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Measuring the Effectiveness of Climate-Smart Practices in the Context of Food Systems: Progress and Challenges

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REVIEW OF PROGRESS IN CSA RESEARCH

The concept of, and case for, Climate-Smart Agriculture (CSA) has been defined since at least 2010, when the FAO published its report outlining the concept and the ways in which policy, practice and finance might orient toward CSA objectives (FAO, 2010). The FAO website at the time of writing gives the three main objectives of CSA as "sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible."[1] Subsequently, research and practice have focussed on identifying how climate-smart a specific strategy or practice is (Campbell, 2017; Lipper and Zilberman, 2018)—and thus methodologies for measurement and assessment of CSA have become important (see e.g., Thornton et al., 2018). The feasibility of CSA interventions at scale, beyond local successful cases, has also become an important topic (Aggarwal et al., 2018). Promoters of CSA such as the FAO and CGIAR ultimately seek reliable and transparent methods for scaling up, prioritization, and monitoring of CSA interventions. Such assessments depend on underpinning research.

Contributions to the Climate Smart Food Systems (CSFS) Section of Frontiers in Sustainable Food Systems (hereafter "Frontiers in CSFS") have provided some of the underpinning research for CSA. As laid out in the journal scope,[2] submissions should include some assessment of each of the three pillars of CSFS–adaptation, mitigation and increasing productivity (the latter is sometimes conceptualized more broadly as food security). Contributions have ranged from studies with a clear focus on one or two pillars, with a third being treated relatively lightly (see e.g., Jennings et al., 2020) to submissions that focus squarely on all three pillars (e.g., Arenas-Calle et al., 2019).

Soon after its inception, Whitfield et al. (2018) set out six research priorities for the Frontiers in CSFS: (i) What is climate smartness and how do we measure it?; (ii) What are the social and economic impacts of climate smart agriculture? (iii) What trade-offs emerge from climate-smart practices, and at what levels do we consider trade-offs to be safe and just?; (iv) How do theory-based climate-smart actions differ across spatial scale?; what are the theoretical and practical feasibility and consequences of scaling up actions within and across systems?; (v) Which climate-smart

[1] https://www.fao.org/climate-smart-agriculture/en
[2] https://www.frontiersin.org/journals/sustainable-food-systems/sections/climate-smart-food-systems#about

actions are feasible? In which systems and at which scales is climate smartness evident?; and (vi) How can diet choices contribute to the climate smartness of the food system in the long term?

Whitfield et al. (2018) highlighted the importance of systems approaches, and of the intersection between the climate-smart agenda and each and every one of the United Nations Sustainable Development Goals (SDGs), thus illustrating the need to go beyond CSA and to address climate-smart food systems more broadly. **Figure 1** shows the number of studies from our review that address each of the research priorities identified in Whitfield et al. (2018). Of particular note is van Wijk et al. (2020), hereafter vW2020, which produced a valuable forward-looking review toward improving assessments in each of the three pillars of CSA.

The analysis of vW2020 decomposed the three CSA pillars into a total of eight categories: three each for the food security and adaptation pillars, and two for the mitigation pillar. Food security is broken down into (i) increasing production; (ii) the extent to which increases in food production and food security can be sustained; and (iii) assessment of the pathways from agricultural production to food security and nutrition. Adaptation is broken down into short- vs long-term actions (in recognition that the term "adaptation" is often used to refer to short-term coping strategies), plus adoptability of adaptation options. Mitigation similarly breaks down into short- vs long-term, recognizing that analysis of emissions intensities is different to analysis of emissions trends.

vW2020 then reviewed 15 CSA assessment frameworks in the light of these categories. The most commonly addressed of the categories were productivity (12/15), short-term adaptation (11) and short-term mitigation (7). The categories that were less covered by the assessment frameworks were trends in mitigation (zero), food security pathways analysis (2), adoptability of technologies (3), sustainability of food production and food security (4), and long-term adaptation (7).

