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Effects of Slash-and-Burn-Farming and a Fire-Free Management on a Cambisol in a Traditional Maya Farming System

Efecto de un manejo de roza-tumba-quema y un manejo sin fuego, en suelo cambisol de un sistema de producción tradicional maya

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Abstract:

In a single study in the Yucatan Peninsula, yield and physicochemical soil properties of a traditional slash-and-burn system, milpa, were compared to a fire-free fallow management consisting in the superficial incorporation of fallow residues. In both treatments, corn, beans, and squash were associated. While corn and bean yields were equal, squash showed higher output with slash-and-burn management. Burning decreased the soil content of organic matter and plant-available N, while it increased the reserves of exchangeable K, Ca and Mg, the salinity, and the bulk density. The alternative fallow management increased the N and the organic matter reservoir in the soil. The results demonstrated that a fire-free milpa requires an additional fertilization from the first year on.

Keywords: shifting agriculture, traditional agriculture, fallow management, nutrient dynamics.

Resumen:

En un estudio anual en la Península de Yucatán, se compararon el rendimiento y las propiedades fisicoquímicas del suelo de una milpa tradicional (asociación de maíz, frijol y calabaza) con roza, tumba y quema (RTQ) con un manejo sin quema basado en la incorporación superficial de residuos de barbecho. El rendimiento de maíz y frijol fue idéntico, pero se produjo más calabaza con RTQ. La quema disminuyó el contenido del suelo de materia orgánica y de N asimilable, pero las reservas de K, Ca y Mg, la salinidad y la densidad aparente incrementaron. El manejo alternativo aumentó el contenido del suelo de N y de materia orgánica. Una milpa sin quema requiere de una fertilización adicional desde el primer año.

Palabras clave: agricultura rotativa, agricultura tradicional, manejo de barbecho, dinámica de nutrientes.

Introduction

Agroforestry, the spatial and temporal arrangement of trees and crops (Young, 1985), is still common in traditional polycropping-systems, which provide 20 percent of the global food supply (Altieri, 2009). In Mesoamerica, *milpa* is the most relevant agroforestry system. Since pre-Columbian times, it stands out for inter- and intraspecific diversity (Altieri, 2009): Maize (usually different landraces at the same time) is associated with diverse legumes (*Phaseolus vulgaris* L., *Phaseolus lunatus* L., *Vigna unguiculata* [L.] Walp.), squash (*Cucurbita maxima* Duchesne) and a number of other crops; their interaction increases the yield of each crop compared to when grown alone (Altieri *et al.,* 2011). Additionally, *milpa* counts with nutrient-enriching plants, insect predators, pollinators, nitrogen-fixing, and nitrogen-decomposing bacteria. Yet, *milpa* is more than a production system: it is intrinsically related with Maya culture (Ebel & Castillo Cocom, 2012) and thanks to its agrobiodiversity, *milpa* can adapt to differing climates (Altieri & Koohafkan, 2008).

In Mexico, this agrobiodiversity started to decrease fifty years ago, when the widespread adoption of fertilizer-responsive, high-yielding hybrids marked the beginning of the Green Revolution (Gregersen, 2003). Recently, Mexico is making an effort to get economically closer to the industrialized world by exploiting natural resources, emphasizing on agricultural exports (Altieri, 2009). A considerable part of this expansion occurs in high-biodiversity regions (Bellard *et al.,* 2012), such as the Yucatan Peninsula. There, particularly cattle farming is causing a conversion of agroforestry used land to pastures (Chargoy-Zamora, 1999). Livestock breeding and an increasing demographic pressure are generating a deforestation rate in the Maya area of Quintana Roo of 0.1 % per annum (Dupuy-Rada *et al.,* 2007).

Central to *milpa* is slash-and-burn-farming (Gliessman, 2014). This variant of shifting cultivation is characterized by a mixed farming and forest system, with a short cropping-season and an extended fallow period (Mariaca, 2011). A plot of jungle is cut, allowed to dry, and then burned. The length of the fallow period can last from two to over fifty years (Fujisaka & Escobar, 1997). This creates a landscape with plots of secondary vegetation of different ages of abandonment (Saenz-Pedroza, 2015) (table 1). Burning increases the nutrient availability; decreases the soil C:N-ratio; eliminates weeds and parasitic arthropods; creates conditions that disfavor pathogen fungi and bacteria as well as prepares the field for seeding. Finally, fire is the cheapest and fastest available tool for peasants (Gliessman, 2014). Through burning, nutrients are removed and soil organic matter decreases; during fallow, a recirculation of minerals between soil and plants causes a renewal of organic matter (Mariaca, 2011).

