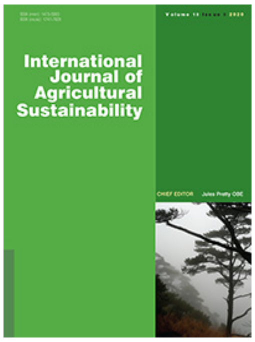


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# Participatory multicriteria assessment of maize cropping systems in the context of family farmers in the Brazilian Cerrado

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**ABSTRACT**
Conservation agriculture (CA) is recognized as a promising crop management strategy for sustainable agricultural intensification. The objective of this study was to evaluate CA cropping systems for rainfed maize as an alternative to the traditional tillage-based cropping systems (CT) in the context of family farms, using a multi-criteria model that represents the point of view of farmers. Farmers considered several aspects for evaluating the cropping systems, thatwere systematized in the model through five criteria (with sub-criteria): (a) costs; (b) yield; (c) labour; (d) human health and environment; and (e) production risks. CA did not differ from CT for the 'costs' criterion but was superior for the 'yield' and 'labour' criteria. In contrast, CT obtained better ratings for the criteria 'human health and environment' and 'production risks'. Considering all criteria, CA was better appraised than CT. However, a new local policy measure that subsidizes the hiring of mechanized tillage services overturns this outcome, indicating the importance of exogenous factors. Overall, the participatory processes in building the model allowed us to better understand the reasons of adoption or non-adoption of CA by small-scale farmers in the tropics.

**KEYWORDS**
Conservation agriculture; cropping system; maize; multi-criteria analysis; smallholder farms

## 1. Introduction

Conservation agriculture (CA) is recognized as a promising crop management strategy for sustainable agricultural intensification (Giller et al., 2015; Hobbs et al., 2008; Pretty & Bharucha, 2014), particularly in the context of mechanized crop production in Brazil (De Freitas & Landers, 2014; Prestele et al., 2018). It is based on three principles (Séguy et al., 2003): (a) no- or minimum tillage, (b) maintenance of a permanent soil cover, and (c) diversification of crop species grown in rotations and/or associations for optimizing the use of the available resources (light, water and nutrients).

In a comprehensive review, Scopel et al. (2013) listed the potential key benefits of CA under tropical conditions, i.e. (a) reduction of soil erosion and improvement of the physical soil qualities; (b) enhancement of soil carbon sequestration; (c) better regularization of the decomposition of soil organic matter during the crop cycle, hereby improving soil nitrogen availability to crops; (d) improved soil water retention; (e) increased soil biological diversity and activity; and (f) better stability of crop yields in the long term.

In the Cerrado, the tropical savanna biome of Brazil, several research projects have studied the development and promotion of CA practices for grain production in the context of large-scale, mechanized farms (Landers, 2001). It was estimated that no-tillage systems are practiced on about 10 million hectares in the Cerrado, mostly on large-scale farms

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(FEBRAPDP, 2012). In contrast, very few small-scale family farmers in the region have implemented CA, even though they are facing similar problems of soil degradation (Oliveira et al., 2009b; Scopel et al., 2013).

The development and implementation of new cropping systems based on the principles of CA is not a simple operation (Brown et al., 2018a; Perego et al., 2019). The task becomes even more challenging when these new cropping systems must reconcile the livelihood needs of family farmers and environmental protection goals. Furthermore, increasing crop productivity is not the only goal of family farmers, meaning that multiple, often conflicting, objectives must be combined (Sadok et al., 2008; Xavier et al., 2012). Besides, family farmers, especially those with limited resource endowments (e.g. low level of mechanization, limited access to inputs), primarily seek outcomes in the short term, often regarding cost reductions and increased income benefits (Pannell et al., 2014). Though, it is well known that several benefits of CA need time in order to become effective (Giller et al., 2009; Rusinamhodzi et al., 2011). Lastly, the implementation of a new technology does not stem from a simple decision but involves a rather complex decision-making process during which the farmers continuously test, and adapt or reject the given technology (Martínez-García et al., 2013; Telles et al., 2019).

New, alternative cropping systems can result in better outcomes for some aspects of the crop production process but could do worse for others. Integrating the multifaceted outcomes of the production process is often seen as the best approach for selecting the most appropriate cropping systems. This usually leads to the question of how to deal with trade-offs in outcomes. The use of multicriteria methods tries to address this (Bergez et al., 2010; Loyce & Wery, 2006; Sadok et al., 2008).

The methodologies of multicriteria analyis fall within the framework of operational research (Zopounidis & Pardalos, 2010), which implies an applied decision theory that usesscientific, mathematical or logical methods to structure and solve problems. They are important tools for the construction of appropriate decision-making models (Bouyssou et al., 2006; Zopounidis & Pardalos, 2010). The use of multicriteria methods for assessing the sustainability of a system has increased over the last decades and has been the focus of research in many branches of science, including agronomy (Diaz-Balteiro et al., 2017). For example, Carof et al. (2013) showed that several multicriteria methods apply for the evaluation and selection of sustainable cropping systems. Some applications were related to the evaluation of CA-based cropping systems and included the economic, social and environmental dimensions of sustainability (Craheix et al., 2016), or only limited aspects of sustainability, such as the impact on water quality (Arondel & Girardin, 2000), or the dependency on external inputs (Giuliano et al., 2016). In other applications, multicriteria methods were used to evaluate different alternatives to conventional cropping systems, e.g. the practice of organic agriculture for the production of potatoes (Reichert et al., 2013), or the practice of no-tillage for maize production (Alary et al., 2016; Pelzer et al., 2012). Finally, multicriteria methods were also used to evaluate specific components of the cropping system, e.g. the choice of cultivars (Mastrantonio et al., 2007) or cover crop species (Peigné et al., 2015; Ramírez-García et al., 2015), and the use of herbicides (Chopin et al., 2016).

However, most studies that use multicriteria methods only partially consider the perceptions of the farmers. In most cases, the evaluation criteria are predefined by researchers, based on scientific knowledge, whilst the perceptions of farmers are only considered to define threshold values for the criteria and/or their relative weights. According to Meinke et al. (2001), this is one of the main reasons why the outcomes resulting from this type of studies are generally not very well accepted and implemented by the farmers.

Romero and Rehman (2003) showed how multicriteria analysis can be used in a series of farmers' decisional problems related to agricultural activities. These authors described MultiCriteria Decision Aid (MCDA) as a tool to increase the understanding of decision-making processes in agricultural production and to support the design of alternative agricultural practices that fit farmers' criteria and social values. MCDA is based on constructivism, i.e. on the concept that reality is produced by the observer, or in other words, is socially constructed (Röling, 1996). From this perspective, the basic premise of MCDA is the recognition of the importance of subjectivity of the decision-makers resulting from their values, goals, prejudices, culture, and intuition (Roy & Venderpooten, 1996). This implies that the actors involved in the implementation of e.g. alternative cropping systems must participate in the problem definition, the model construction and the criteria selection for the evaluation of the alternatives (Ensslin et al., 2001).

The objective of this study is to evaluate, using a participatory multicriteria approach, CA-based cropping systems for rainfed maize, as an alternative to the traditional cropping systems, in the context of family farms in the Cerrado biome in Brazil. In order to capture farmers' priorities and points of view, we designed a multicriteria model through a participatory method in which the farmers, rather than the researchers, were the main protagonists for defining evaluation criteria and their relative importance.

## 2. Material and methods

### 2.1 Description of the study area and farms

The study was carried out in the municipality of Unaí (16°21′S, 46°54′W) located in the state of Minas Gerais, in the Cerrado biome of Brazil (Figure 1).

The mean annual rainfall in the study region varies from 1200 to 1400 mm, and rains are concentrated in the period from October to March (Figure 2). The wettest period is from November to January, whilst the dry season lasts five to six months. The mean annual temperature is about 24–25°C. The soils are mostly Ferralsols, Cambisols, and Podsols (IBGE, 2017), which are important soil classes found in the Cerrado. The Ferrasols are located on the plateaus that are mainly occupied by the large, mechanized farms. The smaller family farms are predominantly concentrated in the valleys between the plateaus, where Cambisols and Podsols are more frequent (Gastal et al., 2003).

The municipality counts 3849 farms in an area of 8447 km$^2$, of which 3177 (82%) are family farms (IBGE, 2017). In this study, we worked with farms issued from the Brazilian agrarian reform that was implemented in the 1990s (Oliveira et al., 2009a). The municipality has 34 settlement areas, with a total of 1639 families (INCRA, 2013). The production systems of these farmers are characterized by mixed crop-livestock systems. Dairy cattle represent the main livestock type, since the region is an important dairy producer with an organized value chain. Maize is the most important cultivated crop (Gastal et al., 2003), grown on small fields (average size of 1.8 ha). Maize production is in the first place intended as feed for swine and poultry, that are mainly auto consumed by the families. Maize grains are also utilized as feed for cattle during the dry season.

Due to its importance, maize is preferably planted on the most fertile soils, locally called 'Terras de cultura' (Silva et al., 2009). These include several soil types, such as Fluvisols along the river banks, and Eutrophic Cambisols or Podsols in the valleys. On average, these soils have a loamy texture (around 30% clay) and are relatively fertile, with adequate levels of organic matter (29 g kg$^{-1}$ soil), calcium (43 mmolc kg$^{-1}$) and magnesium (11.6 mmolc kg$^{-1}$). The average levels of exchangeable potassium (196 mg kg$^{-1}$) are high, while the average available phosphorus levels are low (6.1 mg kg$^{-1}$). Soil acidity is tolerable (pH of 5.9 and aluminium content of 0.4 mmolc kg$^{-1}$) (Xavier et al., 2013).

