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DOCTORADO EN CIENCIAS EN CONSERVACIÓN Y APROVECHAMIENTO DE RECURSOS NATURALES

Efecto de la sedentarización de la milpa en la agrobiodiversidad y diversidad florística de bosques secundarios asociados con el bosque de niebla

TESIS QUE PARA OBTENER EL GRADO ACADÉMICO DE DOCTOR EN CIENCIAS

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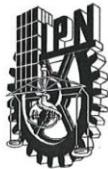
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ACTA DE REVISION DE TESIS

En la Ciudad de __Oaxaca de Juárez__ siendo las __13:00__ horas del día __24__ del mes de __noviembre__ del __2016__ se reunieron los miembros de la Comisión Revisora de Tesis designada por el Colegio de Profesores de Estudios de Posgrado e Investigación del **Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Unidad Oaxaca (CIIDIR-OAXACA)** para examinar la tesis de grado titulada: "Efecto de la sedentarización de la milpa en la agrobiodiversidad y diversidad florística de bosques secundarios asociados con el bosque de niebla"

Presentada por el alumno

Pérez	**García**	**Oscar**
Apellido paterno	materno	nombre(s)

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aspirante al grado de: **DOCTORADO EN CIENCIAS EN CONSERVACIÓN Y APROVECHAMIENTO DE RECURSOS NATURALES**

Después de intercambiar opiniones los miembros de la Comisión manifestaron *SU APROBACION DE LA TESIS*, en virtud de que satisface los requisitos señalados por las disposiciones reglamentarias vigentes.

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En la Ciudad de Oaxaca de Juárez el día 24 del mes noviembre del año 2016, el (la) que suscribe **Oscar Pérez García** alumno (a) del Programa de **DOCTORADO EN CIENCIAS EN CONSERVACIÓN Y APROVECHAMIENTO DE RECURSOS NATURALES** con número de registro B120293, adscrito al Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Unidad Oaxaca, manifiesta que es autor (a) intelectual del presente trabajo de Tesis bajo la dirección del Dr. Rafael Felipe del Castillo Sánchez y cede los derechos del trabajo titulado: **"Efecto de la sedentarización de la milpa en la agrobiodiversidad y diversidad florística de bosques secundarios asociados con el bosque de niebla"**. Al Instituto Politécnico Nacional para su difusión, con fines académicos y de investigación.

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Resumen

La milpa tradicional migratoria de roza, tumba y quema (MS) ha coexistido durante siglos con el bosque de niebla en Mesoamérica principalmente en comunidades indígenas. Este sistema agroforestal tradicional está siendo reemplazando gradualmente por un sistema moderno y semipermanente de producción de maíz (SP) que se caracteriza por la roturación frecuente del suelo, la aplicación de fertilizantes sintéticos, la eliminación del uso del fuego y periodos cortos de descanso del terreno. La Sierra Norte de Oaxaca, México es una región ideal para evaluar los cambios en la agrobiodiversidad y diversidad florística de la vegetación secundaria (acahuales), originados por el uso de estos dos sistemas, ya que podemos encontrar parcelas ambos sistemas de producción de manera cercana unas de otras en el paisaje. En esta zona, se evaluó el cambio en el sistema de producción y su relación con la conservación de la agrobiodiversidad y diversidad florística de la vegetación de acahuales de 2-3 años de edad. En la agrobiodiversidad se evaluó la composición, riqueza y estructura de cultivos y las arvenses asociadas. En los acahuales se evaluó la composición, riqueza y diversidad de plantas vasculares. También se analizó la relación que mantiene la riqueza y densidad de la vegetación de los acahuales con la proporción de bosques colindantes circundantes. Para esto, se establecieron parcelas temporales para el muestreo de cultivos y arvenses, y la vegetación de acahuales en una franja altitudinal entre 1400 y 1900 m.s.n.m. En esta franja se practican indistintamente tanto la agricultura migratoria como el sistema semipermanente de producción.

