



## **Updating of the system for the estimation of forest fuels (SICCO v3.0)**

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### **Abstract:**

Forests face a wide variety of problems, the main of which is fires. Fires require three basic factors: fuel material, favorable environmental conditions and an ignition factor. The fuel is a particularly important factor because it largely determines the fire hazard. The forest fires program of the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (INIFAP) has developed a tool to estimate the

amount of fuel present in a unit of area in a quick, practical and simple way, known as the Forest Fuel Evaluation System (SICCO, Spanish acronym), whose foundational methodology for taking stock of forest fuels is based on planar intersections. The new version of SICCO allows dynamic updates of information regarding the specific gravity, apparent density and mean square diameter using relational databases. It has libraries that extract this information from databases contained within the system itself using the location coordinates of the study areas. Likewise, the users can customize these values according to their specific needs. SICCO makes it possible to estimate forest fuel loads in a simple, transparent way. Thus, the users focus their efforts more on the quality of the collected data than on the use of the equations and processes required for the estimation of the weights per unit of area.

**Keywords:** Forest fuels, fire, specific gravity, forest fires, system, estimate, update.

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## **Introduction**

Among the various problems which the forests face today, fires are the most important. These are caused by nature (Martínez and Rodríguez, 2008) or are produced through anthropic action (Flores *et al.*, 2010). In order for a forest fire to occur, three basic elements are required: the presence of fuel, favorable environmental conditions, and an ignition factor (Santiago *et al.*, 1999). Forest fuels

are one of the most relevant components for the management and control of fires, since they can be manipulated, removed or reduced (Fuller, 1991; Flores, 1996). It is important to highlight that the impact of fire is not always negative; it also triggers the process of vegetal succession, which tends to ensure the continuity of the ecosystems (Pickett and White, 1985), among many other ecological functions.

Because of the above, it is necessary to implement fuel management strategies which favor their reductions without neglecting the protection of the soil. This requires characterizing the fuels and identifying their spatial distribution through the generation of maps. This is generally too costly and difficult; actually, the determination of the spatial distribution of forest fuels is one of the most complex challenges that scientists face (Keane *et al.*, 1999; Flores, 2001). Standardized procedures must be in place in order to allow estimating the fuel loads that will make it possible to compare the registered figures and share the available information.

The fuels are divided into living and dead. The former include herbs, shrubs and trees or plants under the canopy, while the dead fuels are represented by trunks, branches and leaves that are usually lying on the soil (Porrero, 2001; Villiers, 2006) (Figure 1). The dead fuels, in turn, are divided into fine and coarse (Flores and Benavides, 1994).

In order to use the amount of volume as a variable in the potential behavior of the fire, it must be expressed in terms of size classes (Villiers, 2006), associated to the time which the fuel takes to reach a balance in regard to the humidity of the environment, known as "delay time". This is defined as the time in which a fuel loses or wins (due to the environmental humidity conditions) two thirds of the difference between its initial moisture content and the humidity of the environment (Foresberg, 1971). The larger the fuel, the more slowly it will win or lose moisture, *i.e.* the longer the delay time (Villiers, 2006). Thus, there are 1-, 10-, 100- and 1 000-hour fuels; Table 1 details the delay time by diameter class.



Image by INFyS, 2009.

**Figure 1.** Living and dead forest fuels present in the ecosystems.

**Table 1.** Ratio of fuel diameter to delay time.

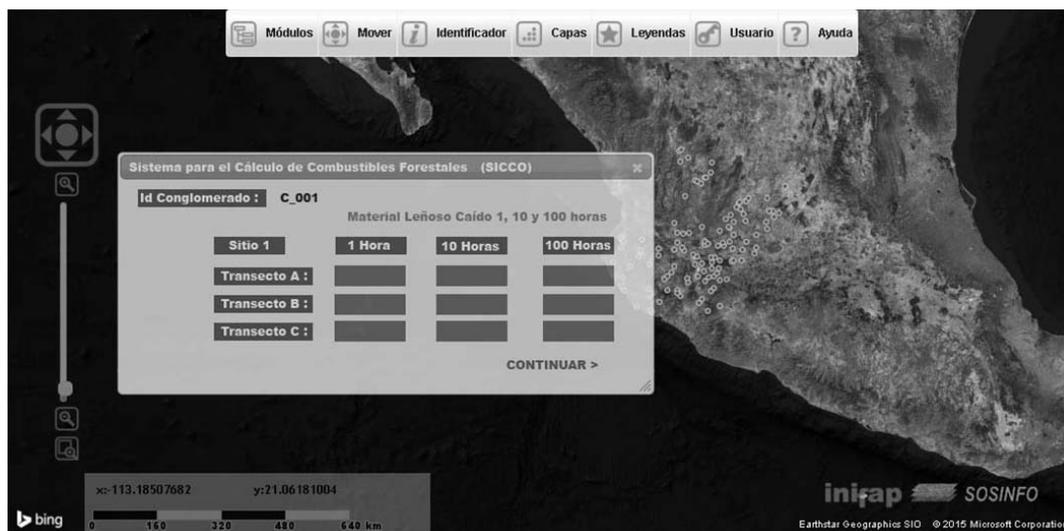
Size (cm)	Class
< 0.60	1 hour
0.61 – 2.50	10 hours
2.51 – 7.60	100 hours
> 7.61	1 000 hours