The current review is grounded in the ever-growing body of CSA research, whilst maintaining a broad definition of climate smart practices that goes, at least in principle, beyond the farm gate and into food systems. In contrast to vW2020, we narrow the focus to those methods that have the greatest potential to assess the synergies and trade-offs inherent in CSA. Sections Indices, Metrics and Participatory Approaches and Recent Progress in

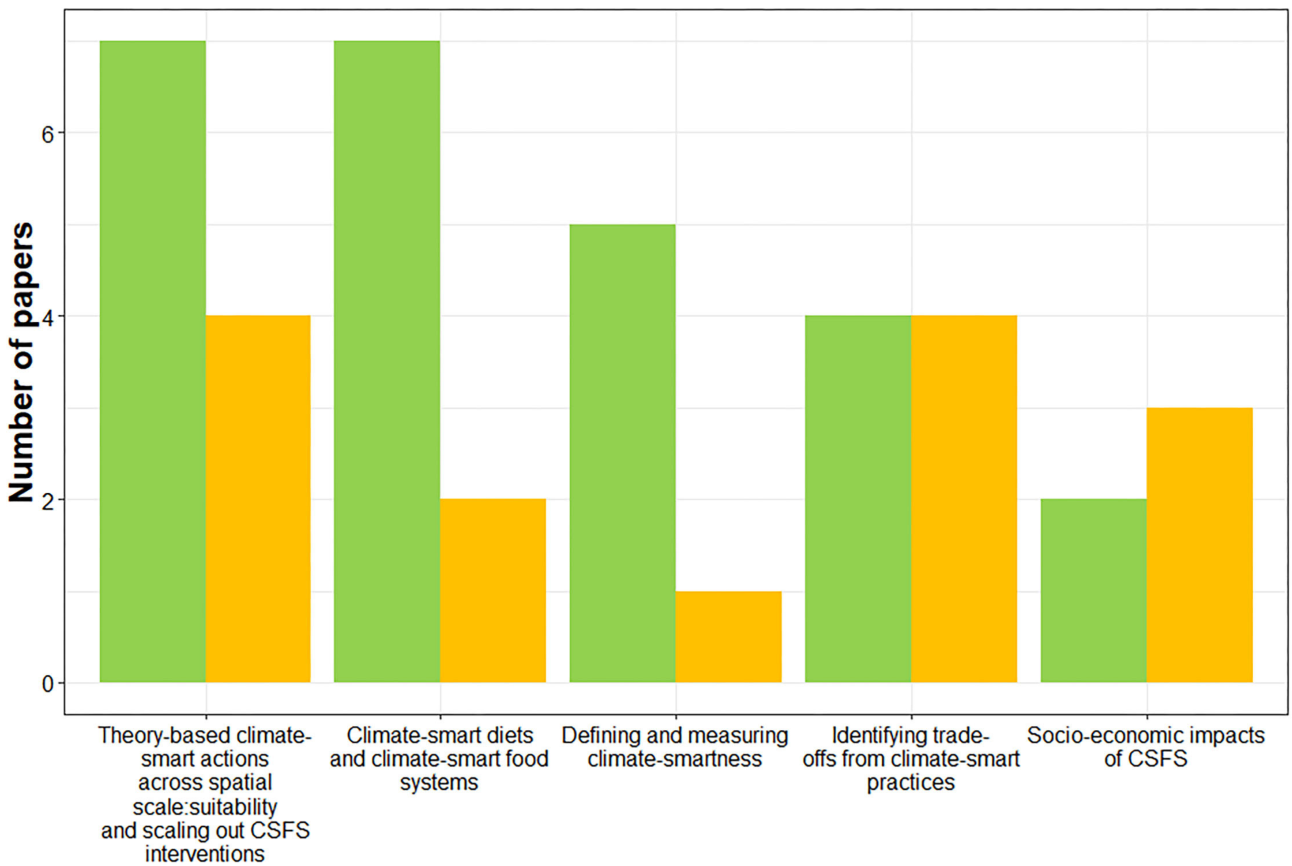

FIGURE 1 | Summary of recent literature addressing either indirectly or partially (amber bars) and directly (green bars) the research questions identified by Whitfield et al. (2018). The first column combines two of the Whitfield questions. The underlying analysis of the way in which each paper contributes to the research question can be found in **Supplementary Table 1**. The analysis in this figure focuses primarily, but not exclusively, on publications in the Climate-Smart Food Systems section of Frontiers in Sustainable Food Systems.

Assessing Trade-offs and Synergies therefore focusses principally on two of the research priorities identified by Whitfield et al. (2018): what is climate smartness and how do we measure it?; and what trade-offs emerge from climate-smart practices? Section the Food System Context: Depth vs. Breadth in CSFS Assessments then brings in the broader food systems context, and with it the other research priorities that emerged from the Whitfield piece.