En la agrobiodiversidad de terrenos cultivados, el maíz Nal-Tel de altura (*Zea mays* L.) fue la única raza de maíz predominante con tres variedades, amarilla, blanca y azul. Sin embargo, en MS, el maíz nativo estuvo asociado normalmente con frijoles trepadores (*Phaseolus coccineus* L. y/o *P. vulgaris* L.) y con una significativa presencia de maíz amarillo. Además, MS albergó el maíz azul, una variedad poco común en la zona de estudio. En contraste, en SP predominó el monocultivo de maíz con una alta densidad de siembra y una significativa presencia de maíz blanco. El cambio en el sistema de producción alteró drásticamente la composición, riqueza, densidad y cobertura total de arvenses. Las parcelas de MS y SP fueron claramente separadas en dos conglomerados de especies de arvenses. En MS, la densidad de arvenses perennes fue alta, la cobertura total arvenses fue baja, y el helecho *Pteridium aquilinum* resultó como especie indicadora. En contraste, SP mostró una alta riqueza y densidad de arvenses anuales, una alta cobertura, y varias especies de arvenses anuales de la familia Asteraceae resultaron como indicadoras.

En la vegetación de acahuales, la composición de especies de árboles y hierbas difirió en los dos sistemas de producción. Las parcelas de MS y SP tanto de árboles como de hierbas fueron claramente

separadas en dos conglomerados respectivamente. Varias especies arbóreas sucesionales pioneras, intermedias y tardías resultaron como indicadoras de MS. En contraste, en SP, varias especies nativas de herbáceas principalmente pastos y hierbas perennes resultaron como indicadoras. La composición de especies de arbustos, bejucos y plántulas de árboles fue similar en los dos sistemas de producción. La riqueza y diversidad de especies de árboles, plántulas de árboles, arbustos y bejucos fue mayor en acahuales de MS; mientras la riqueza y diversidad de herbáceas fue similar en los acahuales de MS y SP. El empobrecimiento de la vegetación de acahuales en SP puede ser aminorada con la presencia circundante de bosques mayores de 20 años de edad. A medida que se incrementó la proporción circundante de estos bosques en particular alrededor de los acahuales, aumentó significativamente la riqueza y densidad de plántulas de árboles en los acahuales de SP. En los acahuales de MS, solo se incrementó la riqueza de plántulas de árboles, y la densidad correspondiente se mantuvo constante con los bosques mayores de 20 años de edad.

Se concluye que la sustitución de la milpa migratoria por el sistema semipermanente de producción puede acelerar la pérdida de frijoles trepadores, maíces pigmentados, arvenses perennes y acahuales arbóreos, e incrementar el monocultivo de maíz, la infestación de arvenses anuales y la permanencia de acahuales herbáceos. Por lo tanto, la sustitución de la milpa migratoria por un sistema semipermanente no solo puede reducir la agrobiodiversidad, la diversidad florística de acahuales y la capacidad de la los acahuales para la regeneración del bosque, sino que también aumenta el riesgo de degradación de los medios de subsistencia de las comunidades indígenas del bosque de niebla mesoamericano.

Palabras clave: Acahuales jóvenes, Arvenses, Legado del uso del suelo, Milpa tradicional migratoria, Monocultivo de maíz, Regeneración forestal, Sucesión secundaria.

