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Moving conservation agriculture from principles to a performance-based production system

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Commentary

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Abstract

Conservation agriculture (CA) is an approach to farming that is defined by three principles: (1) minimal soil disturbance (no-till), (2) crop diversity in time and space, and (3) soil coverage by crop residues and/or cover crops. These principles provide a roadmap to protect and improve soil. However, the narrow criteria for defining CA may fail to account for tradeoffs between soil health and other ecosystem services. A literature review of meta-analyses dealing with CA and an online survey in France were conducted to explore the implementation and performances of CA. Research on CA systems has focused on crop productivity and soil quality whereas research on other dimensions of cropping system sustainability are lacking. The effects of CA on other aspects of sustainability such as biodiversity and profitability are less prevalent in the literature. The online survey results show that 63% of respondents thought that CA helps reduce pesticide use, 91% that CA improves water use efficiency, and 77% that CA helps to store carbon and achieve the objectives of the 4 per 1000 international initiative. Given the prevalence and widespread support for CA, we advocate for moving CA from its current definition based on the means toward a definition that includes performance-based metrics that address different ecosystem services. CA has potential to help address challenges associated with climate change, biodiversity loss, and water pollution, but opportunities may be missed without developing performance targets that go beyond soil conservation.

Introduction

Although highly productive, intensive agriculture that has been promoted and adopted over the past decades is associated with major environmental problems. Between 1985 and 2005, crop yields increased considerably worldwide: 34% for cereal crops, 57% for oilseeds, and 11% for forage crops (Faostat, 2020). Factors responsible for increasing crop productivity are now being questioned for their environmental impacts (Tilman et al., 2002; Stoate et al., 2009). The leaching, runoff, and volatilization of agricultural inputs (i.e., nitrogen and phosphorus fertilizers, pesticides), for example, have led to water and air pollution in many parts of the world (Stoate et al., 2001). The recent French INRAE-IFREMER report on the impact of pesticides on biodiversity and ecosystem services confirms that many terrestrial, aquatic, and marine environments—particularly coastal ones—are contaminated by pesticides (Mamy et al., 2022). The eutrophication of water bodies due to excessive nitrogen and phosphorus fertilization in Europe has increased purification costs and caused low-oxygen conditions that endanger aquatic biodiversity, fisheries, and recreational sites (Diaz and Rosenberg, 2008; Canfield, Glazer, and Falkowski, 2010). In France, some river basins have already exceeded the maximum concentration of active substances authorized for water purification purposes (Dubois and Lacouture, 2011). Water resources are becoming increasingly scarce. For example, 20% of irrigated land in the United States is fed by groundwater pumped in excess of recharge (Postel, 2014). The combined effect of intensive input use (pesticides, fertilizers, irrigation) and landscape simplification has led to a dramatic decline in farmland biodiversity in various parts of the world (Donald, Green, and Heath, 2001; Fried et al., 2009; Sánchez-Bayo and Wyckhuys, 2019). Reversing these deleterious trends represents a colossal challenge and agriculture is facing one of the greatest challenges of the 21st century: providing enough quality food while reducing environmental impacts and ensuring a decent living for farmers.

Conservation agriculture: principles first and foremost

Initiated in the United States in the 1950s to limit soil erosion in response to the 'dust bowl' episodes that destroyed hundreds of thousands of hectares of cultivated soil in the central United States in the 1930s, adopted in Europe in the 1960s and in Latin America in the 1970s (Derpsch, 1998), soil conservation techniques and efforts have evolved into conservation agriculture (CA). According to the FAO, CA is a farming system or production strategy defined by the simultaneous and permanent implementation of three principles, also called principles (FAO, 2021): (i) no-till (no soil disturbance except by a light tine or disc during sowing); (ii) crop diversity in time (crop sequence, rotation) and space (intercropping, companion plants); and (iii) maximum soil coverage by crop residues or sown cover crops (annual or permanent cover).

