Cah. Agric. 2018, 27, 26001
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https://doi.org/10.1051/cagri/2018010

Les agricultures face au changement climatique.
Coordonnateur : Emmanuel Torquebiau

Cahiers Agricultures
Available online at:
www.cahiersagricultures.fr

ARTICLE D'OPINION / OPINION ARTICLE
OPEN ACCESS

Identifying Climate-smart agriculture research needs

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Abstract – Climate-smart agriculture (CSA) is an approach to help agricultural systems worldwide, concurrently addressing three challenge areas: increased adaptation to climate change, mitigation of climate change, and ensuring global food security – through innovative policies, practices, and financing. It involves a set of objectives and multiple transformative transitions for which there are newly identified knowledge gaps. We address these questions raised by CSA within three areas: conceptualization, implementation, and implications for policy and decision-makers. We also draw up scenarios on the future of the CSA concept in relation to the 4 per 1000 Initiative (Soils for Food Security and Climate) launched at UNFCCC 21st Conference of the Parties (COP 21). Our analysis shows that there is still a need for further interdisciplinary research on the theoretical foundation of the CSA concept and on the necessary transformations of agriculture and land use systems. Contrasting views about implementation indicate that CSA focus on the "triple win" (adaptation, mitigation, food security) needs to be assessed in terms of science-based practices. CSA policy tools need to incorporate an integrated set of measures supported by reliable metrics. Environmental and social safeguards are necessary to make sure that CSA initiatives conform to the principles of sustainability, both at the agriculture and food system levels.

Keywords: climate change / adaptation / mitigation / food security / soil

Résumé – Questions de recherche pour l'agriculture climato-intelligente. L'agriculture climato-intelligente (Climate-smart agriculture – CSA) a pour objectifs simultanés l'adaptation au changement climatique, l'atténuation du changement climatique et la sécurité alimentaire, grâce à des politiques, des pratiques et des financements novateurs. De nombreuses lacunes existent pour la mise en œuvre de ce concept afin d'atteindre ces objectifs et permettre les transformations de fond qui sont nécessaires. Nous abordons les questions soulevées par la CSA dans trois domaines : le défi conceptuel de la CSA, sa mise en œuvre et les conséquences en matière de politiques publiques et pour les décideurs. Nous formulons aussi des scénarios sur le futur de la CSA en lien avec l'Initiative 4 pour 1000 (Les sols pour la sécurité alimentaire et le climat) lancée lors de la COP 21 (Conférence des parties de la CCNUCC). Notre analyse montre que le concept de CSA manque de fondements théoriques et qu'une approche interdisciplinaire est nécessaire pour assurer les transformations indispensables de l'agriculture et de l'utilisation des terres. Des points de vue contrastés sur la mise en œuvre de la CSA indiquent que le « triplé gagnant » de la CSA (adaptation, atténuation, sécurité alimentaire) doit être évalué en termes de pratiques scientifiques. Les outils de politiques publiques de la CSA doivent disposer d'un cadre de référence cohérent s'appuyant sur des métriques fiables. Des garanties environnementales et sociales sont nécessaires pour s'assurer que les initiatives de CSA sont conformes aux principes de la durabilité, tant en ce qui concerne l'agriculture que le système alimentaire.

Mots clés : changement climatique / adaptation / atténuation / sécurité alimentaire / sol

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1 Introduction

The Climate-smart agriculture (CSA) concept emerged in 2010 as a response to the imminent threat of climate change. In the original Food and Agriculture Organization (FAO) document (FAO, 2010), the definition of CSA is: "Agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (GHG) and enhances achievement of national food security and development goals". CSA has become known for the so-called "triple win", *i.e.,* working simultaneously to achieve its three objectives (or pillars): "adaptation, mitigation, and food security". CSA is also sometimes presented as a mechanism to achieve synergies between the three pillars in a context-specific manner.

CSA aims to contribute to sustainable landscapes and food systems as well as to resilience, ecosystem services, and value chains. It involves a complex set of objectives and multiple transformative transitions for which there are newly identified knowledge gaps related to the performance and conditions of implementing CSA alternatives and measurable outcomes. For some, CSA is not a scientific or technical concept, but rather a "political" concept aiming at better incorporating agriculture in climate negotiations (Fallot, 2016). CSA nevertheless intends to mobilize science to achieve necessary transitions, and requires bridging a diversity of disciplines in agricultural sciences and the environment. Specifically, the use of climate change science data and models by the agricultural research community, such as the Intergovernmental Panel on Climate Change (IPCC) projections, is important (Rosenzweig *et al.*, 2013). A system approach is needed, along with the organization of relevant scientific data and policy that will help to further refine the CSA concept.