Conventional crop management is manual, usually with family labour, except for soil tillage, which is carried out using a tractor with disc plough. In general, farmers do not own a tractor and rent external services to till the soil. Seeding is done using a hand-held jab planter (locally called 'matraca'), and weeding is done mechanically using manual equipment (hoe) or by animal traction (harrow). A large part of the farmers plant hybrid maize cultivars, whose high yield potential contrasts with the low levels of fertilizers used and the low efficiency of weed control. Harvesting is also done manually (Oliveira et al., 2009b; Xavier, 2010).

Owing to the scarcity of tractors and tillage implements in the region, farmers have little control over both the date and the quality of the tillage operations. In fact, tractors are often only available when soil conditions are inappropriate for tillage, usually after the owners have completed tillage and seeding on their own fields. As a result, the quality of crop germination is often poor, with high early weed infestation (ScopeL et al., 2005; Xavier et al., 2013).

### 2.2 Study approach

The study was conducted with a group of 44 family farmers interested in no-tillage practices. The problems identified for maize production were first discussed, and CA systems were then suggested based on results from previous field experiments carried out in Unaí (Baldé et al., 2011; Silva et al., 2009). The proposed CA systems included the use of an animal-drawn direct seeder and the cultivation of cover crops, avoiding in this way dependence on rented soil tillage services, increasing hereby seeding quality, and improving weed control through cover crop competition. Thirty farmers installed a CA maize plot on their fields. Crop management was monitored during two agricultural seasons and compared with that of the conventional tillage (CT) practice on an

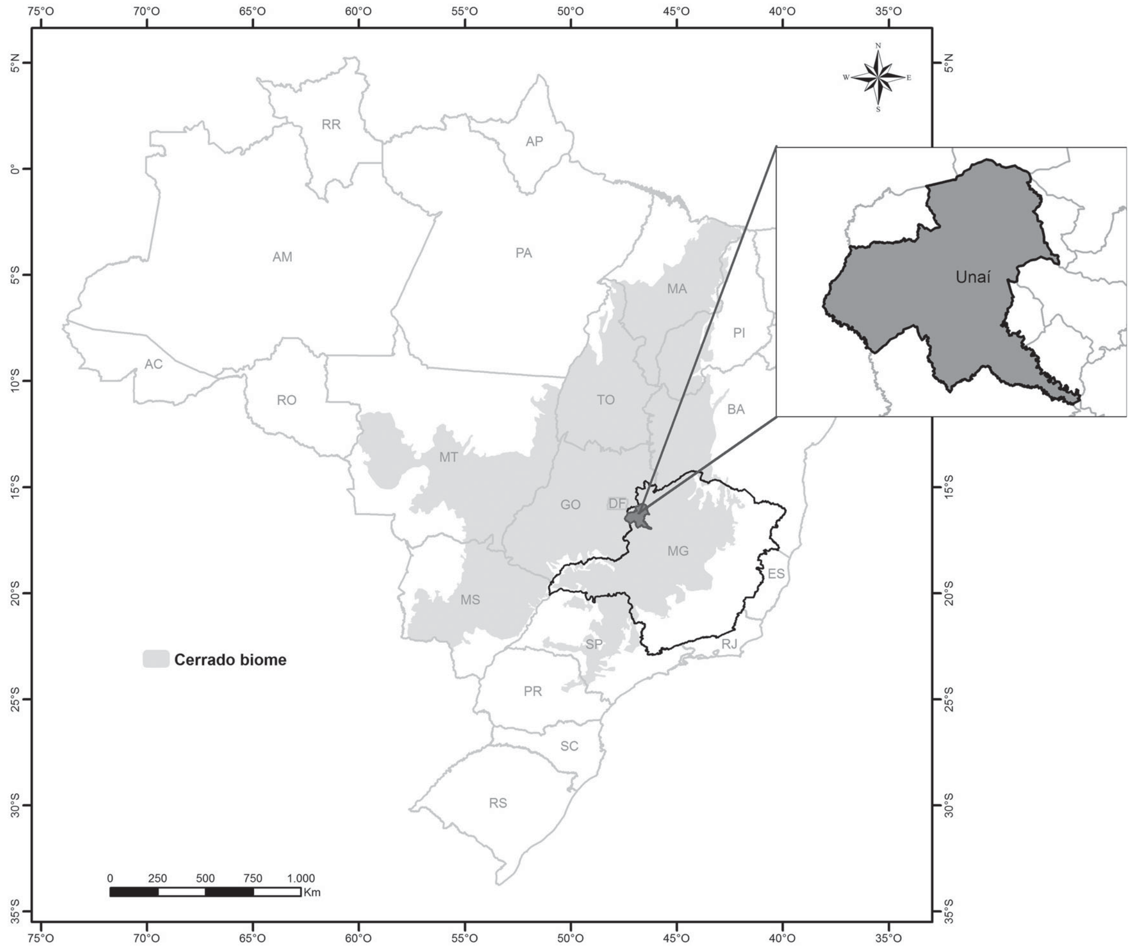


**Figure 1.** Location of the municipality of Unaí, Minas Gerais (MG), and the Cerrado biome of Brazil.

adjacent plot (Table 1). Using a multicriteria model that was constructed with the farmers, the CA and CT systems were evaluated.

### 2.3 Participatory construction of a multicriteria evaluation model

The multicriteria model was constructed using the approach described by Ensslin et al. (2001). The different phases of the model construction are summarized in Table 2. First, in the so-called structuring phase, interviews were conducted with the participating farmers ($n = 44$) to characterize their farms and maize cropping systems. This information was then discussed with the group to select a subsample (subgroup) of farmers, representative of the most common types of farms in the region. The reason for choosing a subsample of farmers is because the model building requires many meetings (Table 2), that are difficult to achieve with a large group.

In this structuring phase, the farmers' knowledge and perceptions about the relevant evaluation dimensions was organized into so-called Fundamental Points of View (FPV). They were arranged in a tree structure using two techniques:

a Cognitive mapping (Eden et al., 1988), designed to answer the following question: which aspects should be considered to assess the crop management for maize production?
b Frame working of the decision-making context (Keeney, 1992; Montibeller Neto, 1996) to divide the cognitive map into clusters with similar evaluation themes.

Subsequently, in each cluster, an essential and controllable point of view was identified.

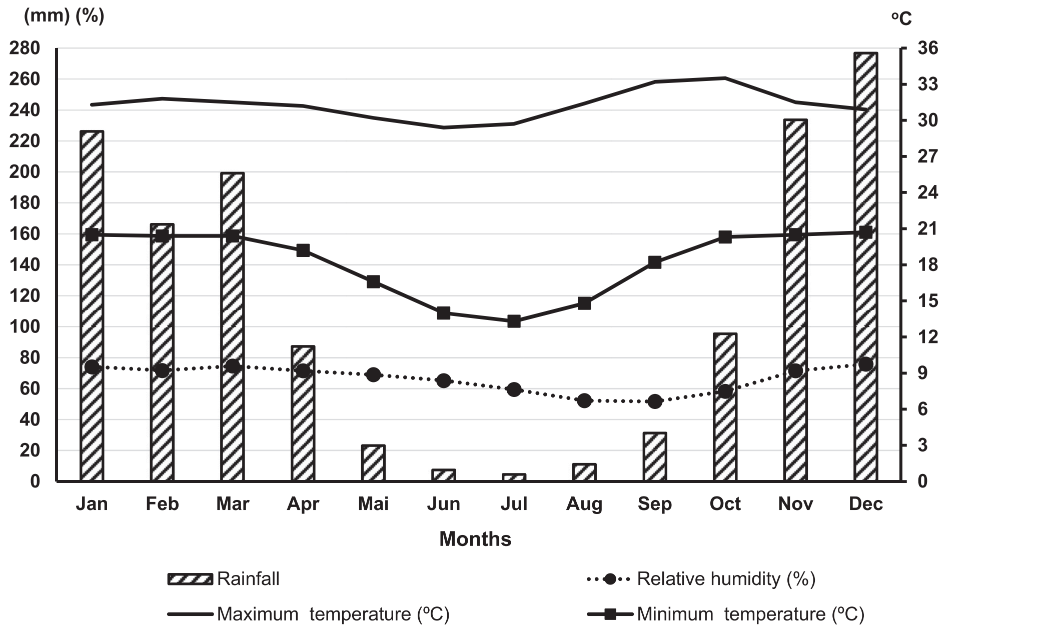


**Figure 2.** Monthly means of rainfall (mm), relative humidity (%) and minimum and maximum temperatures (°C) in the municipality of Unaí, Minas Gerais. Source: Embrapa Cerrados (2019).

Essentiality refers to the importance of the FPV regarding the strategic objectives of the decision-maker. Controllability is associated with the notion that the FPV should represent a factor that can be affected by the cropping systems under scrutiny only.