This definition emphasizes that CA is defined above all by the technical means implemented (i.e. the three principles), which are described in greater detail in numerous writings and contextualized according to regions of the world (Kassam et al., 2009; Kassam and Friedrich, 2011; Friedrich, Derpsch, and Kassam, 2012; Kassam, Friedrich, and Derpsch, 2019). Thus, CA systems are defined as those in which no mechanical disturbance of the soil is carried out except by the seed drill (less than 15 cm wide or 25% of the cultivated area), which grow more than three different crop species pure or in a mixture (of variety or species), and which cover at least 70% of the soil surface with stubble, crop residues or dead or living cover crops at the time of sowing (Kassam, Friedrich, and Derpsch, 2019). CA systems combine a diverse set of agricultural management practices (e.g., rotation, cover, sowing, fertilization, weeding) which may change as the system evolves (Knowler and Bradshaw, 2007; Vankeerberghen and Stassart, 2016; Derrouch et al., 2020). Stopping tillage (such as ploughing, false seeding practices, mechanical weeding) reduces traction time, fuel consumption, labor (West and Marland, 2002; Kertész and Madarász, 2014; Adeux et al., 2022), and soil compaction (Raper, 2005). However, not all crops and not all soil and climate conditions are suitable or optimal for no-till (e.g., industrial crops such as sugar beet or potatoes), and require the maintenance of shallow tillage for their establishment (e.g., ridging), with harvesting also disturbing the soil. The abandonment of these crops on a farm may have economic consequences and/or require the restructuring of farming equipment. For all the reasons outlined above, it remains very difficult to assess on a global scale the areas actually under CA as defined precisely by the FAO (FAO, 2021), despite the existence of surveys in certain countries (Baker, Collins, and Choudhary, 2003; Knowler and Bradshaw, 2007; Kassam et al., 2009; Lahmar, 2010; Friedrich, Derpsch, and Kassam, 2012; Kertész and Madarász, 2014; Kassam, Friedrich, and Derpsch, 2019).

Other dimensions of cropping system sustainability than crop productivity and soil quality are lacking

A systematic review of all the meta-analyses published on CA worldwide was conducted using the Web of Science and Scopus databases with the adapted keywords and their relatives: conservation agriculture, no-till, crop diversification, soil cover, meta-analysis, systematic review, meta-regression. A total of 31 meta-analyses published from 2015 to 2022 were identified that fit the selection criteria (Table 1). These meta-analyses highlight that the effects of CA systems on crop productivity and soil quality (e.g., carbon sequestration, soil structure, soil biological activity) have largely been studied in isolation without considering other dimensions of cropping system sustainability (Table 1).

An in-depth analysis of the modalities compared in the meta-analyses highlighted the diversity of practices described by authors as CA-based practices, and resurrects the confusion between conservation tillage and CA (Reicosky, 2015). Many authors define CA system as a system that implements only one of the principles defined by the FAO (FAO, 2021) (e.g., no-till), without necessarily specifying whether their implementation is permanent or temporary. It is also generally accepted in most meta-analyses that cropping systems involving the simultaneous but partial application of all the three principles can be qualified as CA (Scopel et al., 2013) (e.g., direct seeding on a diversified rotation involving at least three different crops with soil surface coverage of less than 30%, or diversified rotation involving at least three different crops with plant cover and occasional shallow tillage). Therefore, it remains difficult to identify meta-analyses that actually qualify a CA system, as the complete, simultaneous, and permanent application of all three principles, even though such cases do exist (Jat et al., 2020; Dong et al., 2021). It also remains difficult in the scientific literature to quantify the effects of CA in general, as their evaluation requires the selection of plots that have already passed the transition phase estimated at 5–6 years (Chabert and Sarthou, 2020; Derrouch et al., 2020) during which soil properties and farming practices evolve. In addition, farmers who are starting now to transition to CA are benefiting from the advices and experience of pioneering advisors and farmers. This makes difficult to use space-for-time substitution approach (Pickett, 1989) to assess long-term benefits of CA, even if this was done in some primary studies (Trichard et al., 2013; Derrouch et al., 2020, 2021*a*, 2021*b*). Indeed, farmers who now transition to CA know, for example, that time is required to adapt crop rotations (cash crops, companion crops, cover crops, intercrops) and to stop tillage. In addition, it is not unusual for CA farmers to be confronted in certain years with high pest pressure such as slugs (Scaccini et al., 2020), voles (Ruscoe et al., 2022) and/or weeds (Chauhan, Singh, and Mahajan, 2012; Chauvel et al., 2018; Derrouch et al., 2021*a*) sometimes being resistant to herbicides (Gliessman, Engles, and Krieger, 1998; Sammons and Gaines, 2014; Heap, 2021). These high pest pressures can force farmers to contain these problems with occasional and more or less intensive tillage operations.