Abstract

The milpa shifting cultivation agriculture (MS) has coexisted for centuries with tropical montane cloud forests (TMCF) in Mesoamerican indigenous communities. This traditional agroforestry system has being substituted by a modern and semi-permanent system of maize cultivation (SP), characterized by tillage, fire suppression, application of synthetic fertilizers, and short fallow periods. The TMCF area of Sierra Norte, Oaxaca, Mexico is ideal to explore the changes of agrobiodiversity and fallows' vegetation since both MS and SP systems are intermixed in the landscape. In this area, we studied the relationship between the changes in cropping system with the maintenance of agrobiodiversity and floristic diversity of fallows' vegetation of 2-3 years old. We evaluated the composition, richness, and diversity of crop and weed species. Also, we evaluated the composition, richness, and diversity of vascular plants of fallows' vegetation. In addition, we explored the relationship between the fallows' vegetation richness and density with the cropping systems and the proportion of forest surrounding the fallows. The assessment of the agrobiodiversity and vegetation of fallows was conducted in temporary plots at an altitudinal range between 1400 to 1900 m a.s.l. In this range is practiced both MS and SP cropping systems.

In the agrobiodiversity of cultivated plots, we detected that the native maize Nal-Tel de altura (*Zea mays* L.) was the predominant maize landrace in the study area with tree varieties, yellow, white, and blue. However, in MS, maize was often intercropped with climbing bean species (*Phaseolus coccineus* L. and/or *P. vulgaris* L.) with a significant presence of yellow maize. In addition, this system harbored the rare blue maize variety. By contrast, in SP, the monoculture of maize at higher density was common with a significant presence of the white maize variety. The shift of cropping systems altered drastically the composition, richness, density, and cover of weeds. The plots of MS and SP were clearly separated into two clusters of weed species. In MS, the density of perennial weeds was higher, the total weed cover was lower, and the bracken-fern was the indicator species. Contrastingly, SP displayed a higher richness and density of annual weed species, a high weed cover, and several annuals, mostly Asteraceae, were the indicator species.

In fallows' vegetation, we found that the tree and herb species composition was clearly separated into two clusters respectively, one belonging to MS and the other to SP. Several pioneer, middle, and late-successional tree species were distinctive of MS fallows, whereas, several native perennial grass and forb species were distinctive of SP fallows. The species composition of the other life forms could not be separated based on the cropping systems. The species richness and diversity of trees, tree seedlings, shrubs, and vines were higher in MS fallows; whereas the richness and diversity of herbs was similar in

MS and SP fallows. In MS and SP, the richness of tree seedlings increased with the proportion of adjoining forestlands if they were older than 20 years, but not with forestlands younger than 20 years old. Also, tree seedling density increased with the proportion of forestlands older than 20 years adjoining the fallows in SP but not in MS.

We concluded that the substitution of milpa shifting cultivation by a semi-permanent system may accelerates the decline of climbing beans, colored maize, perennial weeds, and forest fallows, by favoring maize monoculture, the infestation of the crop fields by annual weeds, and the prevalence of herbaceous fallows. Therefore, banning of shifting cultivation by the implementation of a semi-permanent system not only can decline the agrobiodiversity, the floristic diversity of fallows, and the capacity of early fallows for forest regeneration, but also increase the risk of degradation of the livelihoods of indigenous communities of the Mesoamerican cloud forest.

Keywords: Forest restoration, Land-use legacy, Maize monoculture, Milpa shifting cultivation, Secondary succession, Weeds, Young fallows.