The most widespread technique for taking stock of the dead fuels is the use of *in situ* planar intersections, as described by Brown *et al.* (1982), whereby their fuel can be estimated using quick, simple procedures that can be utilized in any type of forest (Bautista *et al.*, 2005). Based on this methodological foundation, the program against forest fires of the *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias* (National Institute of Research on Forestry, Agriculture and Livestock) INIFAP) has developed a practical tool which allows estimating the amount of fuel in

a unit of area, known as Forest Fuel Evaluation System (*Sistema para el Cálculo de Combustibles Forestales*, SICCO). This was developed as a series of *Microsoft Excel™* tables (Chávez *et al.*, 2011). The file containing the spreadsheets was divided into 12 tabs, each with data input and output sections.

The system later evolved to its version 2.0, which is a standalone computer system written in the C language, in which certain inconsistencies of its predecessor were corrected and an incursion was made into the concept of Free and Open Source Software (FOSS) and Free and Open Source Software for Geospatial Conference (FOSS4G), which makes it possible to provide access to the data sources it consists of, with a license that allows the free use, study, change and improvement of the original code of the software (Moreno, 2012).

SICCO v2.0 has graphical interfaces based on WebMap technologies which use Apache Server v2.2.8 as a web server; MySQL v5.0.5 as a database manager, and Mapserver v 3.0.6 as a special data viewer (Chávez *et al.*, 2012) (Figure 2).



**Figure 2.** View of SICCO v2.0 with the WebMap interface.

Although SICCO v2.0 is a user-friendly, versatile system, it was soon overrun by the information update demands. The document titled "Characterization and quantification of forest fuels" (*Caracterización y cuantificación de combustibles forestales*) (Morfín *et al.*, 2012), which presents in a simplified manner the basic equations for estimating the load of each class of fuel described by Van Wagner (1982), was published in the year 2012. This document also includes information about the specific gravity (SG) and mean square diameter (MSD) by category of fuel diameter, type of vegetation and bioclimatic region. Morfín-Ríos *et al.* (2007) register the use of the apparent density (AD) by vegetation type and bioclimatic region for the estimations of fuel load in the form of dead leaves and fermentation, and present density tables for montane, submontane, temperate and subtropical forests (tables 2 and 3).

**Table 2.** Information about SG and MSD (Morfín *et al.*, 2012).

<b>Type of ecosystem</b>	<b>Category (hours)</b>	<b>SG (g cm<sup>-3</sup>)</b>	<b>MSD (cm<sup>2</sup>)</b>
Pine and pine-oak forest (PF-general)	1	0.54	0.2
	10	0.54	1.56
	100	0.5	16.16
	1 000 steady	0.46	140.45
	1 000 rotten	0.22	-
Pine and pine-oak forest of the subhumid temperate areas	1	0.52	0.16
	10	0.52	1.46
	100	0.5	17.07
	1 000 steady	0.46	139.58
	1 000 rotten	0.22	-

**Table 3.** Information about AD ( $\text{Mg ha}^{-1} \cdot \text{cm}$ ) for Subtropical Montane Forests (SMF) (Morfín *et al.*, 2007).

Layer	SMF 01	SMF 02	SMF 12	SMF 14	SMF 15	SMF 16	SMF 17
Dead conifer leaves	-	1.75	1.89	1.38	-	2.26	2.26
Dead broadleaf leaves	1.17	1.75	1.89	1.38	2.26	2.26	2.26
Fermentation	5.43	6.78	6.76	7.26	6.75	6.75	6.75

Given the need to have the most recent version of the source information in order to carry out accurate estimations, the SICCO system was updated to its version 3.0, which, unlike its predecessors, allows dynamic updates using relational databases. It includes libraries that draw information about SG, AD and MSD from databases contained within the system itself, and the users can customize those values according to their specific requirements.