Given that the strict implementation of the principles is a difficult task, the entire agricultural community of stakeholders (e.g., farmers, advisors, scientists) maintains a vagueness and a gap between the official FAO definition (FAO, 2021) and the reality of its implementation, which makes difficult the assessment of benefits of CA, whether these benefits are quantified through scientific studies or survey.

Perception of conservation agriculture and its benefits/issues

Agriculture and the farmer are at the heart of many high-profile issues, both positive and negative, such as the use of pesticides and water/air pollution, the preservation of water resources, the emission of greenhouse gas, the need to supply food in quantity and quality, the limitation of soil erosion, the preservation of biodiversity, and the shaping of landscapes. In the media-saturated context, opinions on all these subjects are rife, and it is sometimes difficult to discern what we know or not, and to give credence to this or that statement, either read or heard. Yet scientific activity is not simply a matter of opinions that clash without ever converging. The body of knowledge we have on a subject is obviously evolving, it is not set in stone, but it is the result of a debate based on results we obtained using a scientific approach. Research results must therefore be debated before they become knowledge. But what does this have to do with CA?

Table 1. Indicators identified in the 31 meta-analyses identified in the scientific literature that synthesized the effects of conservation agriculture with total and/or partial but simultaneous application of the three CA principles defined by the FAO (2021)

Sustainability indicators	Indicators	Number of meta-analyses	References
Productivity	Yield	14	(Pittelkow et al., 2015*a*, 2015*b*; Rusinamhodzi, 2015; Cooper et al., 2016; Marcillo and Miguez, 2017; Knapp and van der Heijden, 2018; Hallama et al., 2019; Shackelford, Kelsey, and Dicks, 2019; Toler et al., 2019; Corbeels et al., 2020; Jat et al., 2020; Sun et al., 2020; Reich, Paul, and Snapp, 2021; Adil et al., 2022)
	Stability of the production	2	(Knapp and van der Heijden, 2018; Reich, Paul, and Snapp, 2021)
	Pest pressure	3	(Osipitan et al., 2019; Shackelford, Kelsey, and Dicks, 2019; Toler et al., 2019)
	Water use efficiency	3	(Jat et al., 2020; Kumara, Kandpal, and Pal, 2020; Adil et al., 2022)
Economic sustainability	Farm income	2	(Jat et al., 2020; Reich, Paul, and Snapp, 2021)
	Time/workload	1	(Reich, Paul, and Snapp, 2021)
Environmental sustainability	Carbon sequestration	10	(Powlson et al., 2016; Vicente-Vicente et al., 2016; Kumara, Kandpal, and Pal, 2020; Mondal et al., 2020; Nunes et al., 2020*b*; Dong et al., 2021; Nicoloso and Rice, 2021; Payen et al., 2021; Reich, Paul, and Snapp, 2021; Bohoussou et al., 2022)
	Greenhouse gas emissions	3	(Zhao et al., 2016; Shackelford, Kelsey, and Dicks, 2019; Jat et al., 2020)
	Nutrient dynamics	3	(Hallama et al., 2019; Shackelford, Kelsey, and Dicks, 2019; Nouri et al., 2022)
	Biological activity of soils	4	(Zuber and Villamil, 2016; Bowles et al., 2017; Shackelford, Kelsey, and Dicks, 2019; Kim et al., 2020)
	Soil quality	9	(Basche and DeLonge, 2019; Shackelford, Kelsey, and Dicks, 2019; Mondal et al., 2020; Nunes et al., 2020*a*; Nicoloso and Rice, 2021; Reich, Paul, and Snapp, 2021; Adil et al., 2022; Bohoussou et al., 2022; Nouri et al., 2022)
Social sustainability	Gender equity	1	(Reich, Paul, and Snapp, 2021)
	CA adoption	2	(Reich, Paul, and Snapp, 2021)
Human well-being	Food safety	1	(Reich, Paul, and Snapp, 2021)

CA was not initiated and promoted based on research work and scientific knowledge that would have postulated and converged to affirm that the joint implementation of the three principles (no tillage, plant cover, diversity of cultivated species) would have virtues, even if they pose difficulties. CA has been developed and implemented all over the world by farmers, practitioners, and pioneers, who have rethought farming systems beyond what was known and taught, or at least beyond what was being practiced. Through observation, they deduced empirical knowledge. These CA stakeholders grouped and exchanged as a community and play a very active role, either by increasing the amount of knowledge we have on CA, by circulating them, or simply by circulating ideas and opinions of others. Over the past decades, these observations have often collided with the boundaries of acquired scientific knowledge.