Dedicatoria

A mi esposa Martha

A mis hijos Osmar y Jabel

A mis padres queridos: Medardo y Josefina

A mis hermanos Suilma, July y Cuauhtémoc

A mis sobrinas: Yasidh, Paola, Angélica, Karla, Irene, Yussara y Mariana

A mi sobrino Benjamín

Contenido

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Índice de cuadros

Introducción general

La presente investigación aborda la problemática global del cambio de uso del suelo por la intensificación de la agricultura y su expansión en los bosques tropicales (Jackson et al., 2005; van Vliet et al., 2012). En particular, la sustitución de sistemas agroforestales tradicionales por sistemas agrícolas modernos en los centros de origen y diversificación de cultivos que han coexistido con los bosques tropicales merecen atención especial debido a que es una amenaza para la biodiversidad ligada a culturas ancestrales (Rerkasem et al., 2009; Xu et al., 2009). En Mesoamérica, la milpa migratoria de roza, tumba y quema (RTQ) como sistema agrícola tradicional ha coexistido con uno de los ecosistemas tropicales de mayor biodiversidad y vulnerabilidad al cambio de uso del suelo como lo es el bosque de niebla (Van der Wal, 1999; del Castillo y Blanco-Macías, 2007; Ramos-García, 2007). Por ser un sistema agroforestal secuencial, la milpa tradicional se compone de una fase agrícola temporal de bajo impacto a los suelos forestales y una fase de recuperación del bosque (Watters, 1971; Ribeiro-Filho et al., 2013). De esta manera, este sistema genera una gran cantidad de servicios ambientales, ya que no solo genera la producción de alimentos a las poblaciones locales sino también son reservorios de una gran diversidad genética de cultivos básicos como el maíz y el frijol (Ortega-Paczka, 2003; Finegan y Nasi, 2004). Además, durante la etapa de regeneración de la vegetación generalmente leñosa, las áreas en regeneración forman un mosaico de terrenos recientemente abandonados y bosques secundarios de diferente edad y composición florística conocidos coloquialmente como 'acahuales' (Van der Wal, 1999; del Castillo y Blanco-Macías, 2007; Ochoa-Gaona et al., 2007).

Sin embargo, debido a nuevas políticas ambientales locales motivadas por incentivos económicos gubernamentales, el sistema milpa está siendo reemplazado por un sistema semipermanente de producción de maíz bajo el esquema de la agricultura moderna o convencional (Ibarra et al., 2011; Martin et al., 2011). El proceso de cambio de sistemas agrícolas tradicionales migratorios hacia sistemas más permanentes de producción es conocido como sedentarización de la agricultura (Dounias et al., 2007; Lu et al., 2009; Fan et al., 2014; Hagmann et al., 2015). De acuerdo con la tendencia

global de la sustitución de la agricultura migratoria por sistemas agrícolas permanentes (van Vliet et al., 2012), este es un cambio peculiar de uso del suelo ya que las parcelas con maíz nativo y acahuales persisten en el paisaje pero bajo un sistema de producción agrícola diferente. En contraste con el sistema milpa, el sistema semipermanente consiste en el uso agrícola prolongado y periodos muy cortos de descanso del terreno (González, 2001; Ramos-García, 2007). Este nuevo sistema de producción requiere laboreo del suelo con arado de tracción animal y herramientas manuales para la preparación del terreno y control de arvenses. Además, para asegurar la producción continua se recurre al uso de fertilizantes sintéticos (Kreitlow, 2005; Ramos-García, 2007).

Los efectos de este peculiar cambio de uso del suelo en la agrobiodiversidad y diversidad florística de acahuales en el bosque de niebla y centro de origen de cultivos mesoamericano no han sido estudiados. La sustitución de la milpa tradicional por el sistema semipermanente presupone importantes cambios en la agrobiodiversidad y vegetación de acahuales. Esta sustitución de sistemas de producción agrícola ha sido gradual en algunas partes de Mesoamérica. En este sentido, en el bosque de niebla de la Sierra Norte de Oaxaca, México, aún podemos encontrar parcelas de los dos sistemas agrícolas cercanas unas de otras y bajo condiciones ecológicas similares (Romero-Razo, 1998, Vásquez-Pascual, 2012). Por lo tanto, esta región es ideal para estudiar como este cambio de sistema de producción afecta la diversidad de cultivos y la diversidad florística de la vegetación de acahuales. Por tal motivo, la presente investigación aborda esta problemática en dos capítulos. El primer capítulo se trata del cambio en el sistema de producción agrícola de cultivos básicos y su relación con la conservación de la agrobiodiversidad a escala de especies y dentro de las especies de cultivos, incluyendo la diversidad asociada de especies de arvenses. Por otra parte, el segundo capítulo de la investigación ligada al cambio en el sistema de producción agrícola se enfoca en la comparación de la diversidad florística de la vegetación resultante de los acahuales de los dos sistemas de producción agrícola.