## Materials and Methods

The Forest Fuel Evaluation System v3.0 was developed using the programming language C. One of the most important advantages of this is its great processing power and the portability of the resulting source files. *I.e.* a software developed in the C language can be executed under different platforms once minimal modifications and a simple compilation are made (Blanchette and Summerfield, 2006). Today, SICCO v3.0 can be run in both Windows and Macintosh, and therefore it has a multiplatform status.

The system hosts internally the necessary equations for estimating the dead load fuels. The following equation is used for the estimation of Fallen Woody Material (Morfín *et al.*, 2012):

$$L = ((k) * (\sum D ^2) * SG * (c))/Lt \quad (1)$$

Where:

$L$  = Fuel load (Mg ha<sup>-1</sup>)

$k$  = 1.234

$\sum D ^2$  = Sum of the square diameter of the intersected particles

$SG$  = Specific gravity (g cm<sup>-3</sup>)

$c$  = Slope correction factor

$Lt$  = Length of the transect (m)

For the 1-, 10- and 100-hour fuels, a simplification of the previous equation is used (Morfín *et al.*, 2012):

$$L = ((k) * SG * (MSD) * (f) * (c))/Lt \quad (2)$$

Where:

$L$  = 1-, 10 and 100 hour fuel load (Mg ha<sup>-1</sup>)

$k$  = 1.234

$SG$  = Specific gravity (g cm<sup>-3</sup>)

$MSD$  = Mean square diameter of each category (1, 10 y 100 hours) (cm<sup>2</sup>)

$f$  = Frequency of the intersected particles

$c$  = Slope correction factor

$Lt$  = Length of the transect (m)

The following equation is used for the slope correction factor:

$$c = \sqrt{1 + \left(\% \frac{\text{slope}}{100}\right)^2} \quad (3)$$

Where:

$c$  = Slope correction factor

The following equation is used to calculate the fermentation fuel load (Morfín *et al.*, 2012):

$$Fl = (Oe) * (AD) \quad (4)$$

Where:

$Fl$  = Fermentation fuel load ( $\text{Mg ha}^{-1}$ )

$Oe$  = Depth of the fermentation layer (cm)

$AD$  = Apparent density ( $\text{Mg ha}^{-1} * \text{cm}$ )

The following equation is used to calculate the dead leaf fuel load (Morfín *et al.*, 2012):

$$Dl = (Oi) * (DA) \quad (5)$$

Where:

$Dl$  = Dead leaf fuel load ( $\text{Mg ha}^{-1}$ )

$O_i$  = Depth of the dead leaf layer (cm)

$DA$  = Apparent density ( $\text{Mg ha}^{-1} * \text{cm}$ )

The information tables for SG, MSD and AD are stored in data structures of MySQL v5.5, which is a relational database manager and therefore adds the required flexibility and speed to the searches; furthermore, it supports a wide variety of operative systems. MySQL is a subsidiary of Sun Microsystems™ (Dubois, 2013). The fact that the information tables are kept apart from the rest of the system code makes it possible to provide SICCO with constant updates and allows the users to enter information from their study areas.

The users can enter the values of SG, MSD and AD directly or draw them from the system's databases, in which case they must correspond to the bioclimatic area and vegetation type present in the study area. These data can be assigned automatically using the location coordinates of the in-field sampled sites. For this purpose, they have integrated a set of complementary spatial databases to the system, structured using the American Standard Code for Information Interchange (ASCII) Raster (Murray, 2012). The spatial databases store the map of bioclimatic areas for the Mexican Republic developed by Chávez *et al.* (2014), as well as the map of soil use and vegetation, series IV of the *Instituto Nacional de Estadística y Geografía* (National Institute of Statistics and Geography) (Inegi, 2012).

The bioclimatic areas contained in the system area forests, shrubs, thorny shrubs, steppes and deserts in their various humidity regions (super-humid, perhumid, humid, subhumid, semi-arid, arid, perarid and super-arid); latitude regions (tropical, subtropical, temperate, cold temperate, boreal and sub-polar), and altitudinal regions (basal, pre-montane, low montane, montane, subalpine and alpine). The information regarding the use of the soil and the vegetation includes data about the forest, chaparrals, shrubs, mangroves, grasslands, rainforests, bodies of water, and agricultural and urban areas.

The information about the design of the field clusters is internally structured as “.txt” flat text files, which the users can modify according to their needs. The instructions regarding the design structure of the clusters are established in the user’s manual.