TABLE 1
Stages (in Maya language) of ecological succession after slashing-and-burning of a secondary dry forest used for *milpa* farming, following Saenz-Pedroza (2015) and González-Cruz *et al.* (2014), enriched with information from peasants from the Yucatan Peninsula

Stage	Meaning	Years of fallow	Description	Characteristic species
Sak'aab	Maize stalks	1-2	Dry stalks and leaves of maize and other crops, pasture, bushes, and weeds; low fertility and organic matter content; sparse mulch layer	*Viguiera dentata* (Cav.) Spreng.
Sak'aab hubche	Sprouts	2-5	Mainly sprouts of bush up to 2 m; initial O-horizon and thin A-horizon; strong presence of creepers	*Dalbergia glabra* (Mill.) Standl.
Hubche'	Underbrush	5-8	Small trees and shrubs growing beneath trees; species of former stages decreasing	*Sabal mexicana* Mart., *Brosimum alicastrum* Sw.
Ka'anal hubche	Brush	8-15	Low jungle, less lianas	*Lysiloma latisiliquum* Benth., *Bursera simaruba* Sarg.
K'aax	Jungle with canopy trees	16-30	Intermediate trees with canopy > 10 m.	*Manilkara zapota* P.Royen, *Enterolobium ciclocarpum* Griseb.
Kaabal K'aax	Tall trees	30-50	Most trees with canopy > 15 m; source of timber	*Thrinax radiata* Lodd. ex Schult. and Schult.f.

Slash-and-burn agricultural systems have received a growing attention given their alleged role in tropical deforestation (Fujisaka *et al.,* 1996). Burning (among other impacts) increases nutrient mobilization (Young, 1985) and alters soils. According to a study implemented in Campeche, Mexico, during a period of 30 years, plots with maize under slash-and-burn farming were compared with unburned jungle: In the burned soils, a (not always continuous) decrease of contents of organic matter, Mg and interchangeable Ca was observed; while the contents of P, interchangeable K, Na, Fe, Cu and Zn in the long term were higher than in the unburned plots (Medina-Méndez *et al.,* 2009). In a similar experiment in the state of Jalisco, it was observed that combustion also alters the soil structure where micro-aggregates increase (Castellanos *et* *al.,* 2001). Furthermore, biomass burning reduces biodiversity by harming living conditions for wild animals and plants (Morales, 2011). There is also a continuous risk of causing wildfires (Brady, 1996).

Another argument against burning is climate change. Due to this phenomenon, the total agricultural production in Central America could fall up to 24 % (Cline, 2007), while grain production might decrease even 30 % (Gutiérrez & Espinoza, 2010), in such a way that many farmers will search their fortune out of agriculture (ETC Group, 2009). Soils make up the World's third largest C-pool (after the ocean and rocks). The transfer of atmospheric CO_2 into the soil carbon pools is seen as a key strategy to mitigate climate change. It involves diversified and resources-efficient farming systems (Food and Agriculture Organization of the United Nations, 2015). Consequently, emitting C through burning, instead of fixing it, seems a counterproductive strategy for easing climate change.

Finally, burned soils need time to recover. On the Yucatan Peninsula, fallow periods in *milpa* traditionally lasted at least 30 years. Now, they last sixteen years at most (Castillo-Caamal *et al.,* 1998). This tendency is mainly attributed to political and economic changes, especially to an ongoing debilitation of the prevailing land grant mechanism, the ejido system (Eastmond, 1991).

No wonder there is an ongoing search for alternatives to burning in traditional farming. So far, it has brought ambiguous results, since it involves positive experience in terms of increasing biodiversity (Denevan & Padoch, 1987); however, this does not compensate for the quick mineralization and conversion of jungle into an arable field guaranteed by the use of fire; e.g. mulching the chopped fallow vegetation was proved to cause yield reductions compared to burning the biomass (Kato *et al.,* 1999). Principally, there are two approaches to fire-free fallow cleaning: slash-and-mulch, which provides a long-term nutrient release, and slash-and-incorporate, which stands for a quicker mineralization (Szott *et al.,* 1999).

Thanks to its efficiency, its low cost and easy management, slash-and-burn farming is still popular with Maya peasants. Less soil harming, fire-free managements would only be accepted if they provided similar benefits as slash-and-burn farming or offered additional advantages, such as increased soil fertility in the long term. Therefore, the aim of the present study was to compare a slash-and-incorporate management with classical slash-and-burn farming regarding their effects on main physiochemical soil properties in a *milpa* polycropping system. Furthermore, the yield provided by each management was also evaluated.

