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Scientific and technical knowledge of sugarcane cover-management USLE/RUSLE factor

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ABSTRACT: Sugarcane covers 10.6 Mha of Brazilian agricultural land (13 % of all cropland), mainly in the south-central region. In tropical climate conditions, the physiological characteristics of sugarcane allow a wide range of management systems with contrasting soil erosion outcomes. Models can assess these differences and the Universal Soil Loss Equation (USLE) based models are the most frequently used. The cover-management factor (C Factor) is the USLE input variable that represents the changes in soil cover and management. We collected, compared, and evaluated sugarcane C Factor values reported in technical and scientific literature to support modelers and soil scientists on the adequate choice of these values. We analyzed references reporting primary C Factor values and sources that applied these values or described them. We found 50 references, showing a wide value variation ranging from 0.0012 to 0.5800. Thirteen references were primary sources. We found seven primary sources for Brazilian sugarcane growing conditions, but only two papers were peer-reviewed. Sugarcane C Factor modelers frequently used C values based on a poor understanding and description of the methodological and geographical origin of these values and out of the context of the specific crop management systems of application. Therefore, the results may not be compatible with the study site conditions. The primary sources lack clarity in the description of the site–specific environmental and management conditions in which the C Factors were obtained, hindering the use of these specificities by the end user.

Keywords: bibliometric research, modeling, soil loss

Introduction

Sugarcane is a primary crop in Brazil by the extension of cultivated areas (10.6 Mha, occupying 13 % of total cropped area), the high value of its production chain (US$ 22 billion yr^{-1}) (IBGE, 2016; FIESP, 2020), and for its importance in energy (ethanol and electricity) and food production. Production is expected to increase by 0.8 Mha and 35 % in volume until 2029 driven by increments in energy and food consumption (FIESP, 2020). This increase is directly related to land-use changes, with pastures located in less suitable and susceptible areas to erosion being replaced by sugarcane cultivation (Sparovek et al., 2009; Spera et al., 2017).

The physiological characteristics of sugarcane cultivation in tropical climates enable the adoption of a wide range of management systems including planting date, soil tillage, variety (influencing soil cover dynamic and harvesting date), planting density and row spacing, type of harvest, among others.

Sugarcane crops are planted close to the mills to reduce harvesting and logistic costs. By having the distance of the mills as the main factor defining land use, sugarcane occupies a wide range of soil and slope conditions occurring near the mills. In many cases, this results in sugarcane cultivated in highly erodible soil and slope conditions. According to Medeiros et al. (2016), sugarcane crops have expanded mainly to highly erodible soils and distinct climatic conditions, due to the wide range of available management options.

Models allow the understanding, prediction, and simulation of soil erosion. The Revised Universal Soil Loss Equation (RUSLE), described by Renard et al. (1997), is the currently most widely used model for soil loss prediction (Zhuang et al., 2015), due to its operational simplicity.

The RUSLE consists of six factors (R, K, L, S, C, and P). The cover-management factor (C Factor) reports the interaction of phenological (canopy cover, dry matter production, and production cycle) and management (tillage, planting and harvesting dates, and soil cover) conditions with environmental information (precipitation). The RUSLE C Factor and its subfactors are an evolution from the USLE C Factor (original model described by Wishmeier and Smith (1978)). The USLE C Factor uses tree variables to determinate the soil loss ratio: i) soil cover, ii) canopy cover, and iii) canopy hight. The RUSLE approach is an evolution of USLE and it has five subfactors: i) previous land use, ii) canopy cover, iii) soil cover, iv) soil roughness, and v) soil moisture (canopy hight was merged with canopy cover subfactor).

For semi-perennial crops and crops with highly variable management systems, such as sugarcane, long-term and laborious experimental studies needed to obtain direct C Factors, as described in the USLE manuals (Wischmeier and Smith, 1978), restrict the availability of primary values based on experiments. In addition, the experimental determination of C Factor values for different crop and management systems has focused mainly on temperate climate crops (Wischmeier and Smith, 1978; Morgan, 2005).