The communication between the user and the system takes place by means of an interface, which is executed in two modalities. The first is through a command terminal whose access syntax will depend on the running operative system (Windows or Macintosh). The second is through a Graphical User Interface (GUI), compiled in Qt C++ v5.5 under a general public license (GLP).

## Results and Discussion

Version 3.0 of the SICCO system has multiplatform characteristics and can be run in both the Windows and Macintosh operative systems. The system estimates forest fuel loads based on the analysis of information collected in field. It uses as input data structured in-field information structured in “.txt” flat text files and, optionally, in the “.csv” structure delimited by commas. The input files must include the number of clusters that will be processed, their location coordinates, the number of intersections in each transect for 1-, 10-,100- and 1000-hour fuels, the diameters of both steady and rotten 1000-hour fuels, as well as the depths of the dead leaf and fermentation layers. The information contained in the files must be organized according to the guidelines stipulated in the user’s manual, as shown in the example in Figure 3.

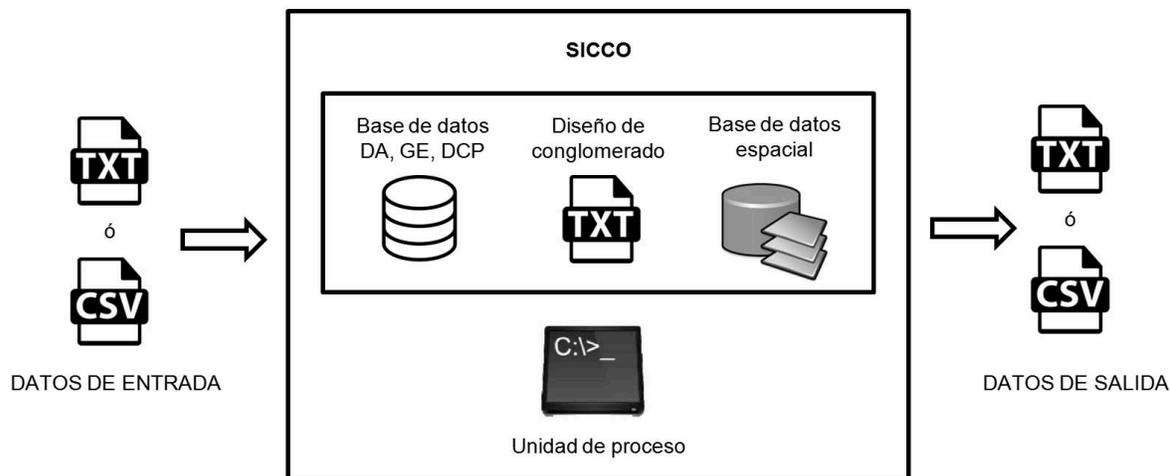
Archivo Edición Formato Ver Ayuda									
No. Congs	BD/Usuario								
Id Cong Lat	Long								
Id Sitio 1	Pendiente	1 hora	Trans 1 ...	Trans n 10 horas	Trans 1 ...	Trans n 100 horas	Trans 1 ...	Trans n	
1000 hrs F									
Trans 1 No.	Diam 1 ...	Diam n							
...	No.	Diam 1 ...	Diam n						
Trans n No.	Diam 1 ...	Diam n							
1000 hrs P									
Trans 1 No.	Diam 1 ...	Diam n							
...	No.	Diam 1 ...	Diam n						
Trans n No.	Diam 1 ...	Diam n							
Hojarasca	Trans 1 ...	Trans n	Ferment	Trans 1 ...	Trans n				
...									
Id sitio n	Pendiente	1 hora	Trans 1 ...	Trans n 10 horas	Trans 1 ...	Trans n 100 horas	Trans 1 ...	Trans n	

**Figure 3.** Structure of the “.txt” file containing the information to be processed.

SICCO v3.0 can be run from the command terminal or from the GUI (Figure 4). In order to carry out the processes, the names of the input and output files will be indicated to the system, and this will be asked to begin the calculations. Once the process is finished, the system will show as a result two output files. The first will provide the result of the calculations by site in terms of  $t\ ha^{-1}$ . The second will be a report of the processes carried out in each cluster: bioclimatic area, vegetation type, and assigned AD, MSD and SG. Likewise, inconsistencies in the processes will be pointed out, and so will processing errors, if there are any. Figure 5 exemplifies the way in which the system operates.