1. Materials and methods

A study, implemented in the community of José María Morelos, Quintana Roo, in the central Yucatan Peninsula, 37 m above sea level (Instituto Nacional de Estadística y Geografía, 2016), in 2013, assessed dynamics of nutrient reserves and fundamental physicochemical soil properties, comparing a classical slash-and-burn system with the incorporation of chopped plant residues; eighty days after the fallow management, *milpa* was seeded in both treatments.

There is tropical savanna climate on the limits between Köppen-Class Aw1 and Aw2. The raining season is from May to October with characteristic less rainfall in August than in July and September (Giddings & Soto, 2003). The annual precipitation is 1195 mm and the mean temperature 25.4 °C (Comisión Nacional del Agua, 2015). The analyzed soil is locally called *K'ankab*, which refers to a dark-red rhodic cambisol, typical for plains and popular for *milpa* in this region (Estrada-Medina *et al.,* 2013). Its texture is sandy loam and its original pH was 7.2. The geological base is Eocene chalk (May-Acosta & Bautista, 2005).

The trial was installed on a five years lasting natural fallow in an area surrounded by secondary tropical dry forest. There were two treatments with four replications each. Consequently, the trial field was divided into eight plots (125 m^2 each). The first treatment consisted in slash-and-burn farming. Therefore, one part of the field was slash-and burned in April 2013, following the traditional *milpa* management in the region. In the second treatment, the management was identical except for a lack of burning: After slashing, the dried biomass was chopped and incorporated to the soil surface at a depth of 0-15 cm using a tiller (table 2).

TABLE 2
Crop management activities during the implementation of the trial in 2013

Month	Activity	Slash-and-burned	Fire-free management
January-March	Cleaning	Cleaning beneath large trees *(January)* and herbs (March)	
March-April	Slashing	Cutting off all large trees, *(March)*; breaking off trunks and branches in order to accelerate the drying process	
April	Preparation	Total cleaning at an equidistance of 2 m around the field, 2 days prior to burning, to prevent that the fire escapes	Chaffing of dried biomass (woody biomass externally with a shredder; the residual on-field with a machete)
	Burning/ incorporation	Generation of fire on opposite borders of the field, so that the fire evolves to the center	Superficial incorporation (15 cm) of chopped biomass using a tiller
July	Seeding	Seeding of maize, legumes and squash together (after 2-3 intense rainfalls) in a cyclic arrangement	
July-September	Weed removal	Selective, focusing on perennials; at least every 2 weeks	
September-October	*Dobla*	Breaking of the maize-stems for reducing height- and vegetative growth, drying husks and improving soil moisture; harvesting of squash simultaneously	
September-November	Harvesting	Maize: Cobs are bent down for drying and harvested when dry; bean: Harvesting starts when 80% of the husks are dry	

As usual in this region, maize (landrace '*Nal tél*'), *Phaseolus lunatus* ('*Ib*') and squash ('*Xnuuk k'úum*') were seeded simultaneously. A dibble stick was employed to make holes at regular intervals, into which the seeds were dropped without other working of the ground (Cowgill, 1962). There were no further nutrition and disease control measures. All plots were rainfed. Weeds were removed manually and pests were monitored with a yellow sticky trap (which did not indicate the need of control).

Soil sampling took place bimonthly from February to December 2013. A grid sampling consisting of four columns at 8 m equidistance and eight rows was applied. This resulted in four sampling spots per plot. Using an auger, samples of 500 g were taken at 15 cm depth (for measuring soil organic matter) and 60 cm depth (nutrients, pH, cation exchange capacity, salinity, bulk density). For analysis, the homogenized samples were dried at 35° C in a hot-air cabinet and screened through a sieve of 2 mm porousness. Inorganic nitrogen (nitrate and ammonium) was determined spectrophotometrically (Hach DR 2800 Spectrophotometer) using the chromotropic acid extraction method (Clarke & Jennings, 1965); available phosphorous was also analyzed with spectrophotometer (Olsen *et al.,* 1954); exchangeable K, Ca and Mg were determined with flame photometer (PG Instruments FP902 Flame Photometer) using ammonium acetate (Simard, 1993); as for organic matter, the volumetric method, as described by Walkley and Black (1934), was applied. Regarding soil pH and electric conductivity (EC), a combined pH and EC meter and a 0.01 M calcium chloride solution for pH sample preparation were used. The cation exchange capacity (CEC) was measured at pH 7 with ammonium acetate (Chapman, 1965). Bulk density was determined from a core sample. Harvesting was done weekly for twelve weeks.