The FAO's original CSA document includes the sub-title: "Policies, Practices and Financing for Food Security, Adaptation and Mitigation", indicating that CSA lies at the interface between science and policy-making and strives to foster action on the ground and the mobilization of financing. The CSA approach encourages coordinated actions by farmers, researchers, the private sector, civil society and policymakers towards climate-resilient pathways through four main action areas:

- building evidence;
- increasing local institutional effectiveness;
- fostering coherence between climate and agricultural policies;
- linking climate and agricultural financing (Lipper *et al.*, 2014).

Six years after FAO's first publication on Climate-smart agriculture, CSA has become a 'buzzword' for many in the agricultural research community as well as among practitioners. There are innumerable websites mentioning CSA. Books and articles focused on CSA are flourishing as well (*e.g.*, Campbell *et al.*, 2014, Lipper *et al.*, 2014, 2017; Harvey *et al.*, 2014; Minang *et al.*, 2015, Torquebiau, 2016, Andrieu *et al.*, 2017). However, there have also been criticisms by some civil society organizations claiming that CSA opens "a new space for promoting agribusiness and industrial agriculture" (http://www.climatesmartagconcerns.info/rejection-letter.html Accessed 13/2/2018) and controversies over the meaning of CSA (Steenwerth *et al.*, 2014). In addition, there are concerns that CSA can be appropriated to support conflicting agendas, such as agroecology or conventional agriculture (Pimbert, 2015).

Has the CSA concept come of age? Are there CSA success stories that match the original CSA definition and achieve the "triple win" (*e.g.*, simultaneous achievement of adaptation, mitigation, and food security)? What does CSA mean today for actual decision-makers such as farmers, companies, and policy-makers at different levels (local, sub-national, national)? How do soil carbon sequestration and the 4 per 1000 Initiative (which has objectives similar to those of CSA) launched at COP 21 integrate into CSA?

To address the above questions and suggest corresponding research topics, the present paper intends to:

- review achievements and current criticisms of the CSA concept;
- assess CSA implementation, taking into account particularly the triple-win challenge and synergies or trade-offs between the three CSA objectives;
- analyze what CSA means for decision-makers;
- analyze the links between soil carbon sequestration and nitrogen management, and CSA.

2 The conceptual challenge

Since the CSA concept did not arise from the academic community, its underlying concepts were not aligned with existing scientific debates, on *e.g.*, sustainability, food security, resilience, or agroecology. This should not preclude CSA from being analyzed rigorously. The presence of the word "sustainable" in the original CSA definition should indicate that CSA is concerned about the impact of agriculture on future generations, and its environmental, economic, and social implications.

Early texts on CSA by FAO (2010, 2013) and Lipper *et al.* (2014) showed a progressive shift in meaning from sustainable increase in productivity to food security. However, food security in itself is a complex concept depending on various conditions (access, availability, utilization, stability) which all need to be taken into account (Richardson, 2010). Some authors are consequently using food security indicators such as the Household Food Insecurity Access Scale or Dietary Diversity with indicators of social resilience and CO_2 emissions to assess the climate smartness of farming systems (Hammond *et al.* 2017).

Resilience and resource use efficiency are key guiding principles for CSA, as presented in Lipper *et al.* (2014). The authors insist that CSA must "emphasize agricultural systems that utilize ecosystem services to support productivity, adaptation, and mitigation". The term 'resilience' is sometimes used interchangeably with 'adaptation' in the definition of CSA (Lipper *et al.*, 2017). The ecosystem approach is a dominant aspect of CSA (*e.g.*, niche partitioning, ecological successions, symbiosis), including practices in which those principles play a key role, such as crop diversification, intercropping, rotations, cover crops, agroforestry, biological control of pests and diseases, plant-animal interactions, and the use of agrobiodiversity.

