisation of each VSS and (i) its overall ambition level (Table 1) in soil issues (sect. 2.2); (ii) its ambition level in individual sub-categories (such as erosion, nutrients, and soil as general principle: see full list of subcategories in Fig. 1); and (iii) the area of standard application measured in hectares of certified land globally. Similarly, we compared environmental specialisation between standards that operate strictly in the tropics and/or subtropics and those that also target temperate crops. To do so we assessed the environmental specialisation of standards with these two geographic foci. The Standards Map was used to extract data about each scheme's geographical scope to differentiate between standards that regulate temperate crops (including those with a wider scope including temperate crops) and those that strictly target only tropical and/or subtropical agriculture.

3. Results

3.1 Market uptake of soil-relevant VSSs

Soils generally rate high among food retailers' environmental concerns (Table 2). Among the 49 sampled retailers, 27% self-report soils as a policy objective, with only two topics – pesticides and water management – mentioned more frequently (both at 33%). Sustainability standards that involve soil protection criteria were applied by 41% of the retailers (Table 3).

Some retailers apply their own requirements, which may include both more general policies and specific in-house standards. Tesco operates a program within their Sustainable Farming Groups (an environmental initiative by Tesco involving its suppliers and farmers) that promotes use of cover crops and other sustainable practices in potato farming. In 2019 the program covered 417 hectares, with expectations to extend it further (Tesco, 2020). However, soil is generally rarely addressed in the in-house standards. Most of them focus on pesticide use or biodiversity.

Objective	**Share of food retailers that report the objective (%)**
Pesticide management	32.7
Water resource management	32.7
Biodiversity	26.5
Deforestation	26.5
Soil health	26.5
Fertiliser management	20.4
Land use change	8.2
Energy consumption	6.1
Manure management	6.1
Pollination	6.1
Ecosystem services	4.1
Habitat/land conservation	4.1
High conservation value areas	4.1
Maximum residue levels	4.1

Table 2: Self-reported priority agrifood sustainability objectives of 49 large retail companies

Standard	Share of retail companies reporting use (%)	Average ambition level	Number of sub-categories covered by the standard	Share of environmental topics in the total number of criteria (%)
Involves temperate crops only or in a combination with tropical/subtropical crops				
PlanetProof	2.04	4.00	10	60
Red Tractor (Combinable Crops)	4.08	2.20	5	56
GLOBALG.A.P (Crops)	26.53	2.00	9	39
LEAF Marque	6.12	3.00	10	71
Rainforest Alliance - 2020	44.90	2.90	10	38
Better Cotton Initiative	20.41	2.89	9	37
Sustainable Rice Platform	2.04	2.67	6	47
Sustainably Grown	2.04	2.33	9	39

Round Table on Responsible Soy Association	24.49	2.25	8	46
Involves tropical/subtropical crops only				
Roundtable on Sustainable Palm Oil	59.18	2.63	8	34
Cocoa Horizons – Barry Callebaut	8.16	1.88	8	36
FairTrade	40.82	1.29	7	39
All standards	41	2.48 (median=2.33)	7.21 (median=8.00)	46

Table 3: Average ambition level across the relevant sub-categories of standards reported as used by retailers, and the share of retailers (*n* = 49) reporting use of the standard. Level rating criteria are explained in Table 1.

Notes:

1. Rating is applied to the sub-categories defined by the Standards Map.

3.2 Impact of soil provisions in VSSs

Practical implementation of policy objectives in explicit VSSs remains limited. Just 56 of the 165 third-party standards relevant to agriculture (excluding organic certification) regulate soil management to a greater extent than only mentioning its importance. Overall, the average ambition level of the standards' soil management requirements by sub-category (Table 1) is less than 2.48, with the median at 2.33 (Table 3); that is, they typically require that farmers are knowledgeable about soil-related risks and show some effort to apply practices to improve soil quality. The most frequent sub-categories are soil erosion, nutrients, soil biodiversity, and productivity (Fig. 1). NPK/pH analysis is the sub-category in which the standards have the most ambitious criteria overall, as compliance with exact thresholds is required; however, it is only rarely applied (*n* = 2). There is not much variability in the level of ambition beyond that (Fig. 1).

While there is a weak negative correlation (Pearson coefficient, *r* = −0.23, *n* = 18) between the standard's ambition level and its hectare coverage in terms of certified production land, the relationship is not statistically significant (*p* = 0.355), possibly due to the lack of available data (Fig. 2). The same is the case with the relationship between the average ambition of the standard and its use by food retailers (Pearson coefficient, *r* = −0.25, *p* = 0.441, *n* = 12). The crops most frequently covered by VSSs are soy and fruits, both in terms of the number of standards and in reporting by the food retailers (Fig. 3). But some standards diverge in these two criteria: for example, while a high number of VSSs cover the sustainability of sugar, nuts or rice, they are rarely reported as used by the retail companies.