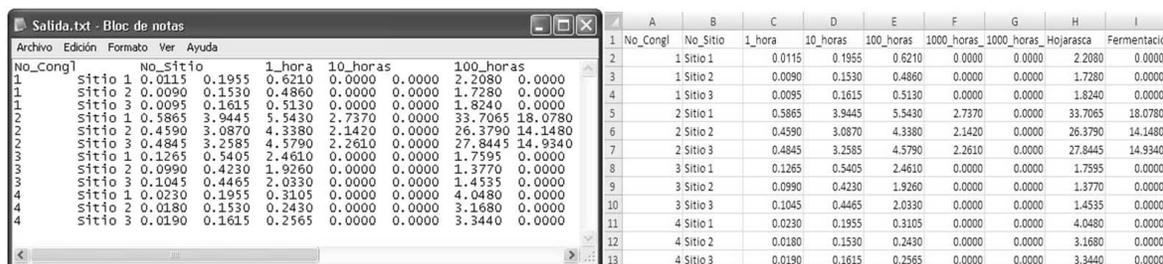


**Figure 4.** Left image: command-line user interface. Right image: GUI user interface.



**Figure 5.** General operation scheme of SICCO v3.0.

The results of the process are visualized in text editors, in spreadsheets such as Microsoft Excel™ or in statistic packages like StatisticalAnalysisSystem™ (SAS) y R™. Figure 6 shows an example.



**Figure 6.** View of the results of the process. Left image: in a text editor. Right image: on a spreadsheet.

When the processes are carried out in a totally satisfactory manner, the system specifies it at the end; conversely, if failures or anomalies occur, these are pointed out and can be revised in the output file with the report of the processes. SICCO has the capacity to estimate the fuel loads of the fallen woody material across the country, but not the dead-leaf or fermentation fuel loads. Although the information from the databases regarding the required the AD for the estimation of dead-leaf and fermentation fuels is the most up-to-date available in the literature, the data are only for temperate and montane forests. When a process is requested in areas for which no information about the AD is available and the user has not previously customized the setup values, the system will carry out the processes and will finalize these with cautions, which it will be possible to revise in the output file with the report of the processes. Figure 7 exemplifies a final file with cautions.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	No_Congl	1_hora	10_horas	100_horas	1000_horas_F	1000_horas_P	Hojari	Ferme	ZB	VEG	DA	DCP1H	DCP10H	DCP100H	GE1H	GE10H	GE100H	GE1000HF	GE1000HP
2	1	0.56	10.96	19.64	0	0	-9999	-9999	Bosque perhúmedo, subtropical piso basal	Selvas altas y medianas	** NULL	0.09	2.56	14.74	0.41	0.41	0.41	0.58	0.21
3																			
4	**	No hay disponible en la BD Información sobre DA. Es necesario que sea especificada por el usuario																	
5	-9999	No fue posible realizar el cálculo debido a carencia de información sobre DA																	

**Figure 7.** View of the output file with the process report and a caution on the lack of information regarding the AD, on a spreadsheet.

Unlike its version on Microsoft Excel™ tables, SICCO v3.0 does not require payment of exclusive licenses in order to be run. One of the most significant evolutions in relation to its version 2.0 is that it keeps the tables of information regarding apparent densities, specific gravities and mean square diameters separate from the rest of the code of the system; therefore, this information can be constantly updated. Furthermore, the users have the option of entering specific information about their study areas.

Finally, a great advantage of SICCO v3.0 in relation to its previous versions is that it allows analyzing a few tenths to up to hundreds of thousands of sites and clusters in only a few minutes. This makes it possible for the users to focus their efforts on the quality of the collected data rather than on the use of the equations and processes required for the calculations of the weights per area unit, and thus, to increase the accuracy of forest fuel management studies.

## Conclusions

The update of the Forest Fuel Evaluation System (SICCO) to its version 3.0 has made it possible to address many needs that were identified in its previous versions. One of these is the possibility to process more than one cluster –even hundreds of thousands of clusters– at a time in only a few minutes. The separation of the databases from the main processing unit makes it possible to dynamically

update the information regarding the SG, AD and MSD, and allows the users to customize their data according to their own needs in order to obtain more accurate results. SICCO v3.0 will be available for downloading at the institutional website of INIFAP once the registry of the copyrights is completed. Thus, the update of SICCO is part of the endeavors to generate simple, expedite tools that may ensure an evolution toward the adequate management of forest fires in Mexico.

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### **Conflict of interests**

The authors declare no conflict of interests.

### **Contribution by author**

Álvaro Agustín Chávez Durán: programming of the system, field data collection, data analysis, and process automatization; Jaqueline Xelhuantzi Carmona: field data collection, data analysis and review of the beta versions; Ernesto Alonso Rubio Camacho: field data collection, data analysis and review of the beta versions; José Villanueva Díaz: review of the beta versions; José Germán Flores Garnica: review of the beta versions.