Nevertheless, a detailed analysis of FAO's reference document on CSA (FAO, 2013) shows that 'land sparing' (intensifying in some areas and conserving nature elsewhere; see Grau *et al.*, 2013) is favored, while 'land sharing' (combining objectives of production and protection on the same land) is not. This does not make biodiversity and ecosystem services appear as top CSA priorities (Tissier and Grosclaude, 2015). Given that higher cultivation intensity in farmed landscapes has been shown to decrease biodiversity richness and the potential for carbon storage (Renwick *et al.*, 2014), more emphasis could be given to land sharing. A landscape approach to CSA could help to address this weakness, yet this is an under-researched topic (Harvey *et al.*, 2014; Minang *et al.*, 2015).

There is a growing consensus that the "unintended social and environmental consequences" of agriculture need to be addressed (IAASTD, 2009). This consensus has led to greater acceptance of agroecological concepts, which is occurring separately from the CSA debates. Agroecology has been defined differently, ranging from the simple 'application of ecological principles' to agriculture (Oxford Dictionnaries, 2016) to the 'integrative study of the ecology of the entire food system', encompassing ecological, economic, and social dimensions (FAO, 2015). There are compelling reasons to link agroecology and CSA and to find solutions that address both (Saj *et al.*, 2017). The practices of CSA and agroecology are often one-in-the-same, and can enrich one another.

Agroecology has sometimes been described as being implicitly climate-smart, but is seldom evaluated for its climatic performance. Its potential for carbon storage, as well as adaptation to – or mitigation of – climate change is sometimes mentioned (*e.g.*, Lichtfouse, 2012; Altieri *et al.*, 2015) but 'climate-compatibility' is not among agroecology initial objectives. On the other hand, CSA has not been defined to encompass agroecological principles, but it explicitly does include elements of such principles. CSA is presented in its original definition as an approach covering "agriculture and food systems". The term 'food system' can be understood as the trajectory 'from field to fork'. This includes production systems, post-harvest interventions, pest, disease and water management, human nutrition, minimizing waste and losses, food transport, and access to markets.

Assessing whether or not CSA can address these requirements along the entire food value chain, while conforming to its original definition in terms of adaptation, mitigation and food security, is not a simple task. Holistic approaches such as life-cycle assessment are useful methodologies. Parallels can be found here with 'sustainable agricultural intensification', which is a 'radical rethinking of food systems not only to reduce environmental impacts but also to enhance animal welfare and human nutrition and support rural economies and sustainable development' (Garnett *et al.*, 2013; Campbell *et al.*, 2014). The need to develop 'inclusive food value chains' in support of CSA was highlighted by the FAO in the founding CSA documents (FAO, 2013). However, innovative research is required to assess CSA under this holistic perspective.

Consequently, there is still a need to carefully rethink the theoretical foundation of CSA. In the thorough review on the CSA global research agenda published by Steenwerth *et al.* (2014), reference is made to the need for further interdisciplinary and transdisciplinary research to better understand and measure CSA processes that may lead to the transformative changes needed in agriculture. This thinking can help in designing an improved, holistic CSA paradigm.

3 The implementation challenge

Although FAO's CSA sourcebook (2013) provides many examples, CSA is described in terms of objectives to be reached and not in terms of the means to be employed to reach those objectives. This leaves it open to users to decide on the approach to the types of interventions they consider 'climate-smart'. Progressively, the CSA concept has also evolved from achieving the triple win more generally and globally, to achieving synergies between the three CSA objectives as a function of local conditions. Indeed, some practices may be climate-smart in a specific local context, but not in another one, given agroecological conditions, market opportunities, and stakeholders' priorities. Consequently, CSA practices are not "set in stone" and a broad range of practices is now being recognized.

This context-specific approach takes into account the diversity of agricultural systems and stakeholders' priorities in order to support CSA implementation and broad adoption (Andrieu *et al.*, 2017). It also explains why for many, CSA is simply a framework to address agriculture under climate change, thus leaving the door open to many interpretations. However, this runs the risk of ignoring one or more of the three pillars with the risk of compromising the overall intentions of CSA.

When the definition of CSA is taken loosely, without the requirements for sustainability and for the three CSA pillars, practices that promote herbicides or energy-or-water-intensive farming – such as in large-scale industrial monocultures or biofuel plantations – have sometimes incorrectly been called 'climate-smart.' Intensive bioenergy crops for instance, have sometimes been described as climate-smart because they contribute to renewable energy production. However, these metrics need to be gauged against other possible land uses (food crops) and in terms of environmental impact (*e.g.*, biochemical inputs, biodiversity, and water). Similarly, drought-tolerant varieties that require high fertilizer inputs may seem well-adapted to climate stress and produce biomass that can contribute to food security, but may not perform in terms of mitigation and resilience to unexpected climatic events.