Considering the importance of sugarcane, its large management options variability, and its impacts on soil conservation, we have carried out a broad literature survey on sugarcane C Factors. We compared and analyzed the sources to subsidize modelers and soil scientists on an adequate choice of this variable and reported on the scientific gaps on the topic. We also reported on how wrong references may be propagated by authors who do not take into account all descriptions of the primary sources of this information.

Materials and Methods

The bibliographic research used online databases and national and international technical and academic publications (up to 18 Mar 2020). The databases used were: Web of Science™, Scopus®, the library system at the University of São Paulo (DEDALUS - USP), the library system at the São Paulo State University (P@rthenon - UNESP), agricultural research databases from the Brazilian Agricultural Research Corporation (BSP@ - EMBRAPA), library system of the Agronomic Institute of Campinas (SophiA® - IAC), Google Scholar, and Google.

The terms used in the survey were "sugarcane C Factor" and its variations in Portuguese and English. We traced the citations back in time to find the original reference that generated the current citation. We labeled the references with the following information:

• value or multiple C values;

• conditions: environmental and management of the research site;

• agreement between the C value and the modeling conditions: comparison between the reference value conditions (quoted) and the conditions where the model was applied;

• methodology to obtain or cite the C value: primary source, indirect C value determination method, or aforementioned citation;

• author(s) (year): authors and publication year of the reference;

• study location: the place where the reference was developed;

• type of reference: i) book; ii) article; iii) dissertation/thesis; or iv) technical/congress paper.

Results and Discussion

In total, we found and analyzed 50 references using sugarcane C Factor. The C Factor values found ranged from 0.0012 to 0.5800 (Table 1). Eleven references are primary sources, with seven developed by experimentation in standard USLE plots and four based on soil cover development data. The C Factors from three references cited were not available in the originals: Wischmeier and Smith (1978), Mitchell and Bubenzer (1980) and Bertoni and Lombardi Neto (1990). Another four were cited; however, we were unable to access their sources: Soil Conservation Service (1975), Hamer (1981), Arsyad (2010), and SASA (2002). A summary of the results is shown in Figure 1, which presents the publication year (y-axis), factor values, reference type, and citation of the primary sources of the references.

The most frequent C Factor values ranged from 0.1 to 0.2 (40 % of the values), followed by the 0.3-0.4 cluster, with 24 %. The mean value was 0.1872 and the median 0.1308 (Figure 2). This variation is partially explained by the great diversity of sugarcane management systems. From a geographical viewpoint, Brazilian references are concentrated in the southern and southeastern regions, as observed in a bibliographic survey on accelerated erosion by Barretto et al. (2008). Although sugarcane is also cropped in the central-western and northeastern regions, most C Factors were also determined for south and southeast Brazil.

Ribeiro and Alves (2007), De Maria et al. (1994), and Donzelli et al. (1992) were the most cited references, each cited by three other authors. Of these, only the work of De Maria et al. (1994) is a primary source.

Of all the references that cited the C Factor values, only nine authors used primary sources (Aragão et al., 2013; Andrade et al., 2011; Bacchi et al., 2003; Sparovek et al., 2000; Vasquez-Fernádez, 1996; Ramos-Scharrón, 2015; Mata, 2009; Vis, 1987; Brooks, 1977). Personal communications or unpublished data were used by two authors (Donzelli et al., 1992; Cavalieri, 1998). Sources that do not include C Factor values for sugarcane occurred in three references (Silva et al., 2007; Morgan, 1986; Costa and Silva, 2012), and the remaining studies use non-primary citations. The primary sources were mainly published in unreviewed formats, such as technical reports, theses, or dissertations, and congress papers (Figure 3). Most references used C Factors in studies related to soil loss predictions.