Statistical analysis. Normality of distribution of means was tested using the Shapiro-Wilk test. Significant differences regarding the impact of fallow management on yield and on soil properties were determined using a one-way ANOVA and a post-hoc analysis with a Tukey test ($p \leq 0.05$).

2. Results and discussion

After one cropping cycle, mineral N was highest in the fire-free treatment (table 3). The burned treatment showed a notable increase of N after burning followed by a slight decrease simultaneously to the vegetative growth of the crops, which intensified with the beginning of the raining season (figure 1). As for P, the burned treatment showed a slight increase after burning, which was reversed after seeding; the unburned treatment was continuously below the burned one (figure 2). It was observed that the intense precipitation during the raining season decreased the soil reserves of N and K in the burned treatment but not in the unburned one. This can be attributed to a higher nutrient leaching in slash-and-burn agriculture (Szott *et al.,* 1999). However, after one production cycle, soil reserves of N and P remained considerably low in both treatments. Consequently, for subsequent production cycles, these nutrients have to be provided by additional (organic or mineral) sources (Kato *et al.,* 1999). As for soil reserves of K, they increased through both treatments, but stronger through burning (figure 3): Exchangeable K rose drastically after burning and started to decrease after the first intense rainfalls; the fire-free management ended up almost 100 kg ha^{-1} below the burned variant. Regarding Ca and Mg, the alternative treatment decreased their reserves, while burning caused an increase (table 3). Yet, these nutrients are relatively abundant in the soils of the region. In this regard, nutrient availability might play a more important role than nutrient supply. A slightly alkali pH of 7.8 was measured in the burned treatment (a value, where the availability of Ca and Mg starts to decrease). This is a higher pH by trend compared to the fire-free management, which showed a pH of 7.2

Organic matter decreased 25 % through burning and continued to decline until the beginning of the raining season, when it started to flatten; the fire-free management caused a continuous increase. The burning also raised the salinity. Finally, burning increased the bulk density more severely than the alternative treatment (table 3).

TABLE 3
Nutrient reserves soil properties at 60 cm soil depth (only organic at 15 cm depth) after a field for *milpa* (initial situation) and after one *milpa* season with slash-and-burn management and with the incorporation of the chopped biomass (fire-free management)

	N†	P‡	K‡	Ca‡	Mg‡	Organic Matter	pH	Conductivity	CEC	BD§
	kg ha^{-1}	kg ha^{-1}	cmol kg^{-1}	cmol kg^{-1}	cmol kg^{-1}	%		µS cm^{-1}	cmol kg^{-1}	g L^{-1}
Initial situation	23.24	28.12	0.42	19.45	0.79	6.79	7.2	2075	29.6	680
Slash-and-burned	16.63 a*	17.28 a	0.97 a	29.19 a	0.82 a	5.16 a	7.7 a	4593 a	30.5 a	832 a
Fire-free management	35.01 b	7.56 b	0.78 a	10.5 b	0.61 b	7.25 b	7.2 a	2112 b	29.4 a	766 b

Note: † Inorganic; ‡ Exchangeable; § Bulk density; * different letters in the same column indicate significant differences ($p < 0.05$) between after a one-way ANOVA and a post-hoc analysis with a Tukey-Test ($p \leq 0.05$).

There was no impact of fallow cleaning on maize and bean yield; both managements generated a yield within the expected ranges for *milpa* in this region (Moya-García *et al.,* 2003). In contrast, squash yield was higher with slashing-and-burning (table 4).

TABLE 4
Yields of maize, squash and bean of a *milpa* after one cropping season during twelve weeks of harvesting, comparing slash-and-burn-farming and a fire-free management

	Maize	Bean	Squash
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Slash-and-burned	1598 a*	421 b	1436 c
Fire-free management	1317 a	464 b	970 d

Note: * Different letters in the same column indicate significant differences ($p < 0.05$) between after a one-way ANOVA and a post-hoc analysis with a Tukey-Test ($p \leq 0.05$).