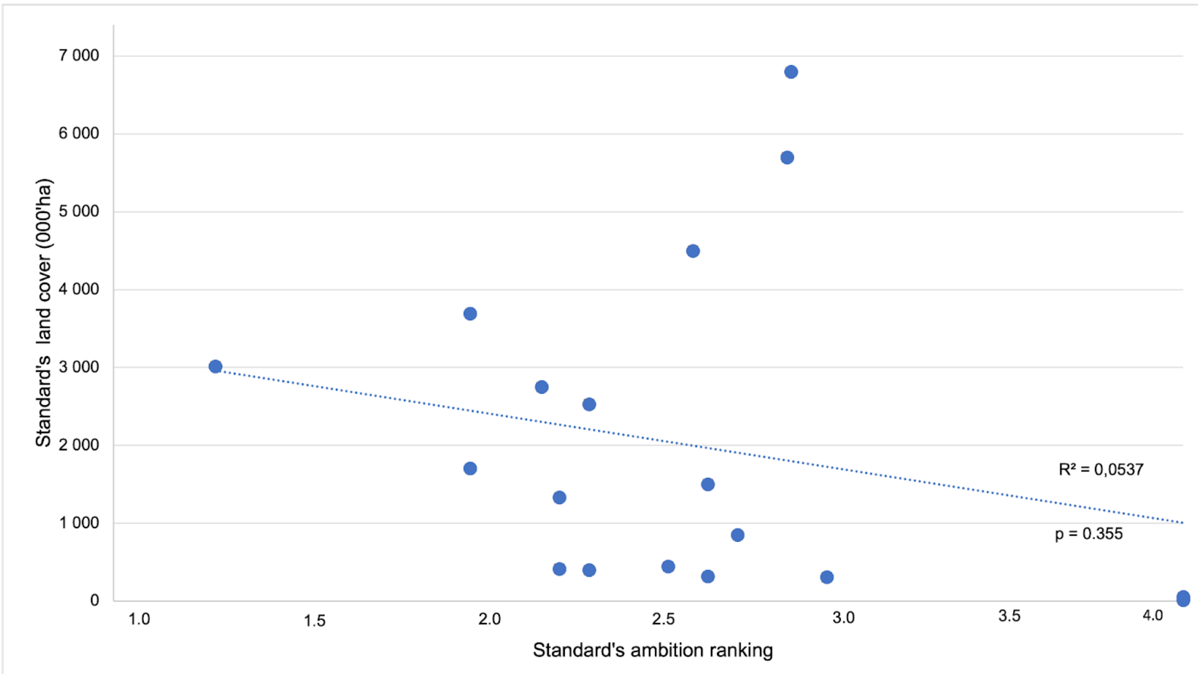

Figure 2: Correlation between standard use measured in thousands of ha of land and standard ambition level using available data (*n* = 18). The relationship is not statistically significant.