C factor values determined in Brazil

Seven out of 13 primary references were developed in Brazil. The first Brazilian efforts are from the 1980s and 1990s and were developed at the Agronomic Institute of Campinas (IAC), as noted in the references by Donzelli et al. (1992) and Cavalieri (1998). These studies cited personal communications from IAC researchers based on ongoing experiments. The first published reference with C Factor calculated in Brazil was prepared by Stein et al. (1987), based on a methodology defined by Bertoni and Lombardi Neto (1985), and published in the Annals of the IV National Symposium on Erosion Control, 1987. The reference by De Maria et al. (1994) was developed in standard plots in a sugarcane management system of three cuts in two different soils

Table 1 – Description of the sugarcane C Factor references ordered by publication year.

Value	Conditions	Compatibility with the original value	Method or Citation from other work	Author(s), (Year)	Study location (State/ Country)	Type of work
0.11 0.29	Sugarcane Winter planting	–	Technical report by the Soil Conservation Service (SCS, 1975)	Brooks (1977)	Hawaii/ United States	Book
0.11 0.29	Sugarcane Winter planting	Compilation	Brooks (1977)	El-Swaify et al. (1982)	Hawaii/ United States	Book
0.13-0.40	Not described	Compilation	El Swaify et al. (1982) Wischmeier and Smith (1978)	Morgan (1986)		Book
0.20	Not described	–	Hamer (1981)	Vis (1987)	Java/Indonesia	Technical report
0.1	Not described	Primary source	Data generated by the authors based on a proposal by Bertoni and Lombardi Neto (1985)	Stein et al. (1987)	São Paulo/ Brazil	Congress work
0.09 to 0.15	Several regions and plant dates	Not described	Estimated by modelling	Platford (1987)	South Africa	Techinical report
0.05 0.10	With straw incorporation Without management	–	Data generated by the soil conservation section of the *IAC* (unpublished), reasons for soil loss in plots	Donzelli et al. (1992)	São Paulo/ Brazil	Technical report
0.11	For planting in Oct	Primary source	Generated due to soil loss in plots in *IAC* areas in two locations in the state of São Paulo	De Maria et al. (1994)	São Paulo/ Brazil	Congress work
0.11	Not described	Compilation	De Maria et al. (1994) Donzelli et al. (1992)	Vázquez–Fernandez et al. (1996)	São Paulo/ Brazil	Congress work
0.1076	First cut, one year after planting	–	*Lombardi Neto (personal communication), preliminary data under development by the author (1998)*	Cavalieri (1998)	São Paulo/ Brazil	Thesis
0.3066	–	Primary source	Calculated based on plant growth (Machado et al., 1982)	Weill (1999)	São Paulo/ Brazil	Thesis
0.3066	–	No description	De Maria et al. (1994)	Sparovek et al. (2000)	São Paulo/ Brazil	Article
0.35 0.58	Planting in Jan with 20 % of initial waste Planting in May without soil cover	Primary source	Concept by Renard et al. (1997) and based on field parameter measurements (crop growth, roughness) for Hawaii conditions	Evensen et al. (2001)	Hawaii/ United States	Technical report
0.121 (CP = 0.0605)	18 month sugar cane (year and a half)	No, same location, but different management system	Cavalieri (1998)	Weill et al. (2001)	São Paulo/ Brazil	Congress work
0.05-0.3066		Compilation	Donzelli et al. (1992) Cavalieri (1998) Weill (1999)	Fujihara (2002)	São Paulo/ Brazil	Thesis
0.114 0.317	With 100 % soil cover With 50 % soil cover	Primary source	Experimental plots, calculating the SLR for two treatments	Amaral (2003)	São Paulo/ Brazil	Completion of course work
0.1533 (CP combined)	No description	No description	De Maria et al. (1994)	Bacchi et al. (2003)	São Paulo/ Brazil	Article
0.06	Cane plant	Primary source	Cites reasons for soil loss from the work of Pundek (1994), calculating the C Factor for the region of interest	Serra (2004)	São Paulo/ Brazil	Completion of course work
0.05-0.3066	Considers the range of values proportional to the coverage rate of each simulation	Yes, there is logic for the range of values	Fujihara (2002)	Prado and Nóbrega (2005)	Paraná/ Brazil	Article
0.3066	No description	No description	Weill (1999)	Ribeiro (2006)	Rio de Janeiro/ Brazil	Thesis
0.104		Primary source	Standard plots over several years and crop cycles	Bengtson and Selim (2007)	Louisiana/ United States	Congress work
0.3066		No citation	Not described	Ribeiro and Alves (2007)	Rio de Janeiro/ Brazil	Congress work
0.1743	No description	No description	Mitchell and Bubenzer (1980)	Silva et al. (2007)	São Paulo/ Brazil	Article