In the subsequent evaluation phase, each FPV was transformed into a criterion by defining an attribute (measurement scale) and a value function associated with this attribute. Complex FPVs were subdivided into Elementary Points of View (EPV), each of them generating a sub-criterion as well. The 'direct rating' technique was used to generate value functions (Beinat, 1997; Belton & Stewart, 2003; Bouyssou et al., 2006). It consists of assigning a score value of 0 (zero) for the minimum impact level and a value of 10 (ten) for the maximum

**Table 1.** The characteristics of crop management of the maize cropping systems, CT and CA, monitored on 30 farmers' maize fields.

| Crop management | Conventional tillage (CT) Mean (range) | Conservation agriculture (CA) Mean (range) |
|---|---|---|
| Soil tillage | Mechanized with hired tractor | Manual back spray desiccation<br>Commercial combinations of active ingredients (a.i.) of glyphosate and 2.4 D amine |
| | 2.8 (1.3–6.0) HM ha$^{-1}$ | 5.9 (2.3–11.0) L ha$^{-1}$<br>1.38 (0.50–2.86) DL ha$^{-1}$ |
| Seeding | With a hand jab planter<br>2.1 (0.8–4.0) DL ha$^{-1}$ | With animal drawn seeder<br>2.3 (0.7–4.0) DL ha$^{-1}$ |
| N fertilizer at seeding | 3.0 (0.0–7.5) kg N ha$^{-1}$ | 8.1 (0.0–38.4) kg N ha$^{-1}$ |
| P fertilizer at seeding | 7.4 (0.0–16.6) kg P ha$^{-1}$ | 17.2 (0.0–42.8) kg P ha$^{-1}$ |
| K fertilizer at seeding | 7.2 (0.0–18.7) kg K ha$^{-1}$ | 11.4 (0.0–57.1) kg K ha$^{-1}$ |
| N fertilizer at topdressing | 12.7 (0.0–40.1) kg N ha$^{-1}$ | 24.1 (0.0–106.0) kg N ha$^{-1}$ |
| Weed control | Hand weeding with a hoe or an animal-drawn cultivator | Chemical with herbicides and manual backpack sprayer<br>Commercial combinations of active ingredients (a.i.) of Alachlor, Atrazine and Nicosulfuron: 2.4 (0 - 4.1) L ha$^{-1}$ |
| | 8.8 (2.0–21.0) DL ha$^{-1}$ | 1.2 (0.0–2.0) DL ha$^{-1}$ |
| Harvest | Manual<br>7.8 (4.0–18.0) DL ha$^{-1}$ | Manual<br>8.3 (4.0–11.4) DL ha$^{-1}$ |

Note: HM: Machine hour; DL: Days of labour.

**Table 2.** Phases for the participatory building of the multicriteria model for the evaluation of the two maize cropping systems, CT and CA.

| Phase | Activities | Products/results |
|---|---|---|
| Structuring | (1) Interviews (44) with farmers | • Characterization of the farms and maize cropping systems. |
| | (2) Meeting to return the interview results to farmers | • Selection of farmers representative of the most common types of farms (subgroup). |
| | (3) Meetings for the construction of a cognitive map and projection of the decisional context | • Identification of Fundamental Points of View (FPVs) for evaluation. |
| Evaluation | (1) Meetings to transform each FPV into a criterion | • Attribute definition (quantitative or qualitative) for each FPV.<br>Definition of impact levels organized in descending order of preference for each attribute.<br>Establishing a value function to each attribute. |
| | (2) Meeting to propose the weights among criteria | • Additive value function of the criteria (aggregation).<br>First model version to be discussed with the subgroup of farmers. |
| Recommendation | (1) Meeting to discuss the weights among criteria | • Initial evaluation of the cropping systems<br>Discussion of results and understanding the trade-offs.<br>Model fine-tuning.<br>Second model version to be discussed with farmers (group). |
| | (2) Meeting to validate the model with farmer group | • Evaluation of the cropping systems.<br>Discussion of results from model evaluation.<br>Model fine-tuning.<br>Final model version for use by farmers. |

impact level of each attribute. The minimum level represents the least desirable but possible situation. The maximum level, on the contrary, represents the most desired situation. The values of intermediate impacts are defined comparatively to the minimal and maximal values. It is noteworthy to mention that the farmers actively participated in the process of defining both the attributes and the value functions.

After defining the farmers' value function, 'neutral' and 'good' impact levels were determined, that is, those that encompassed the range of expectations by the farmers and were taken as a point of comparison to weight the judgment (Bana e Costa & Vansnick, 1997). To these (neutral and good) levels, respective scores of 0 (zero) and 100 (one hundred) were assigned and the value function of each criterion was rescaled by the following linear transformation:

$$v_i(.) = u_i(.).\alpha + \beta$$

where $v_i(.)$ is the score transformed from a generic action according to criterion $i$; $u_i(.)$ is the original score of a generic action according to criterion $i$; $\alpha$ e $\beta$ are linear constants of the scale where $\alpha > 0$.

| | Description | Farmers' notes | Rescaled value function | |
|---|---|---|---|---|
| Maximum impact level | The fertilization performed is equivalent to 250 kg ha$^{-1}$ of the fertilizer urea or more | 10.0 | 111 | |
| Intermediate levels | **The fertilization performed is equivalent to 200 kg ha$^{-1}$ of the fertilizer urea (Good level)** | **9.5** | **100** | RANGE OF EXPECTATIONS BY FARMERS |
| | The fertilization performed is equivalent to 150 kg ha$^{-1}$ of the fertilizer urea | 7.5 | 56 | |
| | **The fertilization performed is equivalent to 100 kg ha$^{-1}$ of the fertilizer urea (Neutral level)** | **5.0** | **0** | |
| | The fertilization performed is equivalent to 50 kg ha$^{-1}$ of the fertilizer urea | 1.5 | -78 | |
| Minimum impact level | The fertilization performed is equivalent to 0 kg ha$^{-1}$ of the fertilizer urea | 0.0 | -111 | |

**Figure 3.** Farmers' values and rescaled value function for nitrogen fertilizer topdressing.

In this way, actions (crop management) with an effect below the neutral level on the scale generate negative scores; whilst actions above the good level generate scores greater than 100. Figure 3 illustrates the value function for nitrogen fertilizer topdressing.

The criteria and sub-criteria were aggregated to an additive global value function, through weights obtained by the swing weighting method (Beinat, 1997; Belton & Stewart, 2003; Keeney & Raiffa, 1976). The ratio between two weights shows the acceptance of the decision-makers to compensate for losses in one criterion by gains in another, or vice versa. Finally, all resulting weights were normalized, and their values defined between zero and one. An additive general model was used to aggregate the local value functions. This is a commonly used technique, as stated by Zardari et al. (2015):

$$V(a) = v_1(a).w_1 + v_2(a).w_2 + \ldots + v_n(a).w_n$$

With,

$$\sum_{i=1}^{n} w_i = 1$$

and

$$1 \geq w_i > 0$$

where $a$ is a random action belonging to the set A of potential actions; $V(a)$ is the overall value of action $a$; $vi$ ($a$) is the local (partial) value of action $a$ according to criterion i; $w_i$ are the weights (or compensation rates) of the $i^{\text{-th}}$ criterion.

In the recommendation phase, the results were validated by a subgroup of farmers. They were asked to design a maize cropping system and evaluate it with the constructed model. Subsequently, the farmers were asked about what changes should be made in order to improve the evaluation model as much as possible. In fact, the subgroup discussions allowed fine-tuning of weights so that farmers became satisfied with the model performance.

Finally, a meeting was scheduled with all farmers (n=44) to discuss the model-building process and check how well their preferences were represented in the model built by the subgroup.

### 2.4 Data collection and evaluation of the cropping systems

Data on crop management were collected, i.e. on soil tillage, seeding, fertilizer at seeding, topdressing, weed control, and harvest (Table 1). All data were converted to equivalent values on one-hectare basis. The economic values were standardized using the average prices paid by farmers for the inputs (fertilizers, pesticides, etc.) and for mechanization services.

Using the multicriteria model, the 30 fields were then evaluated for CT and CA. To test for differences between the two cropping systems, the non-parametric Wilcoxon–Mann–Whitney test for independent samples was used, at 5% significance. This test was selected because of: (a) the relatively low number (30) of cases analysed for each cropping system; and b) the requirements of normality, that were not met by all variables analysed. Tests were done with the Statistical Package for Social Sciences (SPSS Inc, Chicago, IL, USA).

Lastly, a sensitivity analysis was performed to verify the robustness (stability in the preferences represented) of the responses of the model to changes in its parameters. The criterion with the highest weight was selected and a variation of 10% above and below the original value was tested (Ensslin et al., 2001). The weights of the other criteria were also adjusted so to maintain the proportions between them unchanged. Results of the model sensitivity analysis were analysed to detect if there were significant alterations in the scores of the evaluated cropping systems.

## 3 Results

### 3.1 Model evaluation criteria by farmers

The tree structure of the model is presented in Figure 4. Farmers considered many aspects (criteria) for evaluating the cropping systems, which suggests that the choice between the two cropping systems was by no means a simple decision. Overall, the main goal of the farmers was reflected in the model as the demand for a cropping system that enables the production of enough maize grain in order to prevent its purchase, while at the same time not overstretching the production costs nor the workloads, not harming the environment and health, and maintaining production risks at a tolerable level. Thus, the identified criteria addressed factors beyond those purely related to economic issues.

The fact that the major part of the crop management activities is realized by the family, was expressed through the sub-criteria associated with labour, considering both the labour amount and drudgery (the farmers used the Portuguese term 'sofrimento' – suffering, hardship) required to perform the crop management practices. Three sub-criteria were identified in relation to environmental issues and health-related concerns. Two of them, 'pesticide use' and 'caution in the application of pesticides' expressed the duality in farmers' perception on herbicides; on one hand, their use reduces the workload, on the other hand, pesticides represent a risk for environment and health. The other environmental concern was related to soil erosion that was directly linked with land preparation and soil tillage operations. Lastly, the farmers identified production risks as another criterion in the evaluation of the cropping systems. The risk of yield losses caused by dry spells during the maize grain filling stage was associated with the sub-criterion 'machinery dependence'. As the machinery services for land preparation were often delayed, they affected all subsequent operations, leading to higher drought-related risks later in the season. The other sub-criterion, 'confidence in technologies', expressed the fact that farmers felt most comfortable with existing and known cropping practices, for which enough references and recommendations are available in the community.