1. Antecedentes

La región geográfica Mesoamérica en donde se practica la milpa migratoria tradicional pertenece a las naciones megadiversas del mundo (Mittermeier et al., 1997). La biodiversidad de esta región es el resultado de la confluencia de las regiones biogeográficas neotropical y neartica, además de la diversidad de hábitats y culturas ancestrales que han configurado la biodiversidad manejada y asociada de los agroecosistemas tradicionales (Boege, 2008, Piperno, 2011). La máxima evidencia de la confluencia de los factores ambientales y las culturales en la biodiversidad de Mesoamérica fue la domesticación del maíz, frijol y calabaza y su manejo integrado a través del sistema milpa (Boege, 2008). La milpa migratoria de roza, tumba y quema es uno de los sistemas ancestrales de producción que actualmente se practican en los bosques tropicales de Mesoamérica (Aguilar et al., 2003). En estas áreas, se conjugan tanto especies domesticadas como especies silvestres de hierbas, arbustos y árboles (Van der Wal, 1999; Ochoa-Gaona et al., 2007; del Castillo y Blanco-Macías, 2007; Schmook et al., 2013). Por lo mismo, esta zona forma parte de los centros de origen y diversificación de cultivos y de gran importancia como reservorios genéticos para la agricultura y la alimentación mundial (Engels et al., 2006; Piperno, 2011).

La milpa migratoria en el bosque de niebla

Definición de la milpa migratoria

La milpa migratoria de roza, tumba y quema (RTQ) es un sistema de producción agrícola ancestral que se practica en la actualidad en áreas remotas tanto en zonas tropicales como subtropicales de Mesoamérica (Van der Wal, 1999; Ochoa-Gaona et al., 2007; del Castillo y Blanco-Macías, 2007; Schmook et al., 2013). La milpa tradicional es practicada por pequeños productores de diversos grupos étnicos y se caracteriza por ser una agricultura de subsistencia generalmente para el autoconsumo (Boege, 2008).

El sistema milpa de RTQ, similar a otros sistemas tradicionales de RTQ, consiste en la eliminación de una porción relativamente pequeña de bosque secundario maduro para su posterior quema (Watters, 1971). Las cenizas y la materia orgánica acumulada en el suelo son las principales fuentes de nutrición

para los cultivos nativos básicos que son el maíz (*Zea mays*) asociado con frijol (*Phaseolus* spp.) y calabaza (*Cucurbita* spp.) durante un periodo relativamente corto (1 a 3 años). Cuando la fertilidad del suelo declina y la incidencia de malezas es cada vez mayor, el terreno se deja en descanso para la recuperación de la vegetación secundaria leñosa denominada coloquialmente como acahuales (Ochoa-Gaona et al., 2007). El objetivo de la vegetación secundaria o acahuales es la eliminación de la maleza mediante la sombra y competencia que generan las especies arbóreas (de Rouw, 1995). Otra finalidad de los acahuales es la recuperación de la fertilidad del suelo mediante la acumulación de materia orgánica tanto en el suelo como en la biomasa aérea de la vegetación (Kleinman et al., 1995). La fase de descanso o desarrollo de acahuales puede durar generalmente más de una década (Watters, 1971). Un vez que los acahuales acumulan suficiente biomasa en la vegetación y materia orgánica en el suelo, y la eliminación evidente de la maleza, se inicia nuevamente el ciclo de la milpa con la eliminación del bosque secundario (Van der Wal, 1999; del Castillo y Blanco Macías, 2007). Durante la fase de descanso de los terrenos, se buscan y seleccionan nuevas áreas de bosque para asegurar la continuidad de la producción de maíz y cultivos asociados. Este sistema es viable y se ha mantenido en zonas marginales o aisladas que generalmente coincide con las zonas boscosas habitadas por grupos indígenas en pequeñas localidades dispersas (Van der Wal, 1999; del Castillo y Blanco Macías, 2007; van Vliet et al., 2012).