Operationalizing CSA has often been presented in terms of dealing with synergies or trade-offs among the three pillars, but particularly between adaptation and mitigation. Indeed, mitigation may not be a priority in a given context, particularly where farmers use low levels of production inputs. Practices that may be relevant for their positive effects on adaption or food security may not have a direct effect on mitigation (*e.g.*, drought-tolerant varieties). Consequently, some documents indicate that CSA should aim to reduce emissions "where possible" (http://www.fao.org/climate-smart-agriculture/en/ Accessed 13/2/2018). Conversely, mitigation options by small farmers (*e.g.*, options to increase soil organic matter content) may not show co-benefits in terms of adaptive capacity in the short term (Steenwerth *et al.*, 2014).

The question remains whether this is a contradiction with the original CSA definition, or if the CSA concept should be broadened to include options that can at least result in positive outcomes on two pillars. A bias was also introduced in the way mitigation was taken into account by CSA, since it has often been promoted in terms of reducing emissions and not in terms of increasing carbon sequestration through biomass or soil.

Synergies occur when food security, adaptation, and mitigation not only occur simultaneously (*i.e.,* co-benefits) but when there is a positive feedback of either on the others. For instance, if nitrogen-fixing trees are associated with crops to improve soil fertility (adaptation and food security), soil carbon content may increase (mitigation) and the resulting decrease in fertilizer use will lead to a reduction in N_2O emissions (mitigation). Similarly, if compost is incorporated into the soil with the objective of increasing soil organic matter (mitigation), better yields and improved livelihoods will result (adaptation).

There are some CSA ‘success stories’ that provide examples of synergies and positive feedbacks among the three pillars. For instance, intermittent irrigation of flooded rice, also known as the ‘System of Rice Intensification’ (SRI) has been shown to reduce methane emissions (mitigation), decrease water use (adaptation and resilience), and increase yield, and thus food security (Thakur *et al.*, 2016), although some questions persist about weed control or actual yield benefit. Farmer-managed regeneration of scattered trees on cropland in the Sahel (agroforestry) is another case: it contributes to soil and biomass carbon sequestration, buffers heat stress and erosion, improves soil fertility and finally leads to better food security through commodity and income diversification (Sendzimir *et al.*, 2011). But it needs to be acknowledged that not all practices will result in synergies and often may result in trade-offs, and thus, further research is needed.

Stakeholder-driven analyses of Climate-smart agriculture require a transdisciplinary effort to consistently link state-of-the-art data, climate scenarios, and socio-economic trajectories in crop, livestock, and economic models (Rosenzweig *et al.*, 2013). Crop and livestock model outputs are aggregated as inputs to regional and global economic models to determine regional vulnerabilities, changes in comparative advantage, price effects, and potential climate-smart strategies in the agricultural sector (*e.g.*, Rosegrant *et al.*, 2017). For example, the Agricultural Model Intercomparison and Improvement Project (AgMIP) utilizes intercomparisons of these various types of methods to improve crop, livestock, and economic models and ensemble projections to produce enhanced assessments by in-country crop, livestock, and economic modeling communities (Rosenzweig *et al.*, 2013). These new methods of regional integrated assessments include iterative stakeholder inputs to provide an effective science and evidence base for climate-smart decision-making in farming systems.

4 CSA implications for policy and decision-makers

Contrasting views exist about the development of the CSA concept. Some civil society organizations have described simplifications of the CSA concept as ‘green washing’. The triple win has also been described as an ‘illusion’ which can only be resolved with trade-offs through political processes because its three dimensions correspond to negotiating arenas (poverty alleviation, food security, and climate change mitigation) that have different stakes and stakeholders (Caron and Treyer, 2015).

Policymakers in many developing countries, particularly in Africa, have explicitly included CSA in their Nationally Determined Contributions (NDCs) prepared in the context of UNFCCC’s Paris Agreement (http://unfccc.int/focus/ndc_registry/items/9433.php Accessed 13/2/2018) and there are an increasing number of climate change plans and strategies that articulate agriculture and food system adaptation and mitigation at national levels. More effective policies can be designed that take into account complementarity between policy instruments and between implementing institutions. These need to explicitly seek to avoid antagonistic effects such as promoting carbon sequestration and simultaneously subsidizing mineral fertilizers.