By building on a new and more holistic way of visualizing the agroecosystem, and by re-questioning each agricultural practice implemented and its underlying effects on the components of the agroecosystem (e.g., weeds, earthworms, micro-organisms, carbon and nitrogen cycles), CA has given rise to the expression of several well-known cognitive biases in the community of CA stakeholders (Klein, 2020):

- the tendency to give more credence to ideas/results we like than to ideas/results we do not like; a bias that manifests itself in the community of CA stakeholders when a research result—refuted by some or endorsed by others—comes to fuel scientific debates on CA, its virtues, and its shortcomings;
- *ipsedixitism* ('as soon as the master himself has said it, then there is no more discussion'), which means that a statement can no longer be questioned or debated as long as a person, who is recognized by some CA stakeholders as an expert has affirmed it, a bias also known as the 'guru effect' (Sperber, 2010);
- *utracrepidarianism*, the tendency to speak confidently about subjects that one does not master completely and thoroughly, which is growing in the community of CA stakeholders as statements are repeated by word of mouth, losing along the way the elements of proof, explanation, or contextualization of the initial statement; and
- trusting apparent evidence and personal intuition.

In order to compare the opinions of people related to agriculture to those not related to agriculture, we asked ten questions that come up frequently in discussions, field visits, conferences, and meetings with CA stakeholders to a random, non-representative panel of people in France, through the distribution of an anonymous online questionnaire on social networks, via various media, and mailing-lists, from 02/15/2023 to 03/24/2023. After indicating whether or not he/she works in the agricultural sector (farmers, engineers, advisors, technicians, or any activity related to agriculture), the respondent was asked to answer each question with the following choice: 'I don't know',

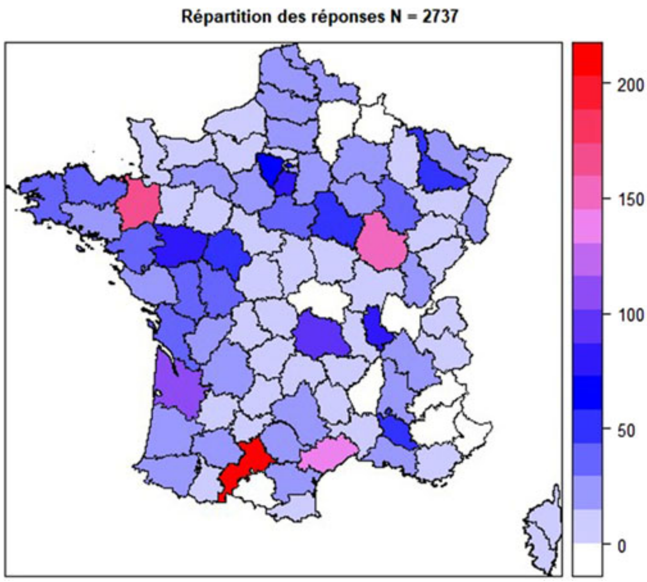

Figure 1. Distribution across France of the 2739 people who answered the online questionnaire about conservation agriculture.

'YES', 'Not so simple—rather YES', 'Not so simple—rather NO', or 'NO'.

The survey received 2739 responses, of which 2181 and 558 were related and non-related to agriculture, respectively, covering almost the whole territory of France (Fig. 1).

The analysis of the responses provides a number of insights (Fig. 2). The proportion of people answering 'I don't know' to a question is higher among people non related to agriculture, for all questions. Sixty-two percent of respondents related to agriculture believe that occasional tillage in CA is not or rather not harmful to soil diversity (yes and rather yes answers). Fifty percent of respondents related to agriculture believe that CA is not impossible without glyphosate (answer no and rather no), and 45% of respondents related to agriculture believe that CA is impossible without glyphosate (answer yes and rather yes). Sixty-six percent of respondents related to agriculture believe that CA is possible under organic principles (yes and rather yes answers). Thirty-five percent of respondents related to agriculture do not know whether pesticides degrade more in CA fields, and 50% think that they do or rather do degrade more. Seventy-seven percent of respondents related to agriculture believe that CA helps to store carbon and achieve the objectives of the 4 per 1000 international initiative (yes and rather yes answers); 7% believe the opposite; 16% are undecided. Sixty-three percent of respondents related to agriculture believe that CA helps reduce pesticide use (yes and rather yes answers); 30% believe the opposite. Ninety-one percent of respondents related to agriculture believe that CA improves water use efficiency and saves water (yes and somewhat yes answers). Fifty-three percent and 69% of agricultural and non-agricultural respondents, respectively, believe that CA helps to provide better quality food (yes and rather yes answers); 21 and 22% of agricultural and non-agricultural respondents, respectively, are undecided. Eighty-three percent of respondents related to agriculture believe that CA helps maintain pollinators in agricultural landscapes (yes and somewhat yes answers). Eighty-seven percent of respondents related to agriculture believe that CA enhances biological regulation (yes and rather yes answers).