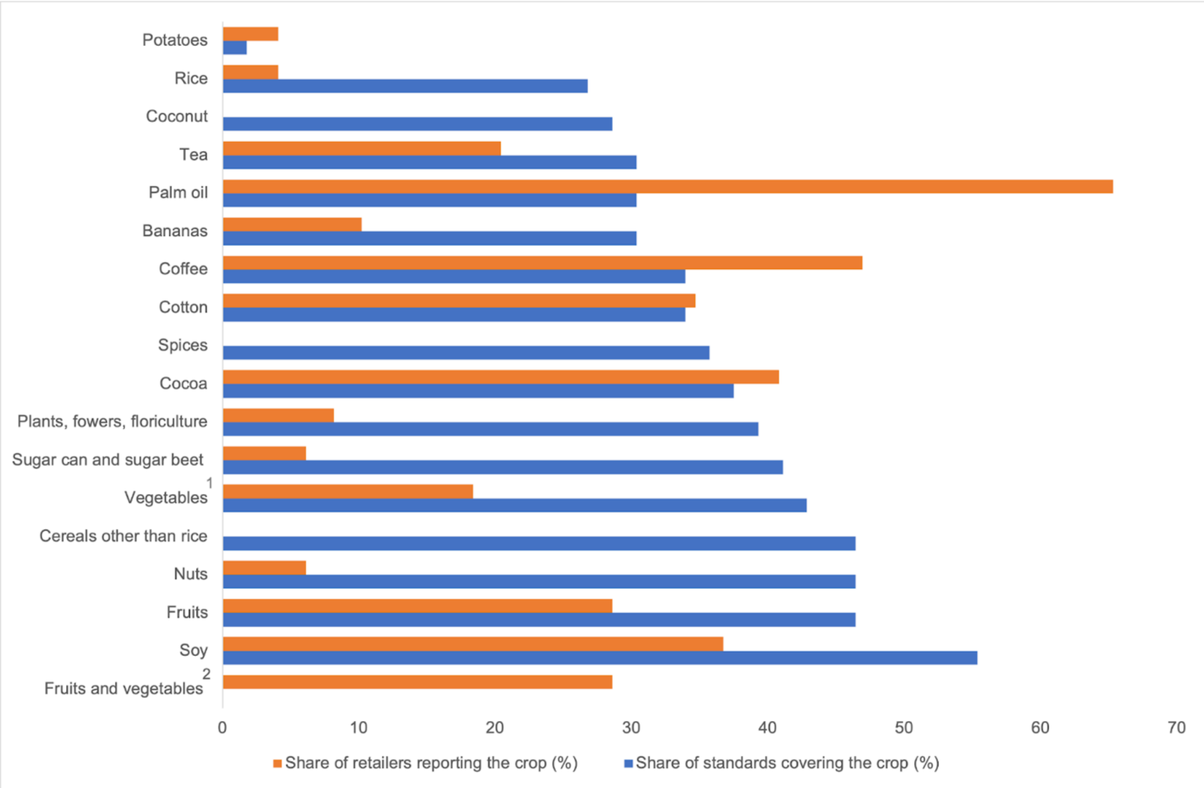

Figure 3: Crops covered by third-party agricultural sustainability standards relevant to soil quality (*n* = 56) and those reported in food retail companies' (*n* = 49) literature as being subject to a specific sustainability standard.

Notes:

1. Retail companies usually report 'sugar' as a commodity, rather than the specific crop; in only one data point (1.8%) is sugar beet explicitly reported.
2. Some companies report 'fruits and vegetables' as a generic crop category.

3.3 Environmental specialisation

Environmental specialisation was weakly but significantly positively correlated to average ambition level of all soil-related criteria in a given standard (Pearson coefficient, r = 0.37, p = 0.005, n = 56). There was also a positive relationship between the relative environmental specialisation of standards and their ambition levels in the erosion (Pearson coefficient, r = 0.41, p = 0.003, n = 56), soil conservation (Pearson coefficient, r = 0.32, p = 0.043, n = 56), and cover crop (Pearson coefficient, r = 0.30, p = 0.069, n = 56) sub-categories. Environmental specialisation was negatively correlated with the use of the standard measured in hectares of certified land globally (Pearson coefficient, r = −0.53, p = 0.025, n = 18); that is, standards with a stronger environmental focus are used on relatively smaller areas, and vice versa. Standards with high environmental specialisation also tend to be those operating in temperate regions, as opposed to standards that target tropical crops only (t test, p = 0.001, n = 56).

4. Discussion

4.1 Current practice

The food retail industry declares a high degree of interest in soil quality. Soil quality and/or its individual parameters are one of the self-declared priority objectives for retail industry sustainability efforts. However, there is an apparent discrepancy between this proclaimed prioritisation and the implementation of any real measures into standards (Fig. 1). Soil-relevant items generally, with one exception, lack more comprehensive and/or specific criteria. Hence, soil protection is often reported as a priority, but practical implementation is limited. Apart from organic food, GLOBALG.A.P. is the most popular standard. Soil quality is covered by the scheme, but its criteria tend to be loose and weak. In order to qualify, suppliers must, for example, develop a crop rotation plan and implement some interventions to mitigate soil erosion and compaction; however, no specific measures or thresholds are explicitly required.

The explanation for the discrepancy between prioritisation and implementation is complex. Partly it is that any evidence-based policy (Mosse, 2004) needs data and data processing, and its implementation is more complex than just the simple declaration of care. This is particularly true for soil. Soil sustainability criteria are also relatively more difficult to develop and control (sect. 4.2). Environmental schemes that prioritise landscape-level threats such as land-use changes in global biodiversity hotspots can use fairly simple metrics such as the absence of deforestation (Lambin et al. 2018, Garrett et al. 2019). Mitigation of soil risks is typically more complex and involves field-level interventions that are often more geographically specific. Companies may be naturally inclined to engage first with topics that are easier to approach, measure, and verify. These complexities are probably visible in the ways current sustainability VSSs specify soil quality requirements. While relatively strict requirements are applied in easily verifiable measures such as use of cover crops, crop-spacing, or soil pH, issues like soil erosion and organic matter loss are left to more vague criteria. We will further examine the complexities and challenges faced by the development of a soil standard in sect. 4.2.