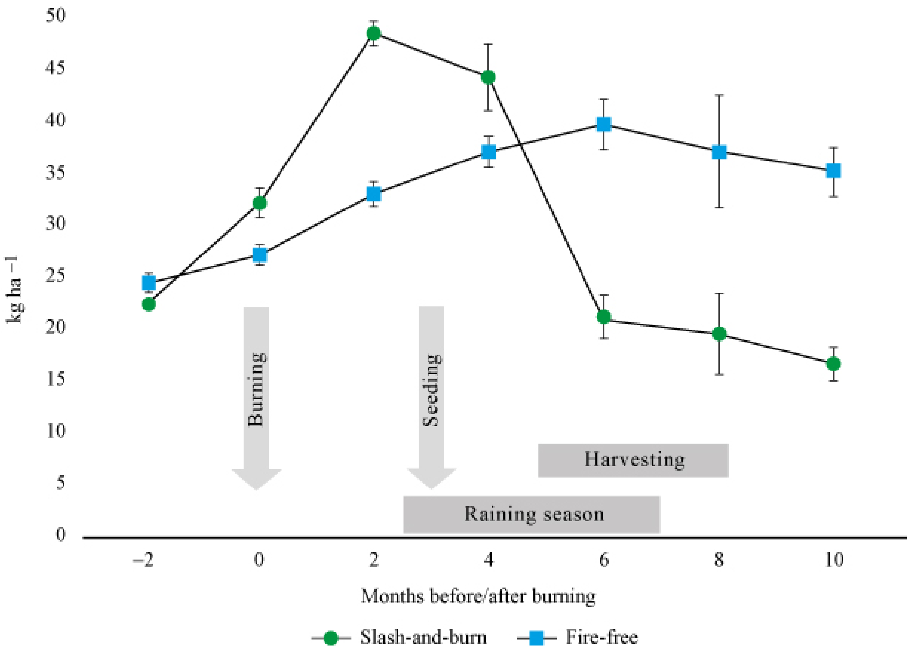

FIGURE 1
Development of soil-reserves of mineral N (ammonium and nitrate) during a *milpa* cycle, comparing slash-and-burn-farming and a fire-free management, in kg ha^{-1}

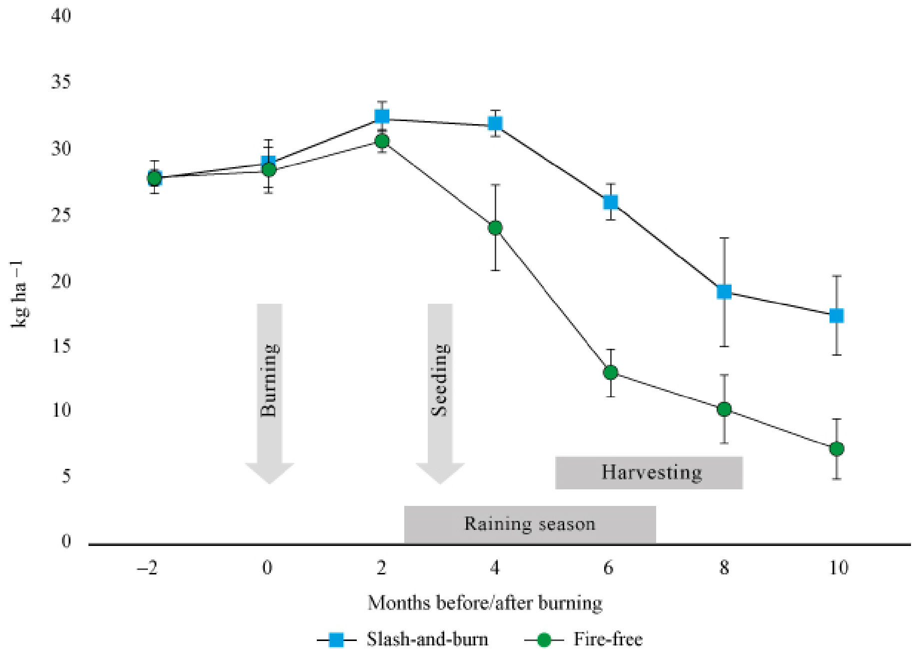

FIGURE 2
Development of soil-reserves of plant-available P during a milpa cycle, comparing slash-and-burn farming and a fire-free management, in kg ha^{-1}