Although the farmers identified several aspects to be considered in the evaluation of the cropping systems, the respective weights of the criteria differed (Figure 4). For example, the 'costs/yield' weight ratio was 1.1, whilst the 'costs/human health and environment' weight ratio was 6.4. This means that losses in 'costs' and/or 'yield' have to be compensated by relatively much higher gains in other criteria. This is consistent with production systems that serve primarily family consumption. The relatively low weight of the criterion 'human health and environment' indicates that, although the farmers were concerned about this aspect of the cropping system, they accepted relatively high losses with this criterion, because of economic and labour constraints in producing maize.

## 3.2 Evaluation of the cropping systems

The main differences in crop management between the two cropping systems, CA and CT, were: (a) desiccation of the vegetative part of the preceding crops with herbicides by hand spraying (use of a backpack sprayer), instead of applying mechanical soil tillage; (b) planting carried out with an animal-drawn direct

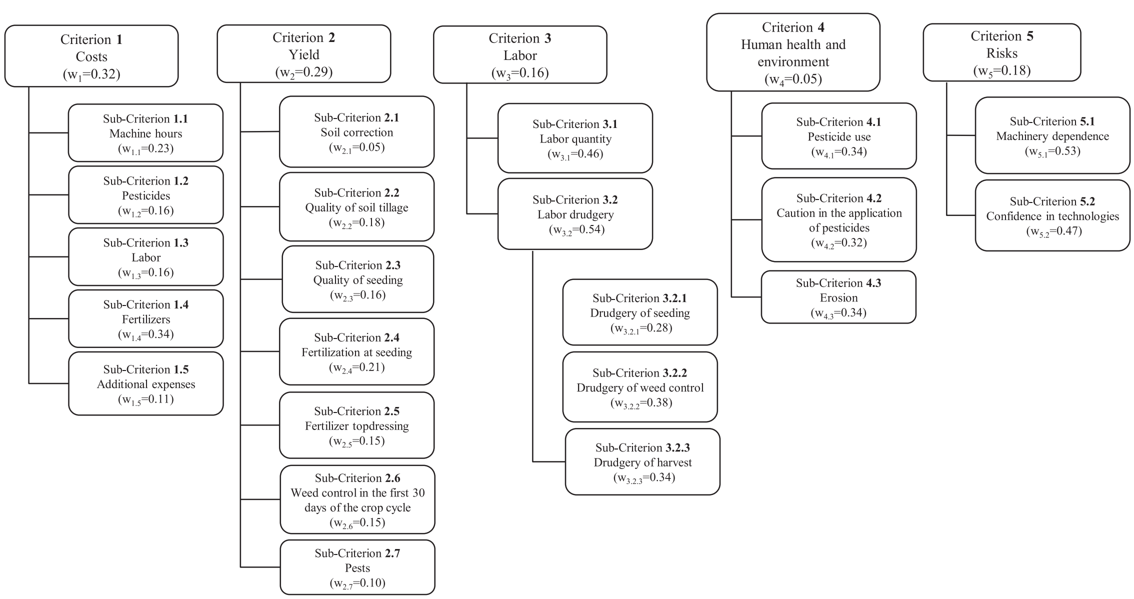


**Figure 4.** Tree structure of the multi-criteria model constructed with the farmers showing the criteria and sub-criteria for evaluation of the cropping systems, and their respective weights (w)

seeder (allowing fertilization at the same time), instead of manual seeding; (c) weed control with herbicides by hand spraying (backpack sprayer) instead of manual weeding.

The farmers' evaluation of the cropping systems for each criterion of the model is presented in Table 3. The production costs were equally ($p = 0.460$) rated between the two cropping systems. Most costs for CT were related to the mechanized tillage, while for the CA the main costs were the herbicides for desiccation and weed control, the higher fertilizers doses (Table 1) and the additional costs related to the acquisition of an animal-drawn direct seeder. Farmers evaluated the yield potential of CA higher than CT ($p < 0.0001$), mainly because of a better quality of soil tillage ($p = 0.001$), seeding ($p < 0.0001$), and fertilization at seeding ($p = 0.035$) (Table 3). The quality of soil tillage was evaluated in terms of tillage depth and the presence of clods on the soil surface. For farmers, soil clods may deteriorate seed germination and the depth of tillage is seen as important for good development of roots at the beginning of the crop cycle. In CT systems, where tillage consisted of a single disc harrow operation, the tillage operation was considered of low quality, because of the shallow tillage depth and the presence of clods on the soil surface. Since with CA the soil is not overturned, there were no soil clods, but soil tillage was considered as shallow. Besides, the use of an animal-drawn direct seeder with CA was associated with a better quality of seeding, due to the better distribution of the seeds, and with higher fertilization levels applied (Table 1).

Regarding labour, CA was evaluated as significantly ($p < 0.0001$) superior to CT (Table 3). This difference corresponded to a decrease in labour requirements for weeding mainly, because of the use of herbicides (Table 1). CT required an average of 8.8 working days per hectare for weed control, while CA only needed 1.2 days. CA was also superior in relation to labour drudgery ($p < 0.0001$) due to less efforts with seeding because of the use of the animal-drawn direct seeder instead of the hand-held jab planter, with weeding due to the use of herbicides instead of the manual control of weeds and with harvesting due to the control of weeds in the second part of the crop cycle (Table 1).

**Table 3.** Evaluation of the maize cropping systems, conventional tillage (CT) and conservation agriculture (CA), on 30 farmers' fields using the multi-criteria model.

| Criteria/sub-criteria and their respective weights | CT | CA | *p* value |
|---|---|---|---|
| Criterion 1 – Costs ($w_1$=0.32) | 60.58 (19.39) | 50.38 (16.13) | 0.460 |
| Sub-criterion 1.1 – Machine hours ($w_{1.1}$=0.23) | −28.00 | 133.00 | <0.0001 |
| Sub-criterion 1.2 – Pesticides ($w_{1.2}$=0.16) | 100.00 | −1.50 | <0.0001 |
| Sub-criterion 1.3 – Labour ($w_{1.3}$=0.16) | 100.00 | 100.00 | 1.000 |
| Sub-criterion 1.4 – Fertilizers ($w_{1.4}$=0.34) | 66.00 | 26.50 | 0.032 |
| Sub-criterion 1.5 – Additional expenses ($w_{1.5}$=0.11) | 100.00 | −14.00 | <0.0001 |
| Criterion 2 – Yield ($w_2$=0.29) | −7.22 (−2.10) | 42.49 (12.32) | <0.0001 |
| Sub-criterion 2.1 – Soil correction ($w_{2.1}$=0.05) | 100.00 | 100.00 | 1.000 |
| Sub-criterion 2.2 – Quality of soil tillage ($w_{2.2}$=0.18) | −122.00 | 0.00 | 0.001 |
| Sub-criterion 2.3 – Quality of seeding ($w_{2.3}$=0.16) | 0.00 | 100.00 | <0.0001 |
| Sub-criterion 2.4 – Fertilization at seeding ($w_{2.4}$=0.21) | −14.50 | 20.00 | 0.035 |
| Sub-criterion 2.5 – Fertilizer topdressing ($w_{2.5}$=0.15) | −111.00 | −74.00 | 0.068 |
| Sub-criterion 2.6 – Weed control in the first 30 days of the crop cycle. ($w_{2.6}$=0.15) | 100.00 | 100.00 | 1.000 |
| Sub-criterion 2.7 – Pests ($w_{2.7}$=0.10) | 75.00 | 75.00 | 1.000 |
| Criterion 3 – Labour ($w_3$=0.16) | 9.84 (1.57) | 91.98 (14.72) | <0.0001 |
| Sub-criterion 3.1 – Labour quantity ($w_{3.1}$=0.46) | 55.00 | 99.00 | <0.0001 |
| Sub-criterion 3.2 – Labour drudgery ($w_{3.2}$=0.54) | 0.00 | 86.00 | <0.0001 |
| Sub-criterion 3.2.1 – Drudgery of seeding ($w_{3.2.1}$=0.28) | 0.00 | 50.00 | <0.0001 |
| Sub-criterion 3.2.2 – Drudgery of weed control ($w_{3.2.2}$=0.38) | 0.00 | 100.00 | <0.0001 |
| Sub-criterion 3.2.3 – Drudgery of harvest ($w_{3.2.3)}$=0.34 | 0.00 | 100.00 | <0.0001 |
| Criterion 4 – Human health and environment ($w_4$=0.05) | 88.60 (4.43) | −4.76 (−0.24) | <0.0001 |
| Sub-criterion 4.1 – Pesticide use ($w_{4.1}$=0.34) | 126.00 | −47.00 | <0.0001 |
| Sub-criterion 4.2 – Caution in the application of pesticides ($w_{4.2}$=0.32) | 143.00 | 0.00 | <0.0001 |
| Sub-criterion 4.3 – Erosion ($w_{4.3}$=0.34) | 0.00 | 33.00 | <0.0001 |
| Criterion 5 – Risks ($w_5$=0.18) | 100.00 (18.00) | 18.01 (3.24) | <0.0001 |
| Sub-criterion 5.1 – Machinery dependence ($w_{5.1}$=0.53) | 100.00 | 167.00 | <0.0001 |
| Sub-criterion 5.2 – Confidence in technologies ($w_{5.2}$=0.47) | 100.00 | −150.00 | <0.0001 |

Notes: The values (medians) in the table refer to the results of the additive global value function, V (a), considering the value functions of the sub-criteria and criteria of model and their respective weights. Larger values mean greater satisfaction (preference) from the point of view of farmers. The value in parentheses refers to the model score considering the respective criterion weight (w).

*p*-values < 0.05 indicate that there is a statistically significant difference between the cropping systems using the Wilcoxon-Mann-Whitney test.