MEASURING THE EFFECTIVENESS OF CLIMATE-SMART AGRICULTURE

Indices, Metrics and Participatory Approaches

We identify two principle ways in which climate-smartness can be measured: (i) metrics that directly measure a component of climate-smartness, e.g., a single pillar, or aspect of a pillar; (ii) indices, which are composite metrics that synthezise and summarize numerically information across or within pillars. Whilst the delineation between metrics and indices is not always clear in practice, since the two terms are often used interchangeably, the distinction is a useful one, since it clarifies what exactly is being measured–an element of CSA, or of a pillar (metrics), or the overall pillar or extent of climate-smartness (indices).

The "Assessment, monitoring and evaluation" section of the CSA sourcebook (FAO, 2013) presents an overview of methodological frameworks for assessing, monitoring, and evaluating CSA. Subsequently, a wide range of biophysical, social, and economic metrics of mitigation, adaption, and productivity have been developed (World Bank, 2016; Duffy et al., 2017; Christiansen et al., 2018). This work has led to a plethora of CSA-related indices. For example, Quinney et al. (2016) collected over 378 CSA-related indicators from several international development agencies and created an interactive database called "CSA Programming and Indicator Tool". The tool examines the scope and CSA intentionality among different project designs and supports an appropriate selection of indicators to measure and monitor CSA-related outcomes.

In contrast to the more top-down approaches outlined above, participatory approaches to CSA metrics permit more grounded assessments. Examples of this include Sain et al. (2017), the rapid appraisal method of Mwongera et al. (2017); the multi-criteria and multi-perspective ranking system of Wassmann et al. (2019); and the participatory ranking of Kumar et al. (2018). The contribution of participatory approaches in the understanding of climate-smartness is limited to a geographical, political, or socio-economic context by the specificity of actors involved. Whilst such approaches are not generally suited to the assessment of trade-offs and synergies across CSA pillars, they can enable a quantitative measure of climate smartness that can be applied at the country level (World Bank, CIAT, 2015).

Indices are the result of equations that combine information, often across all three CSA pillars, in order to assess climate smartness. The water-based and soil-based climate-smartness indices (CSIs) published by Arenas-Calle et al. (2019, 2021) are indices that seek to provide a measure of climate-smartness from an agronomic perspective. Both indices represent trade-offs and synergies between all three CSA objectives (adaptation, mitigation, and productivity) by translating them into quantitative values. One index uses water productivity (yield per unit water used) and Greenhouse Gas Intensity (GHGI) to capture the extent to which water-based adaptation strategies can have the co-benefits of increased yields and low emissions. This index uses seasonal data, providing a short-term measure of climate-smartness. It can also be used in a long-term time series of seasonal records to track improvements in sustainability and adaptation. The soil-based index is aimed at measuring climate-smartness over multiple years. It measures the ability of a soil-based agronomic practice to increase productivity smoothly (i.e., without the year-to-year variations that can result from climate change) whilst also capturing carbon in the soil. Given that Soil Organic Carbon (SOC) is a key driver of agronomic soil function (e.g., water and nutrient retention, biological activity, or structural stability), it can measure resilience and adaptive capacity in agriculture. Moreover, cumulative changes in SOC in the soil in the middle and long term can indirectly indicate carbon storage.

Whilst not technically a metric or index, databases that can be interrogated for information on CSA effectiveness are clearly important in measuring climate-smartness. Meta-analysis based on extensive data provides another way to understand how climate-smartness varies across space and time. Evidence for Resilient Agriculture (ERA) provides such a database of publications, with analytical tools that enable dynamic interrogation (Nowak and Rosenstock, 2020).

Recent Progress in Assessing Trade-Offs and Synergies

The climate-smartness indices (CSIs) reviewed in Section Indices, Metrics and Participatory Approaches are composite indices that define the climate-smartness of certain cropping systems according to the synergies and trade-offs between mitigation, adaptation and productivity indicators. As such, they can act as an integrated attribute that goes beyond individual assessments of CSA pillars. For example, Arenas-Calle et al. (2021) used a soil-based CSI to assess how synergies in adaptation and mitigation evolve over time, demonstrating that maximum synergy in conservation agriculture practices tends to peak at around 5 and 10 years after the practices have been initiated. After 20 years, neither SOC nor yield show evidence of benefiting from the practices. Similarly, CSI-based assessment of Alternate Wetting and Drying (AWD) practices in rice (Arenas-Calle et al., 2019) expressed the extent to which synergistic adaptation and mitigation were achieved across a range of AWD studies.