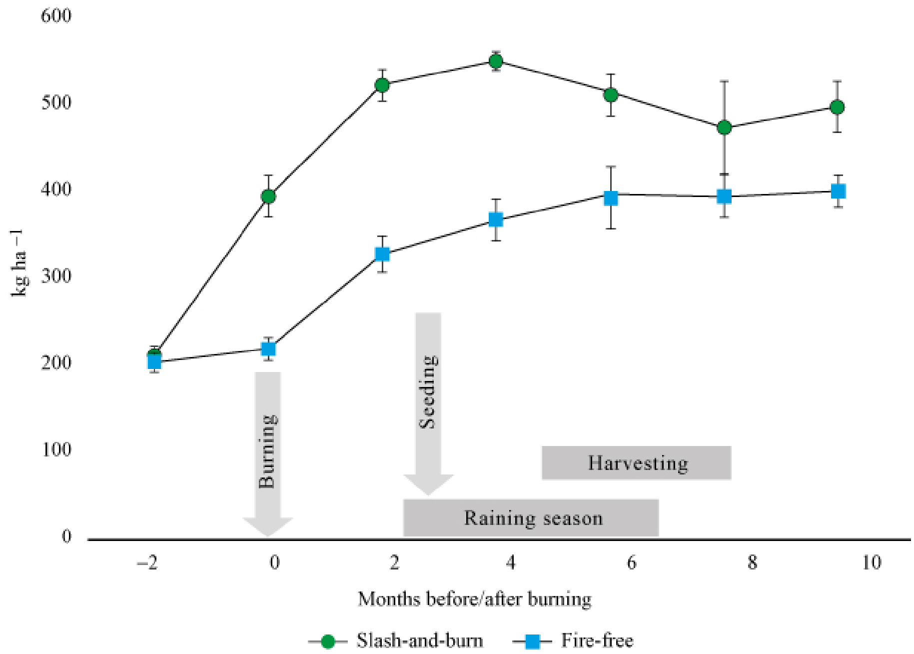

FIGURE 3
Development of soil-reserves of K during a *milpa* cycle, comparing slash-and-burn farming and a fire-free management, in kg ha^{-1}

Conclusions

Milpa has sustained the nutrition of Mesoamerican societies for centuries; and it still has the potential to provide food security and sovereignty for Maya peasants. Even more: thanks to its agrobiodiversity, *milpa* is highly resilient and adaptive to changing environmental conditions, which makes it a source of inspiration for confronting climate change. Thus, there is a need for *milpa* in the 21st century.

Milpa has been widely related with slash-and-burn farming, which today is considered an unsustainable practice that decreases soil fertility in the long term. Particularly, burning increases soil pH and drastically decreases soil organic matter, which was confirmed in the present study.

In most parts of Mesoamerica (also on the Yucatan), *milpa* is also related with land rotation, where burned soils can recover for (up to fifty) years. Due to a growing population, an increasing non-agricultural land use (urbanization, industrialization, tourism, cattle farming) and changes in land tenure, Maya peasants now count with a decreasing area of land available for farming. Consequently, fallows are getting shorter and shorter. This makes a slash-and-burned *milpa* management an unsustainable option for the future. Consequently, a sustainable preservation of *milpa* requires a fire-free management of this agrobiodiverse polycropping system.

Nonetheless, *milpa* is still popular on the Yucatan Peninsula. Apart from being a quick and inexpensive fallow cleaning measure, the use of fire also guarantees a quick mineralization of the cut residues. This circumstance is highly relevant in traditional *milpa*, whose nutrition strategy is only based on burned plant residues and on intercropping legumes. Since the most significant criticism of burning (its effect on soil pH and organic matter) and its appraisal by Maya peasants (quick soil nutrient supply) are both related to chemical and physical soil properties, the present experiment compared a slash-and-burned *milpa* with an alternative (fire-free) management based on these parameters.

It was demonstrated that regarding mineral nutrients, burning increased the reserves of cationic macronutrients (K, Ca, and Mg) compared to the incorporation of chopped residues. This was not true for N, where a converse development was observed. As for P, soil reserves after one cropping season remained low in both treatments. Noteworthily, leaching of N and K was higher in the burned treatment during the raining season.

The maize and legume yields were equal in both treatments. This means that the soil degradation through burning is not as high as to affect the output in a single cropping period. However, burning intensifies the leaching of a considerable part of the nutrient reserves; and the reduction of soil organic matter reduces the nutrient and water retention of burned soils. Without yearlong fallow periods, this development is expected to harm the soil fertility in subsequent slash-and-burn cycles. Additionally, an increased soil pH would decrease the nutrient availability. Finally, the burned soils showed higher conductivity and bulk density. Thus, burning is expected to cause a negative long-term effect on the chemical, the physical and the biological soil fertility.

In contrast, a fire-free management (consisting in the incorporation of chopped residues) resulted in a significant increase of soil organic matter and in a lower pH by trend. This makes a fire-free management a more sustainable option on fields where *milpa* is seeded without long fallow periods. Though, the supplies of most macronutrients were low during the entire cropping season. This circumstance resulted in a lower squash yield; and it would certainly decrease the yields of all crops in a subsequent *milpa*. Consequently, succeeding with a fire-free management as a measure to maintain agrobiodiversity and to guarantee healthy soils in the long term, requires an additional (preferably organic) nutrition management from the first year on.