A second problem can be that the relationship of soil to a final product is mediated by other factors, and soil changes are usually slow, so its degradation may not be perceived as an imminent threat. Consequently, while retail business apparently views soils as a potentially important issue, the initial focus of its supply chain sustainability efforts has been elsewhere. Companies tend to concentrate on major global concerns (climate, biodiversity, deforestation, and other habitat loss). This is associated with public awareness about soil which is, despite recent efforts and some partial successes (Dazzi and Lo Papa, 2022), lower compared with awareness of other issues such as biodiversity and climate. There are many reasons for this. Among others, soil, soil organisms, and soil processes responsible for soil fertility are virtually invisible to most of the population, including customers and company managers. Thus, these matters are spotlighted less than other natural resource issues such as biodiversity, which is easier to visualise, making it easier to build emotional attachment to biodiversity (Hanisch et al., 2019).

The relevant agrifood supply chain impacts are generally higher in tropical and subtropical landscapes (Moran and Kanemoto, 2017; Pendrill et al., 2019) than in temperate zones. Tropical farming is understandably a primary priority for private schemes (Tayleur et al., 2018). These risks are also the key priority for conservation NGOs and other stakeholders who often play a major role in companies' understanding of sustainability agendas and their strategic choices. Reporting of the 49 large food retailers shows that some of the most frequently applied schemes are the Roundtable on Sustainable Palm Oil, the UTZ–Rainforest Alliance, and Fairtrade. These standards have one thing in common: they mostly focus on tropical cash crops such as cocoa, coffee, and palm oil. While they typically include some soil-related criteria, their main environmental components usually revolve around biodiversity and habitat conversion.

4.2. Data limitations

An obvious limitation of the data presented here is that it reports on companies' intentions rather than impacts. Efficient VSSs require robust design, including measurable thresholds and effective verification procedures (ISEAL, 2013). However, practical results on the ground are likely to depend on a complex web of factors that influence farmers' (and consumers') choices. These are probably difficult to discern from design alone. Ultimately, impacts need to be measured directly.

Retail industry is a natural choice of the sector for data gathering because of its key role in agrifood value chains and its broad coverage of different commodities. Nevertheless, the choice entails inevitable trade-offs. Perhaps most importantly, fresh food - a segment where they have direct contractual relationships with farmers - is an understandable priority for retail companies' supply chain sustainability efforts. As a consequence, sustainability of manufactured goods will be less intensively reported. This is, for example, probably the main reason why Sustainable Agriculture Initiative (SAI), a major collaborative platform involved in sustainability standardisation, appears in the standards data (sect. 3.2), but not in the retail data (sect. 3.1).

4.3. Practical applications

Typically, soil is - and probably will continue to be - an element of wider agri-food sustainability standards, rather than a narrow, stand alone issue. However, robust and widely applicable soil health metrics and data infrastructure are key prerequisites for development of VSSs useful for agri-food supply chains (Sharman, 2017).

The need to support soil sustainability has been the focus of many recent initiatives. In particular, the European Commission has invested significant resources in programmes such as the European Joint

Programme Soil and Mission Soil, which bring together researchers, policy makers, farmers and other actors (Chenu et al., 2023) to identify priorities for soil protection (Boruvka et al., 2022) and highlight key management practices that benefit soil health (Rodrigues et al., 2021; Tiefenbacher et al., 2021; Keesstra et al., 2021; Hendricks et al., 2022; Vanino et al., 2023). Attention has also been paid to the impact of different agri-environmental schemes on soil (Polakova et al., 2022). Several EU projects have investigated incentives and business models for soil health (NOVASOIL, SoilValues, InBestSoil). Similar projects are pursued by other researchers (e.g. Soil Health Index) and businesses (Open Soil Index) (Bünemann et al. 2018). While these initiatives focus mainly on the social value of soil, public policy incentives at European, national or local level and the impact on (and support of) farmers, they produce data, monitoring infrastructure, intervention designs and other outcomes that may potentially contribute to the development of effective VSSs. Advances in agricultural mapping and remote sensing including satellite imagery will make localised soil metrics more feasible (Sharman, 2017). Moreover, with the development of AI technology, it is likely that integration of soil mapping with AI will translate into criteria and monitoring models in the future. The development of innovative monitoring, reporting and verification (MRV) methodologies to ensure the environmental integrity of carbon farming schemes generates outputs that are potentially useful for measuring other environmental impacts, including soil health (Radley et al. 2021; Springer, 2023).