This survey shows clear-cut answers on certain aspects, surely reflecting field observations in some cases, or expectations in others. It also reveals gaps in knowledge, either due to a real lack of knowledge on the subject, or a failure to disseminate the knowledge acquired.

Toward conservation agriculture defined by objectives rather than means

According to Kassam, Friedrich, and Derpsch (2019) the adoption of CA has increased because farmers are looking for a new paradigm to sustainably intensify crop production. They also report that the main factors behind the adoption of CA are very diverse. Although farmers adopting CA target some ecosystem services, many remain to be assessed and quantified (Craheix et al., 2016; Chabert and Sarthou, 2020; Adeux et al., 2022). As seen earlier in the review of the meta-analyses, it is generally accepted in most meta-analyses that cropping systems involving the simultaneous but partial application of all the three principles can be qualified as CA. In practice, the strict implementation of the principles is a difficult task and the entire agricultural community of stakeholders maintains a vagueness and a gap between the official FAO definition (FAO, 2021) and the reality of its implementation, which makes difficult the assessment of benefits of CA.

It is probably not easy but necessary to define CA by the ecosystem services targeted rather than by the farming practices and the principles. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) designed the Ecosystem Service Assessment Support Tool (ESAST). It has been designed to provide guidance to users who are new to ecosystem services and need assistance in designing an effective assessment process. Five main steps can be carried out to (i) set the scene, (ii) identify the ecosystem services, (iii) the biophysical assessment, (iv) the valuation, and finally (v) put into practice (https://www.guidetoes.eu/index.html).

CA must be defined by assigned objectives and ecosystem services. The review of the meta-analyses (see above) provides an extended list ecosystem services and indicators to assess them (Table 1). Kassam, Friedrich, and Derpsch (2019) mentioned a list of objectives that CA farmers are targeting when transitioning to CA. This may represent a starting list of ecosystem services targeted and assessed at the cropping system, farm, or landscape level:

- increase input factor productivity
- yield and total farm output
- improved sustainability of production and farm land
- better incomes
- timeliness of cropping practices
- ease of farming and reduction in drudgery
- clean water and atmosphere
- control of erosion and land degradation
- carbon sequestration
- rehabilitation of degraded agricultural lands

Indicators should be listed for each of these ecosystem services targeted as Palm et al. (2014) did on ecosystem services related to climate regulation, through carbon sequestration and greenhouse gas emissions, and regulation and provision of water through soil physical, chemical, and biological properties. These indicators would help to monitor the outcomes of CA.