The present (annual) study demonstrated a positive impact of a fire-free *milpa* management on soil properties, such as soil organic matter content, salinity, and bulk density. However, similar studies over longer periods are necessary to determine the long-term development of the chemical and physical soil fertility in *milpas* implemented in unburned soils. Additionally, the practical and economic viability of a fire-free management (which, compared to burning, or requires more manpower or mechanization) for small-farmers has to be explored.

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References

Altieri, M. A. (2009). Agroecology, small farms and food sovereignty. *Monthly review*, *61*(3), 102-112. doi: 10.14452/MR-061-03-2009-07_8

Altieri, M. A., Funes-Monzote, F. R., & Petersen, P. (2011). Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agronomy for Sustainable Development*, *32*(1), 3-15. doi: 10.1007/s13593-011-0065-6.

Altieri, M. A., & Koohafkan, P. (2008). *Enduring farms: Climate change, smallholders and traditional farming communities.* Penang: Third World Network.

Bellard, C., Bertelsmeier, C., Leadley, P. T., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecologicy Letters*, *15*(4), 365-377. doi: 10.1111/j.1461-0248.2011.01736.x

Brady, N. C. (1996). Alternatives to slash-and-burn: a global imperative. *Agriculture, Ecosystems and Environment*, *58*(1), 3-11. doi: 10.1016/0167-8809(96)00650-0

Castellanos, J., Jaramillo, V., Sanford, R. L., & Kauffman, J. B. (2001). Slash-and-burn effects on fine root biomass and productivity in a tropical dry forest ecosystem in Mexico. *Forest Ecology and Management*, *148*(1), 41-50. doi: 10.1016/S0378-1127(00)00523-5

Castillo-Caamal, J., Sohn, L. F. I., López-Pérez, A., & Jiménez-Osornio, J. J. (1998). *La diversidad en el funcionamiento del sistema productivo campesino en Hocabá, Yucatán.* Paper presented at the Congreso de Agrodiversidad 1998.

Chapman, H. D. (1965). Cation-exchange capacity. In C. A. Black. (Ed.), *Methods of soil analysis* (pp. 891-901). Madison: American Society of Agronomy.

Chargoy-Zamora, C. (1999). La selva agrícola tropical: un ejemplo en el sur de Quintana Roo. Red, *Gestión de Recursos Naturales*, *2*(14), 22-29.

Clarke, A. L., & Jennings, A. C. (1965). Soil analysis, spectrophotometric estimation of nitrate in soil using chromotropic acid. *Journal of Agricultural and Food Chemistry*, *13*(2), 174-176. doi: 10.1021/jf60138a023

Cline, W. (2007). *Global warming and agriculture: impact estimates by country.* Washington, DC: Center for Global Development and Peterson Institute for Economics.

Cowgill, U. (1962). An agricultural study of the southern maya lowlands. *American Anthropologist*, *64*(2), 273-286. doi: 10.1525/aa.1962.64.2.02a00030

Comisión Nacional del Agua. (2015). *Datos históricos de la estación 23003.207.* Retrieved from Servicio Metereológico Nacional: http://smn.cna.gob.mx/climatologia/Estadistica/23003.pdf

Denevan, W. M., & Padoch, C. (1987). *Swidden-fallow agroforestry in the Peruvian Amazon.* New York City: New York Botanical Garden.

Dupuy-Rada, J. M., González-Iturbe, J., Iriarte-Vivar, S., & Calvo-Irabien, L. (2007). Land-use and land-cover changes (1979-2000) in two rural communities in NW Quintana Roo, Mexico. *Investigaciones geográficas*, *62*,1-4.

Eastmond, A. (1991). Modernización agrícola y movilidad social hacia arriba en el sur de Yucatán. *Nueva Antropología*, *39*(1), 189-200.

Ebel, R., & Castillo Cocom, J. A. (2012, September). *X-Pichil: From traditional to "modern" farming in a Maya community.* Paper presented at the VIII International Conference on Sustainable Agriculture, Environment and Forestry.

Estrada-Medina, H., Bautista, F., Jiménez-Osornio, J. J. M., González-Iturbe, J. A., & Aguilar-Cordero, W. (2013). Maya and WRB soil classification in Yucatan, Mexico: Differences and similarities. ISRN *Soil Science, 2013*, 1-10. doi: 10.1155/2013/634260

ETC Group. (2009). ¿Quién nos alimentará?-Preguntas sobre la crisis climática y alimentaria. *ETC Group Comunique 102*. Retrieved from http://www.etcgroup.org/es/content/%C2%BFqui%C3%A9n-nos-alimentar%C3%A1

Food and Agriculture Organization of the United Nations. (2015). Land and water use options for climate change adaptation and mitigation in agriculture. *SOLAW Background Thematic Report*, *4*, 5-26.