Al igual que otros sistemas de agricultura migratoria tradicional, la milpa de RTQ es considerado un sistema de producción agrícola sustentable porque no depende de insumos externos (Kleinman et al., 1995). Las semillas nativas utilizadas provienen de las cosechas locales y no se emplea ninguna clase de insumos sintéticos para la producción agrícola (Ortega-Paczka, 2003). Además, la erosión del suelo y la deforestación son temporales y menos severas en la agricultura migratoria que los generados de forma permanente por la agricultura moderna (Ribeiro-Filho et al., 2013).

La agrobiodiversidad de la milpa migratoria

La agrobiodiversidad es la variedad y variabilidad de organismos vivos que contribuyen a la producción de alimentos y a la agricultura (Jackson et al., 2005; Jackson et al., 2007). Esto incluye tanto a las especies domesticadas manejadas por los agricultores como a las especies silvestres asociadas que colonizan los agroecosistemas. En este sentido, debido a que la milpa migratoria se originó y se practica en un importante centro de domesticación de cultivos básicos, este sistema alberga una gran diversidad de cultivos de maíz, frijol y calabaza a escala de especies y dentro de las especies (Aguilar et al., 2003; Ortega-Paczka, 2003). Esta diversidad de cultivos manejada bajo el esquema de policultivos ha coevolucionado con las arvenses (o mal llamadas malezas) que son de gran importancia alimenticia, medicinal, forrajera y ritual para las poblaciones indígenas y rurales (Finegan y Nasi, 2004).

El bosque de niebla bajo manejo agroforestal de milpa migratoria

La milpa migratoria de RTQ ha coexistido con uno de los ecosistemas tropicales de mayor biodiversidad en el mundo como lo es el bosque de niebla (Van der Wal, 1999; del Castillo y Blanco-Macías, 2007; Ramos-García, 2007). El bosque de niebla presenta una distribución restringida y discontinua en las zonas montañosas cercanas a las costas en la franja intertropical del mundo (Bruijnzeel et al., 2010; Jarvis y Mulligan, 2010). A pesar de que este ecosistema ocupa un área potencial de 2.5% de la superficie total de los bosques tropicales del mundo, en este ecosistema se incrementa la diversidad florística, particularmente a elevaciones intermedias entre los 500 y 2000 msnm (Gentry, 1995; Rzedowski, 1996; Bubb et al., 2004). Así mismo, la diversidad, abundancia y dominancia de plantas epifitas se incrementa en relación con otros bosques tropicales (Frahm y Gradstein, 1991; Zotz, 1999; Nieder et al., 2001). También, entre los bosques tropicales, el número de especies endémicas es mayor en los bosques de niebla (Kessler y Kluge, 2008; Martin y Bellingham, 2016).

Además del aislamiento geográfico por las cadenas montañosas, los eventos de perturbación moderada tanto de origen natural como antropogénica contribuyen al endemismo y biodiversidad de

especies en el bosque de niebla (Kessler y Kluge, 2008; del Castillo et al., 2009; Crausbay y Martin, 2016). Se ha evidenciado en el Neotrópico que el endemismo de especies se presenta con mayor frecuencia en etapas sucesionales iniciales y tardías del bosque después de un evento de perturbación (Kessler y Kluge, 2008; del Castillo et al., 2009). Lo anterior asociado a que muchas especies están adaptadas a eventos de perturbación como los deslizamientos de tierra y la agricultura tradicional migratoria de RTQ (Kessler, 1999; del Castillo y Blanco-Macías, 2007; del Castillo et al., 2009; Robson y Berkes, 2011; Crausbay y Martin, 2016).