In **Table 1**, the eight categories of vW2020 (see section Review of Progress in CSA Research) were used to assess the way in which recently-published CSA assessment methods address the three pillars. On the whole, the CSA assessment methods reviewed here showed similar research gaps to the 15 CSA assessment frameworks reviewed by vW2020. For instance, productivity is addressed in all assessments, whereas other elements of food

TABLE 1 | Summary of recent CSA assessment methods.

Method/reference	Food security			Adaptation			Mitigation	
	Productivity	Sustainability	Food security pathways analysis	Short term	Long term	Adoptability of technologies	Short term	Trend
Soil-based Climate-Smartness Index (SCSI) (Arenas-Calle et al., 2021)	🟢	🟡	🔴	🟡	🔴	🔴	🟡	🟢
Climate Smartness Index (CSI) (Arenas-Calle et al., 2019)	🟢	🔴	🔴	🟢	🟡	🔴	🟢	🔴
CSA technology Index (World Bank, 2016)	🟢	🔴	🔴	🟢	🟡	🔴	🟢	🔴
CSA Results Index (World Bank, 2016)	🟢	🔴	🔴	🟡	🟡	🟡	🟢	🔴
Multi-criteria ranking system for climate-smart agriculture technologies (Wassmann et al., 2019)	🟢	🟢	🟡	🟡	🟢	🔴	🟡	🟢
Climate-Smart Agriculture country profile (World Bank, CIAT, 2015)	🟢	🔴	🔴	🟢	🔴	🟢	🟢	🔴
Evidence For Resilient Agriculture (ERA) platform (Nowak and Rosenstock, 2020)	🟢	🔴	🔴	🟢	🔴	🔴	🟢	🔴
integrated Future Estimator for Emissions and Diets (iFEED) (Jennings et al., 2022)	🟢	🟡	🟡	🟢	🟢	🟡	🔴	🟢

Green circles indicate the sub-component is addressed in detail; yellow circles indicate subcomponents are partially addressed and red circles indicate is not addressed or only to a very limited extent.
The eight categories used are those of vW2020 (i.e., van Wijk et al., 2020).

security are rarely assessed (and then only partially). Similarly, food security pathways, adoptability of technologies, and longer-term adaptation and mitigation all stand out as under-assessed elements. There are some exceptions to this general observation, including assessments of:

- Longer-term mitigation trends, as measured by the soil-based CSI of Arenas-Calle et al. (2021), and projections of GHG emissions and SOC content in iFEED (Jennings et al., 2022).
- Adoptability of CSA interventions: the CSA country profiles published by World Bank and CIAT[3] include an estimation of adoption rate in the climate-smartness assessment. A similar indicator was included in the multi-criteria ranking system developed by Wassmann et al. (2019), where stakeholder groups (farmers, policy/makers), and research-based criteria, were used to rank the potential for scaling out CSA practices.

The Food System Context: Depth vs. Breadth in CSFS Assessments

As a general rule, metrics and indices (as defined in Section Indices, Metrics, and Participatory Approaches) differ in that the former tends toward greater depth of analysis and the latter toward greater breadth across CSA dimensions. This distinction in scope becomes even more important when assessing the broader issue of climate-smart food systems (CSFS), in contrast to the narrower field of CSA. The extent to which multiple context-dependent aspects of CSFS can be integrated into a single indicator, or even a single meaningful and clear assessment, remains an open question. Such integration facilitates comparisons across multiple geographies, contexts and across time (see section Recent Progress in Assessing Trade-offs and Synergies). However, the clarity of a quantified indicators comes at the expense of greater difficulty in accounting for numerous important aspects of food systems, for which one must turn to others tools that assess climate-smartness beyond the farm gate. These tools and emergent research areas are explored below, and they inform the research needs identified in section Research Needs for Measuring CSA and CSFS.