CT was preferred over the CA for the criterion 'human health and environment' ($p < 0.0001$, Table 3). Despite its positive effect on the problem of soil erosion that was identified by the farmers, CA scored lower than CT because soil erosion was not offset by the loss of satisfaction associated with the negative impacts that herbicide use may have on human health and environment. On average, 8.3 L ha$^{-1}$ of herbicides was used in the CA system for desiccation and weeding (Table 1). The high degree of initial weed infestation with high diversity of species complicated weed control and, in many situations, several additional selective herbicides had to be applied under CA.

Farmers rated CA with lower production risks for the elimination of the dependency on rented machinery for tillage. However, these gains were insufficient to compensate for the loss of satisfaction associated with confidence in and knowledge about the applied technologies ($p<0.0001$, Table 3). In fact, CA was perceived as a complex system whose management requires a high level of new knowledge.

The final scores of the evaluation of CA and CT in the farmers' fields are shown in Figure 5a. The variability of scores was high in both CT and CA, because of variable use of fertilizers, herbicides, mechanization and labour by farmers, as shown in Table 1. It should be emphasized that the variability was lower in the CA systems (CV of 15,3%) compared to the CT systems (CV of 34,9%), indicating a standardization in the use of factors in the CA systems. Extreme values occurred more frequently with CT. Nevertheless, the results highlighted statistically significant ($p < 0.05$) differences between the cropping systems in favour of CA systems. It is noteworthy that these differences persisted in the sensitivity analysis (see results in Figure 5b,c). Thus, the outcomes of the model can be considered robust. This is important because preferences were built with farmers and it is not natural for them to express them mathematically.

The evaluation of the cropping systems is strongly affected by the socio-economic environment in which the farmers are operating. In this context, it is important to highlight a public policy in the municipality of Unaí, which offers 14 kg of hybrid maize seed for free and two tractor hours for soil tillage with a cost equivalent to 15 litres of diesel per hour to a farm household. When exploring this effect of reduced

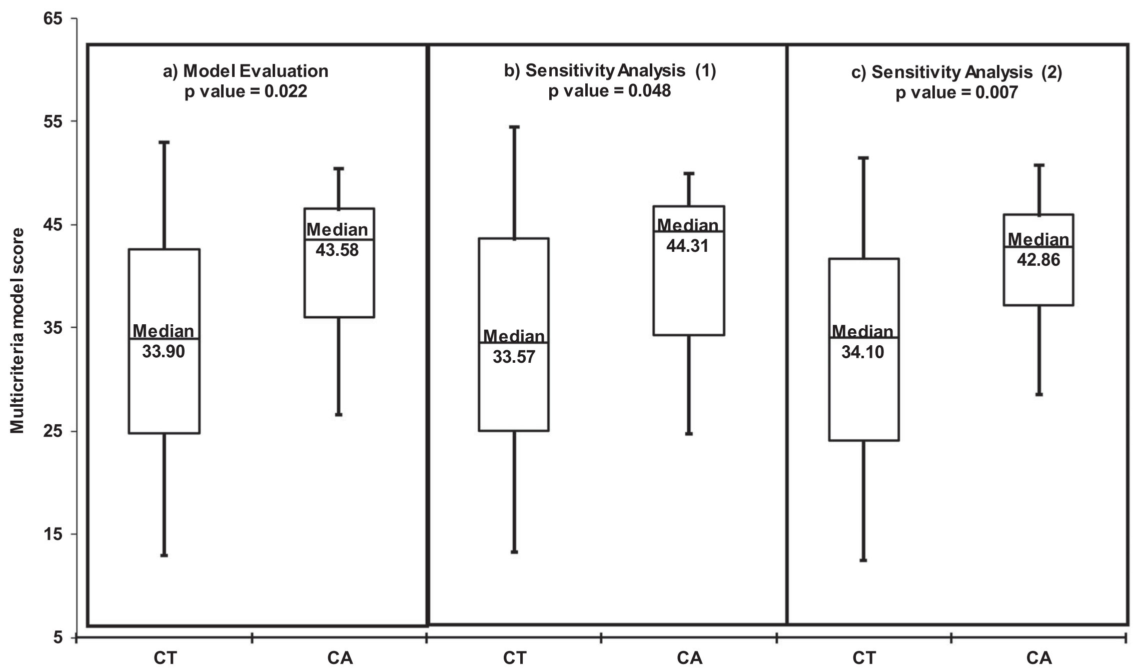


**Figure 5.** (a) Evaluation of maize cropping systems, CT and CA, by means of the multicriteria model constructed with family farmers of Unaí-MG. (b) Sensitivity analysis (1): +10% variation in the weight of the criterion 'Costs'. (c) Sensitivity analysis (2): -10% variation in the weight of the criterion 'Costs'. *p*-values < 0.05 indicate that there is a statistically significant difference between the cropping systems using the Wilcoxon-Mann-Whitney test.

costs with machinery for soil tillage, the attractiveness of the CT increased greatly (Figure 6). The effect of reduced costs for mechanized tillage was reinforced by the high weights of the sub-criterion 'costs with machine hours' and the criterion 'costs' (Figure 4). In this policy context, the CT system scored higher than CA despite the low quality of soil tillage, and, therefore, it is expected that farmers will opt for CT.

## 4. Discussion and conclusions

We evaluated CA for maize production in comparison with the traditionally practiced cropping system based on tillage with a disc harrow, through a multicriteria model that considers the point of view of family farmers in the Cerrado region of Brazil.

Production costs did not differ between CA and CT systems (Table 3), which was related to the fact that the savings resulting from the suppression of costs for hiring tractor services for soil tillage were offset by the money spent on herbicides, mainly post-emergence herbicides. In addition, CA cropping systems require the acquisition of specific equipment, namely the animal-drawn direct seeder. It is also important to consider the expenses associated with fertilization, which were higher with CA due to the higher amounts of fertilizer applied at planting with the animal-drawn direct seeder. The use of the seeder turned, however, fertilizer application at seeding easier and more efficient, explaining why farmers agreed to increase the fertilizer doses (particularly phosphorus), as recommended by research for improvement ofsoil fertility in this region (Sousa & Lobato, 2004). Our results agree with Oliveira et al. (2009b), who also found no difference in average production costs between the two cropping systems implemented by family farmers in Unaí. Thus, cost reduction in crop management was not identified as a determining factor in persuading farmers to use CA, as also pointed out by Brown et al. (2018b), Ngoma (2018) and Wall (2007) for smallholder farmers in Africa.

Several studies indicated increased crop yields as an important factor in motivating the use of CA. For example, Lalani et al. (2016) identified the prospect of higher crop yields in the short term as one of the

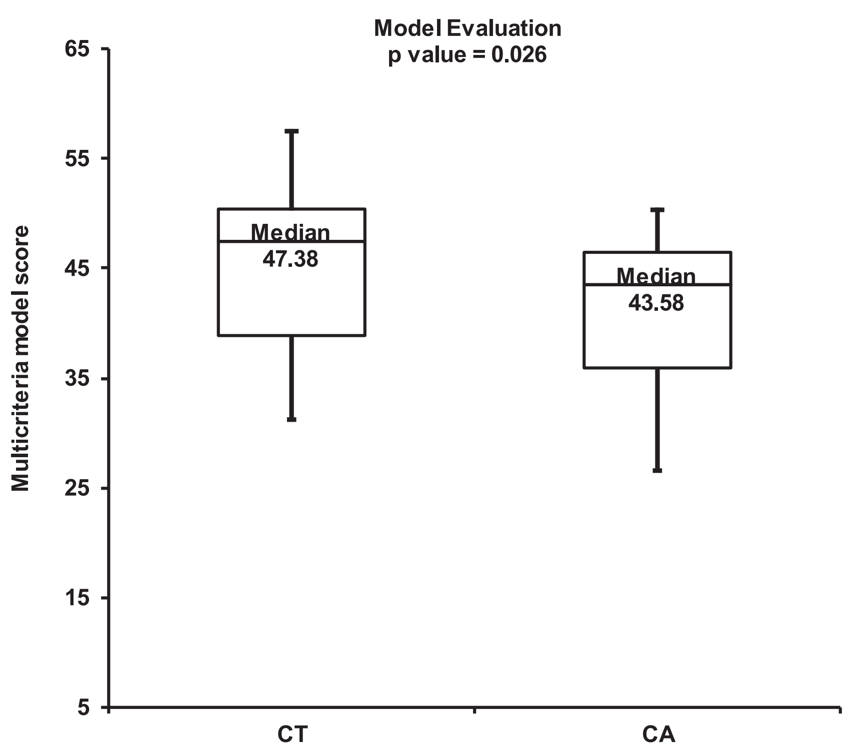


Figure 6. Evaluation of maize cropping systems, CT and CA,by means of the multicriteria model constructed with family farmers of Unaí-MG, considering the cost reduction of soil tillage by a municipality policy. $p$-values < 0.05 indicate that there is a statistically significant difference between the cropping systems using the Wilcoxon-Mann-Whitney test.

main factors for the use of CA by African farmers with limited resources. On the other hand, in a study in Ecuador Barrowclough and Alwang (2018) concluded that even a 10% decline in crop yield in the year following the adoption of CA did not affect the likelihood of farmers selecting this system. In the African context, Corbeels et al. (2014) analysed several studies regarding the short-term CA effect (less than 3 years) on maize yield under no-tillage and concluded that although the short-term yields under CA tend to be positive, they vary and can also be neutral or even negative. The same results were reported in a global meta-analysis of CA yields (Pittelkow et al., 2015). The main factor highlighted for a positive CA yield response in the short term was the increase in soil water availability as a result of soil surface mulching, particularly under drought conditions (Steward et al., 2018).