Continue...

Table 3 – Continuation.

0.3066		Primary source	Calculated on the plant growth (Machado et al., 1982)	Weill and Sparovek (2008)	São Paulo/ Brazil	Article
0.3066	No description	No description	Ribeiro and Alves (2007)	Machado et al. (2009)	Minas Gerais/ Brazil	Congress work
0.1	No description	No description	Stein et al. (1987)	Mata (2009)	Minas Gerais/ Brazil	Thesis
0.09		Primary source	Standard plots over several years and crop cycles	Bengtson and Selim (2010)	Louisiana/ United States	Congress work
0.1124 sugarcane 0.0112 (forage)	Sugarcane and forage sugarcane	No description	No citation and no methodology	Silva et al. (2010)	São Paulo/Brazil	Article
0.16 (1st. cut) to 0.06 (5th.) 0.16 (1st. cut) to 0.13 (5th)	Sugarcane without burning Sugarcane without burning	Yes, similar conditions	Amaral (2003) Serra (2004)	Andrade et al. (2011)	São Paulo/Brazil	Article
0.3066	No description	No, place with very different environmental conditions and management systems not described	Ribeiro and Alves (2007)	Farias and Reis (2011)	Pernambuco and Alagoas/Brazil	Congress work
0.1533	Sugarcane with burning	No, distinct location, with consistency in the management system	Ribeiro and Alves (2007)	Monteiro (2011)	Rio de Janeiro/Brazil	Thesis
0.3066	Sugarcane without burning	Primary source	Standard plots over several years and crop cycles	Bengtson and Selim (2012)	Louisiana/United States	Congress work
0.0012	No description	No, place with different environmental conditions and the management systems were not described	Adapted from Bertoni and Lombardi Neto (1990)	Costa and Silva (2012)	Paraíba/Brazil	Article
0.05-0.10	No description	No, there is geographic coherence, but no management description	Donzelli et al. (1992)	Demarchi (2012)	São Paulo/Brazil	Thesis
0.018		No, place with different environmental conditions and the management systems were not described	Silva et al. (2007)	Silva et al. (2012)	Pernambuco/ Brazil	Article
0.3066	No description	No description	Weill and Sparovek (2008)	Aragão et al. (2013)	Sergipe/Brazil	Article
0.018	No description	No description	Silva et al. (2012)	Xavier et al. (2013)	Paraíba/Brazil	Article
0.018	No description	No description	Silva et al. (2012)	Xavier and Silva (2014)	Paraíba/Brazil	Congress work
0,3066		The same	Weill and Sparovek (2008)	Santos (2014)	São Paulo/ Brazil	Thesis
0.096	Sugarcane without burning	Yes, management consistency	Andrade et al. (2011)	Ayer et al. (2015)	Minas Gerais/Brazil	Article
0.142	Sugarcane with burning	The same	Weill and Sparovek (2008)	Santos (2014)	São Paulo/ Brazil	Thesis
0.1	No description	No description	Andrade et al. (2011)	Olivetti et al. (2015)	Minas Gerais/Brazil	Article
0.35-0.55		No, location with very different environmental conditions and the handling systems were not described	Evensen et al. (2001)	Ramos-Scharrón et al. (2015)	Porto Rico/Porto Rico	Article
0.1308 to 0.43	Sugarcane	Primary description	C Factor in plots, in productive area	Corrêa (2016)	São Paulo/Brazil	Thesis
0.1308-0.41	Sugarcane	Primary description	C Factor in plots, in productive area	Corrêa et al. (2016)	São Paulo/Brazil	Article
0.3066	Sugarcane	Same state	Weill (1999)	Medeiros (2016)	São Paulo/Brazil	Thesis
0.3066	Sugarcane	Same state	Weill (1999)	Medeiros et al. (2016)	São Paulo/Brazil	Article
0.1124	Sugarcane	There are no informations in primary description	Silva et al. (2010)	Couto Júnior et al. (2019)	São Paulo/Brazil	Article
0.20	Sugarcane		Arsyad (2010) (not founded, indonesian book)	Yulnafatmawita et al. (2019)	Indonesia	Article
0.09-0.20	Sugarcane	Same country	Platford (1987) and others (not founded)	Otim et al. (2019)	South Africa	Article
0.3066	Sugarcane	Yes, the similar environmental conditions.	Weill and Sparovek (2008)	Martins et al. (2020)	São Paulo/Brazil	Article