Por la naturaleza itinerante de la milpa migratoria de RTQ y la dinámica espacial y temporal de uso de la tierra en el bosque de niebla, se genera un paisaje heterogéneo de mosaicos integrados por áreas de bosques secundarios de diferentes etapas sucesionales, zonas agrícolas activas y bosques primarios (del Castillo y Blanco-Macías, 2007; Robson y Berkes, 2011). Estos paisajes con alta heterogeneidad ambiental son considerados como de alta diversidad biológica en comparación con paisajes homogéneos o simples (Finegan y Nasi, 2004; del Castillo y Blanco-Macías, 2007). Esto relacionado principalmente a que las etapas sucesionales de la vegetación contrastantes en edad difieren en la composición de especies, y como consecuencia una diversidad beta alta (del Castillo, 2015). Por lo tanto, la biodiversidad a escala de paisaje en el área del bosque de niebla mesoamericano es el resultado del manejo tradicional de la milpa migratoria de RTQ en los bosques por las culturas locales (del Castillo y Blanco-Macías, 2007; Robson y Berkes, 2011).

La modernización de la agricultura en zonas de milpa migratoria

La agricultura moderna en el mundo inicia con la revolución verde, en tanto que en México inicia en la década de los 40's (Sonnenfeld, 1992). El uso de semillas híbridas, el fomento de monocultivos, la mecanización y el uso de agroquímicos y energía fósil son los componentes principales de la agricultura moderna. Todo esto con la única finalidad de incrementar el rendimiento de ciertos cultivos básicos como el trigo y el maíz. La modernización de la agricultura en México ha prosperado en regiones susceptibles a la mecanización e irrigación bajo el esquema de la agricultura empresarial a

gran escala (Aguilar et al., 2003). Desde entonces, diversos programas gubernamentales focalizaron sus objetivos de modernización hacia las zonas de agricultura campesina e indígena (Aguilar et al., 2003; Kreitlow, 2005).

La modernización de la agricultura tradicional en zonas de milpa migratoria de RTQ inicia en los 70's en la Sierra Norte de Puebla (Kreitlow, 2005). Desde entonces, la mayoría de los programas se ha enfocado en la sustitución del sistema tradicional de milpa por paquetes tecnológicos propios de la revolución verde (Aguilar et al., 2003; Vielle-Calzada y Padilla, 2009). Sin embargo, la adopción de la agricultura moderna por los campesinos e indígenas ha sido parcial (Kreitlow, 2005; Ramos-García, 2007; González-Amaro et al., 2009). Básicamente se han adoptado algunos componentes de la revolución verde tales como la producción continua en un mismo terreno (o sedentarización), la roturación del suelo, el uso de fertilizantes sintéticos y en algunos casos la aplicación de herbicidas (Kreitlow, 2005; Ramos-García, 2007). Llama la atención la resistencia de las localidades indígenas a la adopción de semillas híbridas de maíz (Brush y Perales, 2007; Ramos-García, 2007). Kreitlow (2005) ha documentado que una de las razones principales al rechazo de semillas mejoradas es su periódica compra con comercializadoras de insumos agrícolas. Otra razón ha sido la desventaja de adaptación y productividad de los maíces mejorados frente a las razas nativas de maíz producidas y adaptadas localmente.

Las zonas en donde ha sido difícil la promoción de la agricultura moderna son las zonas marginadas de difícil acceso como áreas montañosas y selváticas remotas del país (Van der Wal, 1999; del Castillo y Blanco Macías, 2007; Moreno-Calles et al., 2013). Estas áreas representan los últimos reservorios de la agricultura tradicional de milpa migratoria y biodiversidad correspondiente altamente amenazada por la programas de modernización agrícola (Boege, 2008).

2. Objetivos e hipótesis

Objetivo general

7

Evaluar la relación que existe entre la sustitución gradual de la milpa migratoria por un sistema semipermanente de producción en la agrobiodiversidad y diversidad florística de acahuales en una zona de bosque de niebla de la Sierra Norte de Oaxaca, México.