Weed infestation and problems with seed germination are main factors affecting crop yields in the first years under CA in comparison with CT (Nichols et al., 2015; Sims et al., 2018). Studies carried out in the Cerrado on fields of family farmers showed high weed infestation in areas under CT as one of the main problems of low crop productivity (Affholder et al., 2003). Both the higher quality of soil tillage and seeding, and the less labourious chemical weed control were evaluated by farmers as positive aspects of CA, in comparison with CT (Table 3). However, Oliveira et al. (2009b) highlighted the need for training of farmers in the use of the direct seeder and the application of herbicides.

Labour savings have been highlighted as one of the benefits of CA in several studies. For example, Craheix et al. (2016) stated that CA entails reduced workloads on farms in France during labour-intensive periods, such as during land preparation, seeding and weeding. According to Lalani et al. (2016), the reduction in workload was the second most important motivation for African smallholders to use CA after the prospect of higher crop yields, especially for farmers with low resource endowments. Corbeels et al. (2014), who analysed 10 case studies of research projects of development and dissemination of CA practices with smallholders in sub-Saharan Africa found different results: some farmers indicated that CA reduced the workload, whilst others found that CA increased it. This may be due to differences in family structures among the different farms and different regions. In our study, CA was found to reduce the workload by 30% (Table 1), which is an important feature in view of the limited availability of family labour in the region. It is hereby important to note that a decline of around 30% in family labour was observed over the course of 17 years in two communities of our study region as a result of aging and the younger family members migrating to the cities (Xavier, 2010).

Another advantage of CA that so far has received little attention is the reduced drudgery (hardness) of work. According to Alary et al. (2016), based on an analysis of economic impacts of CA at the farm level, the fact that the study did not take the qualitative aspects of labour into account could explain, at least partially, the discrepancy between the simulated trends of CA adoption and farmers' preferences. Effectively, in our study, the drudgery aspect of labour appeared important, since the ratio of the weights of the sub-criteria 'labor quantity' and 'labor hardness' (Figure 4) indicated that farmers would accept a loss of satisfaction in relation to the amount of labour (more work), if there is a decrease of labour drudgery in compensation. Less drudgery was associated with less efforts for seeding due to the use of an animal-drawn seeder instead of a hand-held jab planter, for weeding due to the use of herbicides instead of manual weeding, for harvesting due to more favourable conditions in fields free of weeds until the end of the maize cycle.

Although herbicides allow efficient weeding with less work, they are also seen by farmers as source of an important risk for their health (Figure 4). This reinforces therefore the need to reduce the amount of herbicides used in CA systems (Bajwa, 2014). Integrated strategies for weed management would help in reducing gradually the potential of weed infestation (seed banks), which is usually very high on the farmers' fields in the study region. It is expected that the systematic use of cover crops can contribute to reduce this problem (Baldé et al., 2011; Oliveira et al., 2009b; ScopeL et al., 2005; Sims et al., 2018). However, farmers' interest in cover crops was little, mainly because planting of cover crops means an extra operation that increases the workload (Oliveira et al., 2009b). Farmers listed the following difficulties/disadvantages associated with the use of the cover crops (Xavier et al., 2013): (a) lack of knowledge about their management; (b) competition of (relay) cover crops with maize; and (c) the need of seed production with risks of insect and bird attacks.

According to Teasdale and Mohler (2000), CA without herbicide use is possible, but the production of crop residues for mulching would have to be increased to ensure an effective physical control of weed growth. Ranaivoson et al. (2017) reported that residue mulching was effective for controlling weeds with amounts of at least 4000 kg ha$^{-1}$ of dry matter, although the results were variable depending on the species of cover crops and weeds. Silva et al. (2009) tested different cover crops in relay intercropping with maize under no-tillage in Unaí and concluded that they only added 100–2000 kg ha$^{-1}$ of biomass dry matter. *Cajanus cajan* and *Crotalaria juncea* were the cover crops with the highest productivity of biomass. In contrast, in an on-station field experiment conducted in Unaí, Baldé et al. (2011) found dry matter yields of *Cajanus cajan* in consortium with no-tillage maize of up to 10000 kg ha$^{-1}$, without affecting maize productivity. However, they observed high variability of *Cajanus* productivity depending on seeding dates and weather conditions, especially the distribution of rainfall.

In general, the family farmers in the study region are risk-averse, as highlighted by Silva et al. (2009). Farmers defined two kinds of risks with maize production, climatic risk and risk with the use of new technologies. Climatic risk was related to the dry spells that typically occur in January and February (Assad et al., 1993). For farmers, this climatic risk was associated with their reliance on rented machinery for soil tillage for which they cannot control the date of the operation. Therefore, CA systems were evaluated superior to CT, since the seeding date could be chosen in function of rainfall.

Knowledge and confidence about CA practices are important factors for adoption (Barrowclough & Alwang, 2018; Brown et al., 2018b; Perego et al., 2019). CA is recognized as a complex cropping system whose management requires a high level of knowledge (Ekboir, 2003; Scopel et al., 2013). Wall (2007) cites this as one of the main problems with the adoption of CA by smallholder farmers. In our study, CA clearly obtained a lower evaluation than CT for this sub-criterion, which was not offset by the better evaluation of CA concerning the dependency on external machinery for soil tillage (Table 3).

Our model highlighted the conflicts between some evaluation criteria established by the farmers, e.g. increasing fertilization use versus decreasing production costs. This clearly shows the need for trade-off analyses. Considering all criteria of the farmers, the CA-based cropping system was evaluated as the most satisfactory system (Figure 5). However, it is important to note that changes in agricultural (local) policies that e.g. subsidize the costs of mechanized soil tillage may not favour the use of the proposed CA system (Figure 6).

Another point that deserves attention is that the multicriteria evaluation was focused on a cropping system, as part of a whole farm production system. Although the cropping system implies a significant level of decision-making, aspects related to the whole farm management should also be considered when evaluating CA systems (Corbeels et al., 2014). It is particularly important to assess whether the investments required for the CA system are compatible with the farmers' preferences and capabilities, considering the diverse activities of the whole farm.

Our results reinforce the need to improve assessment methodologies for designing attractive alternatives for crop production systems for family farmers that are not primarily market-oriented, but are of strategic importance for the livelihoods of the families. We chose to co-develop with farmers a multicriteria model in order to better consider their own priorities and their own values. Some aspects of this approach need to be highlighted. First, the high number of meetings necessary to build the model makes a careful time arrangement with farmers essential. Second, precautions must be taken to observe to which extent the constructed numerical values are actually representative in terms of the farmers' preferences. It is rather difficult to reduce the complexity of the decisional rationality of family farmers to a simple mathematical approach. Therefore, the model should be considered as a complementary tool to analyze and understand the choices and perceptions of farmers. Third, it must be clear that an extrapolation of the modelling results to farmers in other contexts is only partially possible, if at all. Therefore, it is important to understand the context and the diversity of farming conditions in which the model is being constructed and applied. Validation mechanisms of the model (approach) with other farmers will allow understanding the differences in farmers' preference systems and contexts and will lead to necessary changes in the model construction. For example, model modifications are to be expected, in case of changes in the role that maize has in the farming system. In the study region, maize gains importance as a (silage) fodder crop on farms that are evolving towards more intensified dairy production (Alary et al., 2016).

Finally, since the use and adoption of CA may result in a set of improved ecosystems services at local and/or regional scale (e.g. reduced soil erosion, soil carbon sequestration) (Palm et al., 2014), there are other potential beneficiaries of CA, such as local or national governments. Besides, private institutions, upstream (e.g. seed or equipment providers) or downstream (e.g. milk cooperative), may likewise benefit from CA adoption by local farmers (Jaleta et al., 2019) and consequently may have an opinion on the best cropping systems to be developed. Despite the importance of these various actors, the relevance of the farmers stands out as they are the direct users of the cropping systems, which is the main reason for our choice to build a model that allowed us to express their point of view.

In spite of the above aspects, the participatory process in building the model and in assessing cropping system performances allowed us to better understand the reasons for adoption or non-adoption of CA by small-scale farmers in the tropics.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## References

Affholder, F., Scopel, E., Madeira Neto, J., & Capillon, A. (2003). Diagnosis of the productivity gap using a crop model.

Methodology and case study of small-scale maize production in central Brazil. *Agronomie*, *23*(4), 305–325. https://doi.org/10.1051/agro:2003004

Alary, V., Corbeels, M., Affholder, F., Alvarez, S., Xavier, J. H. V., Silva, F. A. M. D., & Scopel, E. (2016). Economic assessment of conservation agriculture options in mixed crop-livestock systems in Brazil using farm modeling. *Agricultural Systems*, *144*, 33–45. https://doi.org/10.1016/j.agsy.2016.01.008

Arondel, C., & Girardin, P. (2000). Sorting cropping systems on the basis of their impact on groundwater quality. *European Journal of Operational Research*, *127*(3), 467–482. https://doi.org/10.1016/S0377-2217(99)00437-3

Assad, E. D., Sano, E. E. S., Masutomo, R., Castro, L. H. R. D., & Silva, F. A. M. d. (1993). Veranicos na região dos Cerrados brasileiros: Frequência e probabilidade de ocorrência. *Pesquisa Agropecuaria Brasileira*, *28*(9), 993–1003. http://seer.sct.embrapa.br/index.php/pab/article/view/3962.

Bajwa, A. A. (2014). Sustainable weed management in conservation agriculture. *Crop Protection*, *65*, 105–113. https://doi.org/10.1016/j.cropro.2014.07.014

Baldé, A. B., Scopel, E., Affholder, F., Silva, F. A. M., Corbeels, M., Xavier, J. H. V., & Wery, J. (2011). Agronomic performance of no-tillage relay intercropping with maize under smallholder conditions in Central Brazil. *Field Crops Research*, *124*(2), 240–251. https://doi.org/10.1016/j.fcr.2011.06.017

Bana e Costa, C. A., & Vansnick, J. C. (1997). Applications of the MACBETH approach in the framework of an additive aggregation model. *Journal of Multi-Criteria Decis. Analysis*, *6*(2), 63–114. https://doi.org/10.1002/(SICI)1099-1360(199703)6:23.0.CO;2-1.