Decision-making tools for CSA need to incorporate a complete set of measures that foster change towards the concurrent consideration of food security, adaptation and mitigation in land-use practices and equally importantly, to promote changes in governance and financing (Torquebiau *et al.*, 2016). Furthermore, local adaptation and food security refer to private goods, while mitigation refers to a public (global) good (Steenwerth *et al.*, 2014); thus they are consequently funded by distinct financing schemes.

Many decision support tools for policy makers and local actors have been proposed to take into account the synergies and trade-offs between the CSA pillars (Campbell *et al.*, 2016) but these tools falter due to the lack of scientific evidence on the effectiveness of CSA practices (Rosenstock *et al.*, 2016). Reliable indicators are required to separate CSA from non-CSA activities. For this, the development of consistent CSA metrics, either biophysical, policy-based or finance-related, is needed. Rosenstock *et al.* (2016) proposed a reference framework, with easy-to-measure parameters, such as proxies for soil carbon sequestration, reduction of GHG emissions, and cost-benefit analyses of the simultaneous fulfillment of CSA’s three pillars. Well-designed metrics will contribute to the ex-post quantification of adaptation or mitigation, and the achievement of robust cross-site comparisons.

The development of environmental and social safeguards for CSA is also a very important issue. Specific indicators are required to ensure that selected CSA technologies and approaches comply with the implicit CSA sustainability requirements, *e.g.*, inclusivity of relevant stakeholders; sensitivity to gender, age, class, or ethnicity; biodiversity protection; role of family farming and traditional knowledge; contribution to rural employment; and property or water rights.

Since climate change plans and strategies are relatively new, there is a lack of documentation of their implementation at the local level. Some case studies show that farmers have a growing perception of climate change and of the need to adapt, but they do not clearly understand the direct consequences to their farm in the short-, medium- and long-terms (Bormann *et al.*, 2012). In developing countries where the level of inputs can be low, mitigation is hardly the entry point to trigger changes. Collective action is therefore necessary to steer governance rules and financing towards the three goals of

CSA. Innovative thinking is required in order to reconcile policy and practice along complementary lines.

CSA implementation also faces a better understanding of the capacity of extension services or consultants in each country to help training farmers on climate-smart practices. It is well-known that innovative technologies (*e.g.*, agroforestry) require specific extension support, sometimes not readily available (Chitakira and Torquebiau, 2010). A better understanding of farmers' views and actions on CSA practices is also required. In the end, it all comes down to whether or not individual farmers are willing to adopt the required changes or have the knowledge and capacity to make those changes (Chatrchyan *et al.*, 2016).

New financing instruments are also needed to support changes at all levels, from local, to national and global. The COP21 Paris Agreement provided a sound basis for further raising the profile of agriculture within the UNFCCC negotiations and developing new financing instruments for climate change and agriculture. The recent COP23 (November 2017) has officially brought agriculture into the negotiations. This will bring greater focus on implementing climate actions in the sector as opposed to negotiations focused on scientific and technical aspects only. Finally, there is an increasing awareness that achievement of CSA globally will require policy interventions at all levels, and including multiple actors (Chatrchyan *et al.*, 2018 forthcoming).

5 Case study: the 4 per 1000 Initiative

At COP21 climate negotiations in Paris, the *4 per 1000 Initiative 'Soils for Food Security and Climate'* was launched to promote the role of soil organic matter in addressing the triple challenge of food security, adaptation of agriculture to climate change, and mitigation of greenhouse gas emissions *(*Lal *et al.*, 2015; Minasny *et al.*, 2017; Soussana *et al.*, 2018). The similarity with CSA is striking in terms of objectives, but the *4 per 1000* initiative focuses solely on soil carbon management as a means to achieve its goals. The rationale for the *4 per 1000* program is that a 0.4% annual growth rate of the carbon stock of all soils of the world would make it possible to offset the present annual increases in atmospheric CO_2.