Fujisaka, S., & Escobar, G. (1997). Towards a practical classification of slash-and-burn agricultural systems. Retrieved from https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/1152.pdf

Fujisaka, S., Hurtado, L., & Uribe, R. (1996). A working classification of slash-and-burn agricultural systems. *Agroforestry Systems*, *34*(2), 151-169. doi: 10.1007/BF00148159

Giddings, L., & Soto, M. (2003). *The lowland Maya area: three millennia at the human-wildland interface.* Binghampton: Haworth Press.

Gliessman, S. (2014). *Agroecology: The ecology of sustainable food systems* (3rd ed.). Boca Raton: CRC Press. doi: 10.1007/978-1-4612-3252-0

González-Cruz, G., García-Frapolli, E., Casas-Fernández, A., & Dupuy-Rada, J. M. (2014). Conocimiento tradicional maya sobre la dinámica sucesional de la selva. Un caso de estudio en la Península de Yucatán. *Etnobiología*, *12*(1), 60-66.

Gregersen, H. (2003). Crop variety improvement and its effect on productivity. In R. E. Evenson, & D. Gollin (Eds.), *Crop variety improvement and its effect on productivity - The Impact of International Agricultural Research* (pp. 8-10). Cambridge: CABI Publishing.

Gutiérrez, M. E., & Espinoza, T. (2010). *Vulnerabilidad y adaptación al cambio climático: Diagnóstico inicial, avances, vacíos y potenciales líneas de acción en Mesoamérica.* Washington, DC: Interamerican Development Bank.

Instituto Nacional de Estadística y Geografía. (2016). *México en cifras.* Retrieved from http://www3.inegi.org.mx/sistemas/mexicocifras/default.aspx?e=23

Kato, M. S., Kato, O. R., Denich, M., & Vlek, P. (1999). Fire-free alternatives to slash-and-burn for shifting cultivation in the eastern Amazon region: the role of fertilizers. *Field Crop Research*, 62(2), 225-237. doi: 10.1016/S0378-4290(99)00021-0

Mariaca, R. (2011). La milpa en el sur de México. *Ecofronteras*, *42*, 22-26.

May-Acosta, C., & Bautista, F. (2005). Colección de monolitos de suelos de la Península de Yucatán. In F. Bautista, & G. Palacio (Eds.), *Caracterización y manejo de los suelos de la península de Yucatán. Implicaciones agropecuarias, forestales y ambientales* (pp. 87-103). Campeche: Instituto Nacional de Ecología.

Medina-Méndez, V., Volke-Haller, H., Galvis-Spínola, A., & González-Ríos, J. (2009). Propiedades químicas de un Luvisol después de la conversión del bosque a la agricultura en Campeche, México. *Agronomía Mesoamericana*, *20*(2), 217-235.

Morales, J. (2011). *La agroecología en la construcción de alternativas hacia la sustentabilidad rural* (2nd ed.). Mexico City: Siglo XXI Editores.

Moya-García, X., Caamal, A., Ku-Ku, B., Chan-Xool, E., Armendáriz, I., Flores, J.,… Xool-Domínguez, J. (2003). La agricultura campesina de los mayas en Yucatán. *LEISA Revista de Agroecología*, *19*, 7-17.

Olsen, S. R., Cole, C. V., Watanabe, S. F., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium carbonate. *United States Department of Agriculture Circular*, *939*, 19.

Saenz-Pedroza, I. (2015). La milpa maya y la sucesión secundaria. *Herbolario CICY 7*(1), 35-37.

Simard, R. R. (1993). Ammonium acetate-extractable elements. In M. D. Carter (Ed.), *Soil sampling and methods of analysis* (pp. 39-42). Boca Raton: Lewis Publishers.

Szott, L. T., Palm, C., & Buresh, R. (1999). Ecosystem fertility and fallow function in the humid and subhumid tropics. *Agroforestry Systems*, *47*, 163-196.

Walkley, A., & Black, I. A. (1934). An Examination of Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. *Soil Science*, *37*(1), 29-37. doi: 10.1097/00010694-193401000-00003

Young, A. (1985). The potential of agroforestry as a practical means of sustaining soil fertility. *ICRAF Working Paper*, *34*, 4-29[A2] .