Barrowclough, M. J., & Alwang, J. (2018). Conservation agriculture in Ecuador's highlands: A discrete choice experiment. *Environment, Development and Sustainability*, *20*(6), 2681–2705. https://doi.org/10.1007/s10668-017-0011-0

Beinat, E. (1997). *Value functions for environmental management*. Springer. Series Environ. & Management, vol.7, 242p.

Belton, V., & Stewart, T. (2003). *Multiple criteria decision analysis: An integrated approach*, 381. Kluwer.

Bergez, J. E., Colbach, N., Crespo, O., Garcia, F., Jeuffroy, M. H., Justes, E., Loyce, C., Munier-Jolain, N., & Sadok, W. (2010). Designing crop management systems by simulation. *European Journal of Agronomy*, *32*(1), 3–9. https://doi.org/10.1016/j.eja.2009.06.001

Bouyssou, D., Marchant, T., Pirlot, M., Tsoukiàs, A., & Vinke, P. (2006). *Evaluation and decision models with multiple criteria: Stepping stones for the analyst*, 459. Springer.

Brown, B., Llewellynb, R., & Nuberg, I. (2018b). Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. *Global Food Security*, *17*, 213–220. https://doi.org/10.1016/j.gfs.2017.10.002

Brown, B., Nuberg, I., & Llewellyn, R. (2018a). Further participatory adaptation is required for community leaders to champion conservation agriculture in Africa. *International Journal of Agricultural Sustainability*, *16*(3), 286–296. https://doi.org/10.1080/14735903.2018.1472410

Carof, M., Colomb, B., & Aveline, A. (2013). A guide for choosing the most appropriate method for multi-criteria assessment of agricultural systems according to decision-makers' expectations. *Agricultural Systems*, *115*, 51–62. https://doi.org/10.1016/j.agsy.2012.09.011

Chopin, P., Tirolien, J., & Blazy, J. M. (2016). Ex-ante sustainability assessment of cleaner banana production systems. *Journal of Cleaner Production*, *139*, 15–24. https://doi.org/10.1016/j.jclepro.2016.08.036

Corbeels, M., Graaff, J. de., Ndah, T. H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, D. H., & Adolwa, I. S. (2014). Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems Environment*, *187*, 155–170. https://doi.org/10.1016/j.agee.2013.10.011.

Craheix, D., Angevin, F., Doré, T., & Tourdonnet, S. de. (2016). Using a multicriteria assessment model to evaluate the sustainability of conservation agriculture at the cropping system level in France. *European Journal of Agronomy*, *76*, 75–86. https://doi.org/10.1016/j.eja.2016.02.002.

De Freitas, P. L., & Landers, J. N. (2014). The transformation of agriculture in Brazil through development and adoption of zero tillage conservation agriculture. *International Soil and Water Conservation Research*, *2*(1), 35–46. https://doi.org/10.1016/S2095-6339(15)30012-5

Diaz-Balteiro, L., González-Pachón, J., & Romero, C. (2017). Measuring systems sustainability with multi-criteria methods: A critical review. *European Journal of Operational Research*, *258*(2), 607–616. https://doi.org/10.1016/j.ejor.2016.08.075

Eden, C., Jones, S., & Sims, D. (1988). *Messing about in problems: An informal structured approach to their identification and management*, 122. Pergamon Press.

Ekboir, J. M. (2003). Research and technology policies in innovation systems: Zero tillage in Brazil. *Research Policy*, *32*(4), 573–586. https://doi.org/10.1016/S0048-7333(02)00058-6

Embrapa Cerrados,. (2019). *Serviços Climáticos*. http://clima.cpac.embrapa.br/clima/balanco-hidrico/#.

Ensslin, L., Neto, G. M., & Noronha, S. M. (2001). *Apoio à decisão: Metodologias para estruturação de problemas e avaliação multicritério de alternativas*, 296. Insular.

Febrapdp. Federação brasileira de plantio direto na palha. (2012). *Evolução do plantio direto no Brasil*. www.febrapdp.org.br/port/plantiodireto.html.

Gastal, M. L., Xavier, J. H. V., Zoby, J. L. F., Rocha, F. E. d. C., Silva, M. A. d., Ribeiro, C. F. D. d. A., & Couto, P. H. M. (2003). Projeto Unaí: diagnóstico rápido e dialogado de três assentamentos de reforma agrária. Planaltina, DF: Embrapa Cerrados, 74 p. (*Embrapa Cerrados. Boletim de Pesquisa e Desenvolvimento*, 118). https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/571272.

Giller, K. E., Andersson, J. A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O., & Vanlauwe, B. (2015). Beyond conservation agriculture. *Frontiers in Plant Science*, *6*, 870–883. https://doi.org/10.3389/fpls.2015.00870.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. https://doi.org/10.1016/j.fcr.2009.06.017

Giuliano, S., Ryan, M. R., Véricel, G., Rametti, G., Perdrieux, F., Justes, E., & Alletto, L. (2016). Low-input cropping systems to reduce input dependency and environmental impacts in maize production: A multi-criteria assessment. *European Journal of Agronomy*, *76*, 160–175. https://doi.org/10.1016/j.eja.2015.12.016

Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363* (1491), 543–555. https://doi.org/10.1098/rstb.2007.2169

IBGE. (2017). *Censo Agropecuário Brasileiro. Sistema IBGE de Recuperação Automática*. Banco de Dados Agregados. http://www.sidra.ibge.gov.br.

INCRA. (2013). Apresentação sobre a Assessoria Técnica, Social e Ambiental no município de Unaí. [Brasília, DF], Relatório.

Jaleta, M., Baudron, F., Krivokapic-Skoko, B., & Erenstein, O. (2019). Agricultural mechanization and reduced tillage: Antagonism or synergy? *International Journal of Agricultural Sustainability*, *17*(3), 219–230. https://doi.org/10.1080/14735903.2019.1613742

Keeney, R. L. (1992). *Value-focused thinking: A path to creative decision making*, 416. Harvard University Press.

Keeney, R., & Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*, 565. John Willey &Sons.

Lalani, B., Dorward, P., Holloway, G., & Wauters, E. (2016). Smallholder farmers' motivations for using conservation agriculture and the roles of yield, labour and soil fertility in decision making. *Agricultural Systems*, *146*, 80–90. https://doi.org/10.1016/j.agsy.2016.04.002

Landers, J. (2001). *Zero tillage development in tropical Brazil: The story of successful NGO activity*, 147. FAO. Agricultural services bulletin.

Loyce, C., & Wery, J. (2006). Les outils dês agronomes pour l'évaluation et la conception de systèmes de culture. In T. Doré, M. L. Bail, P. Martin, B. Ney, & J. Roger-Strade (Coord.), *L'agronomie aujord'hui*, 77–95. Quae.

Martínez-García, C. G., Dorward, P., & Rehman, T. (2013). Factors Influencing adoption of improved Grassland management by small-scale dairy farmers in Central Mexico and the Implications for Future research on smallholder adoption in Developing Countries. *Livestock Science*, *152*(2-3), 228–238. https://doi.org/10.1016/j.livsci.2012.10.007

Mastrantonio, J. J. d. S., Porto, R. G., & Gomes, M. C. (2007). A escolha de cultivares de feijão através de um modelo multicritério baseado no saber local. *Revista Brasileira de Agroecologia*, *2*(1), 694–697.

Meinke, H., Baethgen, W. E., Carberry, P. S., Donatelll, M., Hammer, G. L., Selvaraju, R., & Stockle, C. O. (2001). Increasing profits and reducing risks in crop production using participatory systems simulation approaches. *Agricultural Systems*, *70*(2-3), 493–513. https://doi.org/10.1016/S0308-521X(01)00057-9

Montibeller Neto, G. (1996). *Mapas Cognitivos: Uma Ferramenta de Apoio à Estruturação de Problemas*. 221f. Dissertação (Mestrado) – Programa de Pós-Graduação em Engenharia de Produção, Centro Tecnológico. Universidade Federal de Santa Catarina. UFSC, Florianópolis.

Ngoma, H. (2018). Does minimum tillage improve the livelihood outcomes of smallholder farmers in Zambia? *Food Security*, *10* (2), 381–396. https://doi.org/10.1007/s12571-018-0777-4

Nichols, V., Verhulst, N., Cox, R., & Govaerts, B. (2015). Weed dynamics and conservation agriculture principles: A review. *Field Crops Research*, *183*, 56–68. https://doi.org/10.1016/j.fcr.2015.07.012

Oliveira, M. N. de, Sabourin, E., Altafin, I. G., & Almeida, S.C.R. de. (2009a). As organizações sociais: trajetórias, lições eperspectivas. In M. N. de Oliveira, J. H. V Xavier, S. C. E. de Almeida, & E. Scopel (Eds.), *Projeto Unaí: pesquisa e desenvolvimento em assentamentosde reforma agrária*. (pp. 94–141). Brasília: Embrapa Informação Tecnológica. https://www.alice.cnptia.embrapa.br/bitstream/doc/856429/1/oliveira01.pdf.