Practices put forward to contribute to soil carbon sequestration include permanent soil cover, agroforestry, crop rotations (especially with legumes), organic fertilizers, conservation agriculture, agroecology, precision agriculture, improved grazing practices and quality of fodder, integrated soil fertility management, and improved water management. The practices encouraged under the *4 per 1000* concept consider mitigation both in terms of increasing carbon sequestration through biomass or soil and in terms of reducing GHG emissions. CSA can correct some of its weaknesses (and provide answers to criticisms) through a stronger focus on increasing soil organic matter by incorporating the *4 per 1000* principles as a component. This can be achieved not only in terms of soil carbon sequestration practices, but also by encouraging policies and institutional reforms that alert more stakeholders to the need for better soil management. But further evidence is needed to document the actual benefits and long-term metrics of both CSA and *4 per 1000* measures. This in turn could increase farmers' adoption of sustainable practices and attract more financing for CSA and 4 per 1000 alike. However, it must be clarified that soil carbon sequestration does not happen independently from other sources of nutrients, especially phosphorus and nitrogen.

Indeed, synthetic nitrogen fertilizer continues to be the largest used macro-element on the planet for crop production systems. Over-use of nitrogen fertilizer is among the known causes and is the largest anthropogenic source of the potent GHG, nitrous oxide (N_2O) emissions in the biosphere (Denman *et al.*, 2007). In parallel, the nitrogen use efficiency continues to be less than 50% globally (Lassaletta, *et al.*, 2014). Multipronged approaches and research are needed to empower farmers globally to adopt practices to increase the efficient use and application of nitrogen fertilizer. Rather than slow, incremental and evolutionary progress, revolutionary advances are needed in fertilizer management, such as the "Five-R" approach to reduce the ecological footprint (Right Input, at the Right Time, in the Right Amount, at the Right Place, and in the Right Manner) which can be applied to nutrient stewardship and is among the techniques that are scale independent (for large and small scale farming systems). It has been shown to optimize input sources, placement, amount, timing, and manner, while reducing nitrous oxide emissions, and maximize output, efficiency, and profitability in a sustainable manner (Khosla, *et al.*, 2008).

Biological nitrogen fixation through legume plants and symbiotic rhizobia has also a key role to play. Provided there are adequate phosphorus concentrations and sufficient water, symbiotic nitrogen fixation, combined with improved nutrient management, can certainly match CSA requirements in terms of adaptation (particularly in multiple cropping situations), mitigation (accumulated biomass and decrease of N_2O emissions) and food security.

6 Conclusions

As a major paradigm breakthrough, CSA raises unexpected questions. In this article, we have shown that CSA is both a technical and a political concept, requiring the bridging of several disciplines, and that achieving the three pillars of CSA concurrently is certainly not an easy task. We have described major implementation challenges of CSA and detailed key implications for policy and decision-makers. We have shown how soil carbon sequestration and CSA can be integrated and encouraged as complementary approaches. These reflections have raised several research questions which need to be addressed for CSA to be adopted. Compared to conventional, monodisciplinary research questions (*e.g.*, breeding a crop for higher yield), CSA research entails a fair amount of uncertainty. Questions remain around how to strike the right balance between the three CSA criteria, how to measure CSA performance, and how to reconcile such a complex paradigm with farmers' decisions. Not to mention the required negotiation processes between stakeholders and the necessary policy changes that need to take place. The tangled web of climate change mechanisms makes the equation "mitigation + adaptation + food security" a thorny one to solve (Torquebiau *et al.*, 2016).

Agriculture, the human activity probably most dependent on the climate, was initially seen as a victim of climate change.

Increasing temperature trends, higher frequency of weather extremes and greater seasonal variability have all been described as representing new threats for agriculture worldwide. Agriculture has then been regarded as one of the culprits responsible for climate change, because of direct greenhouse gases emissions through ruminants, fertilizer manufacturing and application, and on-farm energy use or indirect emissions related to land use change. Agriculture is now beginning to be also viewed as a solution to climate change, because of the role it can play in terms of GHG mitigation. Climate-smart agriculture can help to design land-use systems that make the adaptation-mitigation connectivity a reality at all scales and hence help farmers to become leading actors of climate change solutions.

Acknowledgements. We thank two anonymous reviewers for useful comments on an earlier version of the manuscript.

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Cite this article as: Torquebiau E, Rosenzweig C, Chatrchyan AM, Andrieu N, Khosla R. 2018. Identifying Climate-smart agriculture research needs. *Cah. Agric.* 27: 26001.