Companies mostly serving European and North American markets appear to prioritise sustainable production of (i) tropical commodities and (ii) fresh produce (fruit, vegetables). They are often traded in different ways (complex global supply chains vs. direct purchases), with practical implications for implementation of supply chain sustainability (schemes such as third party certifications and direct cooperation with farmers, respectively). A meaningful intervention in soil quality in temperate landscapes would involve addressing common field crops such as cereals and oilseeds. The market model (and governance of supply chain sustainability) for many of these is more similar to that of globally traded tropical commodities, rather than fresh produce, although the physical distance of trade flows is shorter. The complexities of crops entering parallel supply chains, with supplies of different origins mixed together, and multiple tiers of manufacturers can pose challenges to the application of VSSs.

Precompetitive initiatives (i.e. agreed and applied by several companies in a sector, potentially with involvement of other relevant stakeholders) could be a viable solution for sectoral and even cross-sectoral collaboration (Waldman et Kerr, 2014; Barker et al., 2021), enabling companies to identify best practices for their shared supply chains and focus on developing robust criteria for soil sustainability that can be measured, validated and applied interchangeably across countries and continents. Sustainable Agriculture Initiative (sect. 4.2), while not strictly a VSS, is one of the more prominent precompetitive initiatives currently on the market.

The growing breadth and depth of available life cycle assessment (LCA) data has rapidly improved our understanding of environmental footprints along agri-food value chains in recent years (Poore et

Nemecek, 2018). Practical tools have been developed to apply LCA approaches at scale, such as the Product Environmental Footprint (Damiani et al. 2022). While soil quality is challenging to incorporate into LCA methodologies due to the diversity of relevant impact criteria and limited amount of soil data, numerous models and indices have been proposed (Vidal Legaz et al. 2017; De Laurentiis et al., 2019). LCA provides useful information that highlights key risk points and the relative contributions of value chain stages. As such, it is essential for reporting and labelling initiatives. Nevertheless, LCA-based criteria are rarely used in VSSs when applied to business-to-business relationships. There are probably two reasons for this. One is tradition. VSSs grew out of practice-based policies such as the organic farming standard, and more recent instruments mostly tend to follow the traditional route (Komvies and Jackson, 2013). Perhaps more importantly, LCA tends to be complex, and users (companies and especially farmers) would find it difficult to collect the necessary data and apply it to farm-level decision-making.

Soils are complex, and effective sustainability standards require practical solutions that are feasible for farmers to implement and for companies to standardise, measure, and control. Companies' preference for universal rules across markets is constrained by the variability of soils, farming practices, and regulatory environments. Soil and sustainability research can contribute with the development of relevant tools such as multidimensional sustainability criteria, compliance metrics, and spatially explicit, commodity-relevant datasets. Some of these approaches can be reasonably applied to other complex dimensions of agrifood supply chain sustainability such as small-scale farmland biodiversity.

5. Conclusions

Companies' efforts to implement sustainability standards in their supply chains are a potentially important instrument of farmland soil sustainability. While companies show a rising interest in combating market risks related to soil degradation, the practical interventions have remained in early phases so far.

We (i) found that the food retail industry, a key sector in agrifood supply chains, generally considers soil sustainability as part of its sustainability strategy. Sustainability standards that include soil protection criteria were applied by 41% of the sampled retail companies. However, (ii) the sustainability standards used by companies tend to have only a limited impact on soil protection. Only 56 of the 165 third-party standards relevant to conventional agriculture regulate soil management to a greater extent than simply mentioning its importance. Surprisingly, there was no significant relationship between the impact of the standard and its market penetration (hectares of certified production area). (iii) Schemes that emphasise the environment are more likely to have a greater impact on soil, particularly for criteria related to the erosion, soil conservation and cover crops.

There seem to be several major reasons for this. Companies focus their supply chain interventions on globally important environmental risks such as loss of high-biodiversity habitats, particularly in the tropics, and more easily manageable topics such as pesticide use management. Also, soil sustainability standards require relatively complex interventions and criteria. Provisions in the existing standards tend to be too generic to have a substantial impact.

Data availability

Original research data are available on Figshare.com under DOI: 10.6084/m9.figshare.23295851

Author contribution

Conceptualisation, investigation, writing (lead), revision and funding acquisition: Vojtěch Kotecký. Conceptualisation, investigation, writing and revision: Jan Frouz. Conceptualisation, investigation, data analysis, writing and revision: Vojtěch Čemus. Investigation: Jaroslava Frouzová, Alena Peterková.

Competing interests

The authors declare that they have no conflict of interest.

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