Oliveira, M. N. de., Xavier, J. H. V., Silva, F. A. M. da., Scopel, E., & Zoby, J. L.F. (2009b). F. Efeitos da introdução do sistema de plantio direto de milho por agricultores familiares do município de Unaí-MG (Cerrado Brasileiro). *Pesquisa Agropecuária Tropical, Goiânia*, *39*(1), 51–60. http://www.revistas.ufg.br/index.php/pat/article/view/3953/4513.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., & Grace, P. (2014). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems Environment*, *187*, 87–105. https://doi.org/10.1016/j.agee.2013.10.010

Pannell, D. J., Llewellyn, R. S., & Corbeels, M. (2014). The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems Environment*, *187*, 52–64. https://doi.org/10.1016/j.agee.2013.10.014

Peigné, J., Lefèvre, V., Craheix, D., Angevin, F., & Capitaine, M. (2015). Évaluation participative de prototypes de systèmes de culture combinant agriculture de conservation et agriculture biologique. *Cahiers Agricultures*, *24*(2), 134–141. https://doi.org/10.1684/agr.2015.0737

Pelzer, E., Fortino, G., Bockstaller, C., Angevin, F., Lamine, C., Moonenf, C., Vasileiadis, V., Guérina, D., Guichard, L., Reau, R., & Messèana, A. (2012). Assessing innovative cropping systems with DEXiPM, a qualitative multi-criteria assessment tool derived from DEXi. *Ecological Indicators*, *18*, 171–182. https://doi.org/10.1016/j.ecolind.2011.11.019

Perego A., R., Cattivelli, A., Tabaglio, V., Fiorini, V., Barbieri S, A., Schillaci, C., Chiodini, M. E., Brenna, S., & Acutis, M. (2019). Agro-environmental aspects of conservation agriculture compared to conventional systems: A 3-year experience on 20 farms in the Po valley (Northern Italy). *Agricultural Systems*, *168*, 73–87. https://doi.org/10.1016/j.agsy.2018.10.008

Pittelkow, C., Liang, X., Linquist, B. A., Groenigen, K. J. V., Lee, J., Lundy, M. E., Gestel, N. V., Six, J., Venterea, R. T., & Kessel, C. V. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, *517*(7534), 365–368. https://doi.org/10.1038/nature13809

Prestele, R., Hirsch, A. L., Davin, E. L., Seneviratne, S. I., & Verburg, P. H. (2018). A spatially explicit representation of conservation agriculture for application in global change studies. *Global Change Biology*, *24*(9), 4038–4053. https://doi.org/10.1111/gcb.14307

Pretty, J., & Bharucha, Z. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, *114*(8), 1571–1596. https://doi.org/10.1093/aob/mcu205

Ramírez-García, J., Carrillo, J. M., Ruiz, M., Alonso-Ayuso, M., & Quemada, M. (2015). Multicriteria decision analysis applied to cover crop species and cultivars selection. *Field Crops Research*, *175*, 106–115. https://doi.org/10.1016/j.fcr.2015.02.008

Ranaivoson, L., Naudin, K., Ripoche, A., Affholder, F., Rabeharisoa, L., & Corbeels, M. (2017). Agro-ecological functions of crop residues under conservation agriculture. *Agronomy for Sustainable Development*, *37*(4), 1–17. https://doi.org/10.1007/s13593-017-0432-z

Reichert, L. J., Gomes, M. C., & Schwengber, J. E. (2013). Metodologia multicritério de apoio à decisão para avaliar sistemas de produção de batata orgânica na região Sul do Rio Grande do Sul. *Revista Brasileira. de Agroecologia*, *8*(1), 116–129. https://doi.org/orgprints.org/24478/

Röling, N. (1996). Towards an interactive agricultural science. *European Journal of Agricultural Education and Extension*, *2* (4), 35–48. https://doi.org/10.1080/13892249685300061

Romero, C., & Rehman, T. (2003). *Multiple criteria analysis for agricultural decisions*, 186. Elsevier.

Roy, B., & Venderpooten, D. (1996). The European school of MCDA: Emergences, basic features and current works. *Journal of Multi-Criteria Decision Analysis*, *5*, 23–38. https://doi.org/10.1002/(SICI)1099-1360(199603)5:1;22::AID-MCDA93>3.0.CO;2-F.

Rusinamhodzi, L., Corbeels, M., Van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for Sustainable Development*, *31*(4), 657–673. https://doi.org/10.1007/s13593-011-0040-2

Sadok, W., Angevin, F., Bergez, J. E., Bockstaller, C., Colomb, B., Guichard, L., Reau, R., & Doré, T. (2008). Ex ante assessment of the sustainability of alternative cropping systems: Implications for using multi-criteria decision aid methods. *Agronomy for Sustainable Development*, *28*, 163–174. https://doi.org/10.1051/agro:2007043

Scopel, E., Triomphe, B., Affholder, F., Silva, F. A. M. da., Corbeels, M., Xavier, J. H. V., Lahmar, R., Recous, S., Bernoux, M., Blanchart, R., Mendes, I. d. C., & Tourdonnet, S. (2013). Conservation agriculture cropping systems in temperate and tropical conditions, performances and impacts. *Agronomy for Sustainable Development*, *33*(1), 113–130. https://doi.org/10.1007/s13593-012-0106-9.

ScopeL, E., Triomphe, B., Goudet, M., Xavier, J. H. V., & Macena, F. A. M. (2005). *Da. Potential role of CA in strengthening small-scale farming systems in the Brazilian Cerrados, and how to do it*. World Congress on Conservation Agriculture, Nairobi, October 3-7, 2005. In: *World Congress On Conservation Agriculture*, 3, Nairobi, Kenya. 8 p. https://agritrop.cirad.fr/530208/ >

Séguy, L., Bouzinac, S., Scopel, E., & Ribeiro, M. F. S. (2003). *New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: The CIRAD experience, partnership and networks*. World Congress on Conservation Agriculture, Foz do Iguaçu, Brazil, August 11-15, 2003. World Congress on Conservation Agriculture, 2., 2003, Foz do Iguaçu. Producing in harmony with nature: proceedings. [S.l.: s.n.].

Silva, F. A. M. da., ScopeL, E., Xavier, J. H. V., & Triomphe, B. (2009). Processos de inovação em plantio direto no cultivo de milho grão sequeiro para agricultura familiar. In M. N. de. Oliveira, J. H. V. Xavier, S. C. E. d. Almeida, & E. Scopel (Eds.), *Projeto Unaí: Pesquisa e desenvolvimento em assentamentos de reforma agrária* (pp. 183–217). Embrapa Informação Tecnológica. https://www.alice.cnptia.embrapa.br/bitstream/doc/856429/1/oliveira01.pdf.

Sims, B., Corsi, S., Gbehounou, G., Kienzle, J., Taguchi, M., & Friedrich, T. (2018). Sustainable weed management for conservation agriculture: Options for smallholder farmers. *Agriculture*, *8*(8), 118–138. https://doi.org/10.3390/agriculture8080118

Sousa, D. M. G. de., & Lobato, E. (2004). *Cerrado: Correção do solo e adubação. 2. Ed. Brasília, DF: Embrapa Informação Tecnológica; Planaltina* (pp. 416). Embrapa Cerrados.

Steward, P. R., Dougill, A. J., Thierfelder, C., Pittelkow, C. M., Stringer, L. C., Kudzala, M., & Shackelford, G. E. (2018). The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: A meta-regression of yields. *Agriculture, Ecosystems Environment*, *251*, 194–202. https://doi.org/10.1016/j.agee.2017.09.019

Teasdale, J. R., & Mohler, C. L. (2000). The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Science*, *48*(3), 385–392. https://doi.org/10.1614/0043-1745(2000)048[0385:TQRBWE]2.0.CO;2

Telles, T. S., Righetto, A. J., Costa, G. V. d., Volsi, B., & Oliveira, J. F. d. (2019). Conservation agriculture practices adopted in southern Brazil. *International Journal of Agricultural Sustainability*, *17*(5), 338–346. https://doi.org/10.1080/14735903.2019.1655863

Wall, P. C. (2007). Tailoring conservation agriculture to the needs of small farmers in developing countries: An analysis of issues. *Journal of Crop Improvement*, *19*(1-2), 137–155. https://doi.org/10.1300/J411v19n01_07

Xavier, J. H. V. (2010). Avaliação de sistemas de cultivo de milho grão sequeiro no contexto da agricultura familiar: uma aplicação da metodologia multicritério de apoio à decisão (MCDA). 318 f. Tese (Doutorado) – Programa de Pós Graduação em Sistemas de Produção Agrícola Familiar. Faculdade de Agronomia Eliseu Maciel. Universidade Federal de Pelotas, Pelotas. http://guaiaca.ufpel.edu.br/handle/prefix/4849.

Xavier, J. H. V., Gomes, M. C., Anjos, F. S. dos., Almeida, S. C. R. de., Oliveira, M. N. de., Scopel, E., Corbeels, M., & Muller, A. G. (2012). Metodologia multicritério de apoio à decisão como ferramenta para avaliação de sistemas de cultivo de milho. *Cadernos de Ciência & Tecnologia*, *29*(1), 89–131. .http://seer.sct.embrapa.br/index.php/cct/article/view/14545.

Xavier, J.H.V., SILVA, F.A.M. da., Scopel, E, Muller, A.G., Almeida, S.C.R., Oliveira, M.N. de, Sabourin, E., Triomphe, B., Corbeels, M., Silva, D. S., Lima, T.M., & Ribeiro, C. F.D. de A. (2013). Plantio direto de milho grão sequeiro: referência construída com agricultores familiares assentados de reforma agrária do Município de Unaí, MG. Planaltina-DF: Embrapa Cerrados, (Série Documentos, 314). https://www.infoteca.cnptia.embrapa.br/bitstream/doc/978520/1/doc314.pdf.

Zardari, N. H., Ahmed, K., Shirazi, S. M., & Yusop, Z. B. (2015). *Weighting methods and their effects on multi-criteria decision making model outcomes in water resources management*, 713. Springer. https://link.springer.com/book/10.1007%2F978-3-319-12586-2.

Zopounidis, C., & Pardalos, P. (2010). *Handbook of multicriteria analysis*. Springer. 481 p.