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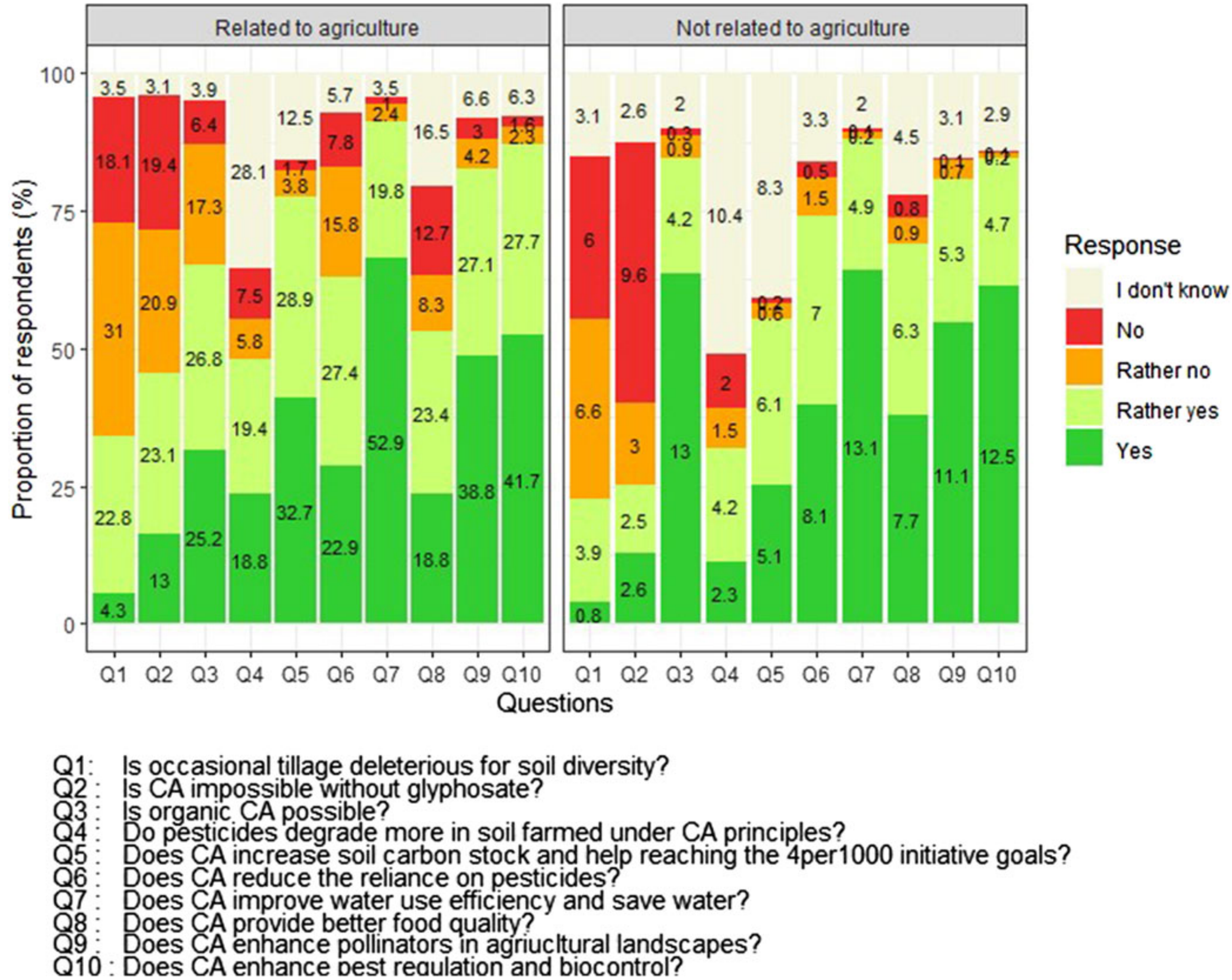

Figure 2. Proportion of respondents (*N* = 2739, expressed as % of 2181 or 558 respondents related and non-related to agricultural, respectively) to the ten questions asked about conservation agriculture (CA). Respondents were asked first whether they were related or not related to work in the agricultural sector (farmers, engineers, advisors, technicians, or any full or partial activity related to agriculture). The values in the bars correspond to percentage of respondents.

The change proposed in the definition and the way to assess CA has major technical and financial barriers. However, this paradigm shift would allow us to glimpse the diversity of virtuous ways of producing, rather than continuing to try to fit systems (and the farmers who implement them) behind a strict definition that reality, pragmatism, and common sense constantly challenge.

Conclusion

The definition of CA given by the FAO (2021) provides a vision for the implementation of soil conservation practices into a system (Reicosky, 2015) and defines CA by principles and not by the ecosystem services CA intend to deliver. Despite the clear definition provided by the FAO (Kassam, Friedrich, and Derpsch, 2019; FAO, 2021), CA remains difficult to characterize when we look at systems in their agricultural, climatic, and economic reality. Given the prevalence and widespread support for CA, we advocate for moving CA from its current definition based on the means toward a definition that includes performance-based metrics that address different ecosystem services (Palm et al., 2014; Jayaraman et al., 2021; Kassam and Kassam, 2021). CA has potential to help address challenges associated with climate change, biodiversity loss, and water pollution, but opportunities may be missed without developing performance targets that go beyond soil conservation.

Competing interests. None.

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