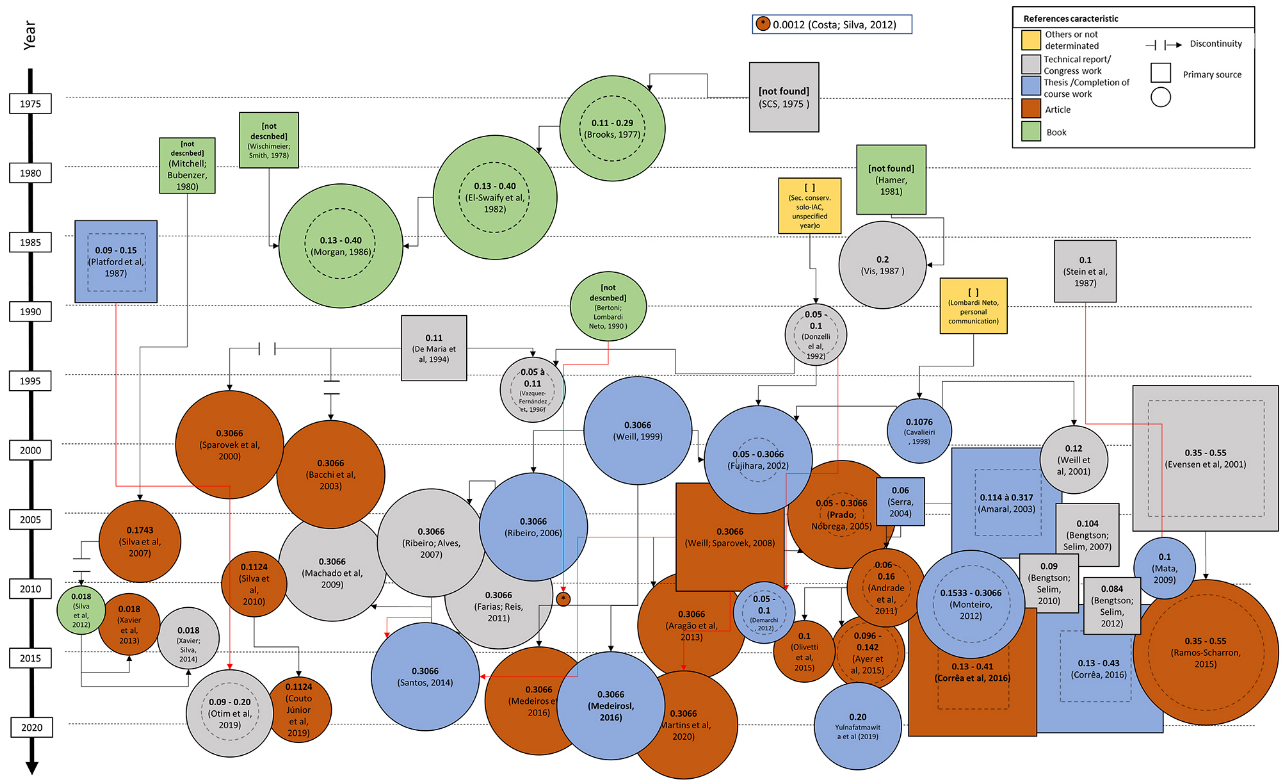

Figure 1 – References of sugarcane C Factors and its connections (arrows): by value range (the shape size is proportional to the values, the continuous lines represent maximum values and internal dotted lines the minimum values), by type of publication (color), year (vertical position in the graph), and primary source or citation (format). The red arrows transpose citations or other arrows, but not a new symbol.

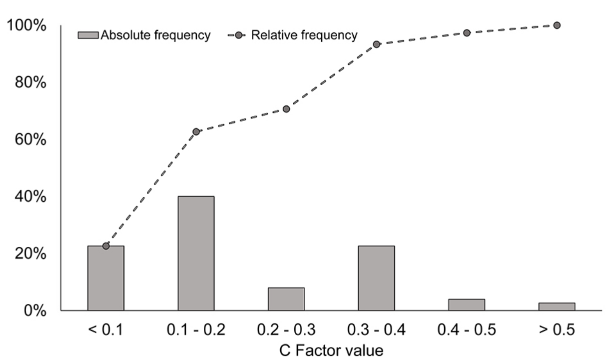

Figure 2 – Total and relative frequency of the C Factor in the analyzed references by range of values.

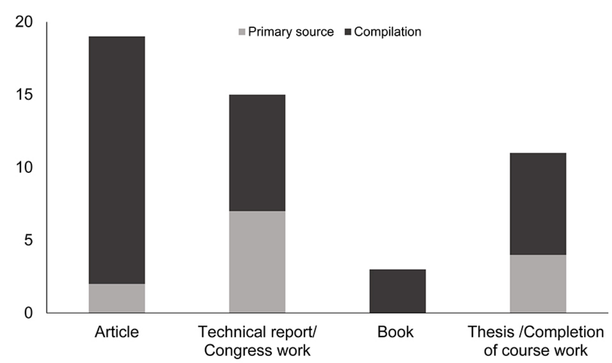

Figure 3 – Quantity of each reference class by type of information (primary or citation) of the works analyzed.

and could be considered a milestone because it was the first publication based on experimental values obtained in field plots. The reference is available in summary form with limited detail in methodology description, printed in the Proceedings of the Brazilian Soil and Water Management and Conservation Meeting (1994), with no peer-review.

Amaral (2003) and Serra (2004) developed Sugarcane C Factor values for the Catanduva (SP) and Jaboticabal (SP) regions, respectively. Amaral (2003) used standard plots, with the adoption of artificial rain and collecting gutters, while Serra (2004) used previous values of soil loss ratio (SLR) determinated by Pundek (1994). Both are undergraduate course completion studies, with restricted circulation and no peer-review.

Weill and Sparovek (2008) developed soil erosion modeling using sugarcane C Factors. In their study, the C Factor value (0.3066) was calculated based on a publication by Machado et al. (1982), in which biometric indices for sugarcane were determined according to days after planting. The methodology determined is not specified in the study. This was the first Brazilian article submitted to a peer-review in which a new C Factor value for sugarcane was published.

An article (Corrêa et al., 2016) elaborated from a PhD thesis (Corrêa, 2016) comprehensively explored C Factors and Modified Universal Soil Loss Equation (MUSLE), in which four values were calculated based on standard plots and natural rainfall, with variations in the planting date, number of cuts (ratoon or first harvest), previous use, and straw maintenance on the soil surface, resulting in values from 0.1308 to 0.4100.

Primary sources generally have a simplified description of the management systems. Important crop management features were not described or were only partially defined, such as tillage date, planting technology, rotation with soil cover crop, number of harvet cycles, and straw management.