Life Cycle Assessment (LCA) enables estimates of the environmental sustainability and adaptation potential of agricultural systems and subsequent value chains beyond farm. Emissions and pollution metrics assess sustainability, whilst adaptation is measured through various means, e.g., inventory of use of fertilizers, pesticides, energy, and water use. The use of LCA in the assessment of climate smartness was applied by Acosta-Alba et al. (2019) who designed the LCA4CSA assessment framework (Life Cycle Assessment for Climate Smart Agriculture) which intend to provide climate-smartness assessments by integrating life cycle analysis structure. More broadly, Iannetta et al. (2021) and Lemay et al. (2021) present examples of how to frame different elements of food systems

[3] https://ccafs.cgiar.org/resources/publications/csa-country-profiles

connected with on-farm agronomic decisions that have off-farm implications (e.g., value-chain, diets, public health, culture).

Whilst clearly important and moderately well-researched for mitigation, livestock has received less attention than crops in the area of full climate-smart assessments. Gaitán et al. (2016) published an assessment of mitigation potential of some practices in livestock in Nicaragua and defined climate-smart livestock as those systems that could achieve higher efficiency in terms of GHG emissions per kg of milk produced, as well as increased capacity to store carbon *in silvo*-pastoral systems. Such mixed cropping and livestock systems are very common and thus it is important to assess them. March et al. (2021), discussed the use of different alternatives to feed livestock with human-inedible products, while Espitia Buitrago et al. (2021) explore the opportunities and constraints in the production and consumption of alternative protein sources for humans and livestock like forage-fed insects. This work points the way forward to smarter ways of distributing land and resources to produce food.

Nutrition security is another important aspect of food systems, since it goes beyond the narrower views offered by calorie- and protein- based assessments of food security. Mustafa et al. (2021) make reference to "climate-smart and nutrient dense crops" as a way of capturing this idea. The rise of atmospheric CO_2 and soil degradation (and subsequent depletion of micronutrients) represents a threat for crop nutrient quality. Whilst it is increasingly common in climate impact studies, the assessment of nutrient quality as an aspect of climate-smartness has been overlooked in climate-smartness assessments. There has, however, been some progress in assessing nutrition security at the country scale (e.g., Jennings et al., 2022).

RESEARCH NEEDS FOR MEASURING CSA AND CSFS

Chandra et al. (2018) identified the lack of studies assessing trade-offs and synergies in climate-smart practices as a limitation on the design of integrative indicators across multiple dimensions, or across on- vs. off- farm activities. As shown in section Measuring the Effectiveness of Climate-Smart Agriculture, recent years have improved this situation somewhat. Important questions can now begin to be addressed: how do we measure trade-offs and synergies at the food system level (i.e., CSFS rather than just CSA)? We identify three related research needs:

1. **Developing agreed sets of standard metrics, in order to facilitate Intercomparison.** Indices and metrics can provide assessments of the inter-relationships within food systems, which are multi-scale and dynamic. Such assessments permit comparisons across multiple geographies and time periods, thus lending themselves to both learning across regions, and synthesizing information to the global scale.
2. **Indices and metrics as part of wider toolkits.** CSIs measure trade-offs and synergies across time and space in an objective manner, but this necessarily simplifies and omits context. CSIs might be used in combination with other CSA/CSFS assessment metrics in order to produce assessments that both manageable (not too deep or broad) and meaningful (deep and broad enough). Such toolkits may range from highly quantitative assessments to more inclusive approaches, for example combining food security metrics with ethnographic work on the lived experiences of food insecurity (Beveridge et al., 2019).
3. **Expanding CSI approaches beyond agriculture to food systems would facilitate greater inclusion of agriculture in global climate change negotiations.** There is significant potential for agriculture to be more integrated into the United Nations Climate Change Conferences (commonly known as the Conference of Parties), and the mitigation and adaptation targets and financing that result from that process. Measuring CSFS could help not only in monitoring and evaluating individual commitments to adaptation and mitigation, but also in recognizing that these commitments intersect and therefore need to be addressed in a coordinated, systemic way. Metrics for CSFS could be developed into systemic benchmarks or goals that enable measurement of progress toward COP commitments, whilst being fully cognisant of the implicit trade-offs and synergies.

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LA-C performed the literature review and analysis. AC prepared manuscript. All authors contributed ideas and text and edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.853630/full#supplementary-material

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