Variations regarding the C Factor value

The lowest C Factor value among the references analyzed was 0.0012 by Costa and Silva (2012) in a humid tropical climate in the Atlantic Forest biome of Paraíba State. This value has the same magnitude order as natural forests (Martins et al., 2010; Wischmeier and Smith, 1978). The highest value was 0.5800 by Evensen et al. (2001), in a study developed in the state of Hawaii (USA), where the sugar cane cycle lasts 24 months and soil cover develops slower than in the Brazilian growing conditions, resulting in larger C values. Considering the range between the lowest and highest C Factors in the references, soil erosion modelers who choose C values based only on land use may produce results in a range of 480 times in soil loss values. Crop management systems and site conditions are more influential on C Factors than the land use by itself. The range of the sugarcane management systems is an issue for modelers to choose the right C Factor value. Few references describe deeply the management systems (see columns "Conditions" and "Compatibility with the original value" in Table 1).

Another critical point is the discontinuity or adaptations of C values among citations without further explanations. The book of Mitchel and Bubenzer (1980) does not present C Factor values for sugarcane; nevertheless, it is the reference Silva et al. (2007) used as source with a value of 0.1743. The primary source in De Maria et al. (1994) presents a value of 0.11, but Sparovek et al. (2000) and Bacchi et al. (2003) present this reference with changed C Factor value of 0.3611.

The C Factor is conceptually and originally annual; however, for semi perennial crops such as sugarcane, the entire crop cycle, including ratoons and crop rotations, should be taken into account for C Factor determination (Wischmeier and Smith, 1961; Wischmeier and Smith, 1978). For sugarcane, it is not possible to determine the C Factor for USLE (Wischmeier and Smith, 1978) or RUSLE (Renard et al., 1997) with a single year of data collection. However, it is possible to have a partial C Factor value of the crop for the period in one year. Therefore, multi-annual long-term studies are necessary until the soil cover and management variables become constant. This original concept does not invalidate the generation of partial C Factor values, nor their use, as long as this aspect is consistent with the results reported.

Conclusion

The analyses presented here allow affirming that:

- There are few references from primary sources (predominance of citations).

- We found cases of errors in referenced values (misleading citations).

- As expected, because of the large variation in crop management options, there is a wide range of described C Factor values.

- By linking the C Factor to land use types rather than to the management system, the considerable variation for C Factors is disregarded and may lead to estimation errors.

- There are few primary data sources for Brazilian conditions (six) and only one reference with peer-review.

There is a trend towards more significant scientific advances in modeling than in experimental work, as historically reported by Hartemink et al. (2001). The demand for reliable input data for modelers is growing. The use of primary sources as inputs is essential to learn about the reference origin and methodology assessment, reducing the chance of errors or incompatibility of values.

Modelers need to rethink the use of soil erosion models, mainly the data input, otherwise, mistakes may be made and credibility could be lost. All uncertainty must be clearly explained in the sources. If there are gaps in the input database, alternatives soil loss models could be considered.

The search for regional values, analysis of the complete sugarcane crop cycle, and a clear description of the adopted management system are basic premises for generating and using precise C Factor values. The experimental determination of C-factors values for all possible and practically adopted management systems for sugarcane production in Brazil is challenging, if not impossible, due to its diversity and constant improvements.

An alternative way to determine such a wide range of C Factors is the development of sugarcane C Factor modeling tools with an interface sensitive to the most common C Factor parameters, such as harvesting and planting dates, row spacing, soil tillage, and varieties, allowing thus, soil erosion modelers to represent crop management rather than the oversimplified land-use approach for sugarcane soil loss estimation.

Authors' Contributions

Conceptualization: Rocha, G.C.; Sparovek, G. **Data acquisition:** Rocha, G.C. **Data analysis:** Rocha, G.C. **Design of methodology:** Rocha, G.C.; Sparovek, G. **Writing and editing:** Rocha, G.C.; Sparovek, G.

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