Objetivos específicos

Determinar que cultivos (especies y variedades) y arvenses se están fomentando con el cambio en la manera de producir cultivos básicos en una zona importante de domesticación y diversificación de cultivos.

Evaluar la diversidad florística de la vegetación de la sucesión secundaria inicial de acahuales derivados de la milpa migratoria y del sistema semipermanente de producción en una zona importante de bosque de niebla.

Hipótesis

Hipótesis 1

La sustitución de la milpa migratoria tradicional por un sistema permanente de producción favorece la simplificación del agroecosistema debido a que solo se fomenta el monocultivo del maíz y la presencia de arvenses anuales. Esto asociado a que la adopción de ciertos elementos de la agricultura moderna en el nuevo sistema de producción impide el manejo diversificado y asociado de cultivos y arvenses de vida larga.

Hipótesis 2

La sustitución de la milpa migratoria tradicional por un sistema permanente de producción puede modificar la composición de la vegetación secundaria de acahuales iniciales y disminuir la riqueza y diversidad de árboles, arbustos y bejucos. Esto asociado a que el laboreo del suelo y cultivo frecuentes en el nuevo sistema puede erradicar cualquier propágulo de árboles, arbustos y bejucos y fomentar el

establecimiento de herbáceas en los acahuales (de Rouw, 1993; de Rouw, 2001). Sin embargo, la presencia de bosques maduros circundantes puede aminorar la simplificación de la vegetación de los acahuales mediante la aportación de semillas de especies arbóreas (del Castillo and Pérez-Ríos, 2008). De esta manera, se espera que la provisión de semillas arbóreas sea más importante para los acahuales del nuevo sistema de producción que para el sistema de milpa tradicional. Por lo tanto, se espera que la riqueza y abundancia de plántulas de árboles en los acahuales de nuevo sistema se incremente con la proporción de bosques maduros circundantes.

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Capítulo 1. The decline of the itinerant milpa and the maintenance of traditional agrobiodiversity: Crops and weeds coexistence in a tropical cloud forest area in Oaxaca, Mexico

The decline of the itinerant milpa and the maintenance of traditional agrobiodiversity: Crops and weeds coexistence in a tropical cloud forest area in Oaxaca, Mexico

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A B S T R A C T

The Mesoamerican *milpa* shifting cultivation (MS), characterized by slash-and-burn practices and long fallow periods, has being substituted by a semi-permanent system (SP), characterized by fire suppression, tilling, the application of synthetic fertilizers, and shorter fallow periods. We compared the composition, richness, and structure of crops and weed species associated with these two cultivation systems in a tropical montane cloud forest area in Sierra Norte, Oaxaca, Mexico. We studied how such changes are associated with crop species and varieties, weed life-cycle, and weed cover. We could detect three maize varieties of the local maize landraces (*Zea mays* L.) in MS, and only two in SP. The yellow variety was the indicator crop of MS, while the white variety was that of SP. In MS, maize density was lower but often intercropped with climbing bean species, whereas in SP, maize monoculture was common. The shift of cropping systems altered drastically the composition, richness, density, and cover of weeds. The plots of MS and SP were clearly separated in two clusters of weed species. In MS, the density of perennial weeds was higher, the total weed cover was lower, and the bracken-fern was the indicator species. Contrastingly, SP displayed a higher richness and density of annual weed species, a high weed cover, and several annuals, mostly Asteraceae, were the indicator species. We conclude that MS is a better reservoir of agrobiodiversity, and its substitution may accelerate the decline of climbing beans, maize varieties, and perennial weeds, by favoring maize monoculture and the infestation of the crop fields by annual weeds. Banning of shifting cultivation in indigenous communities can contribute to the decline of agrobiodiversity, reduce the nutritional apportionment of the crops to the local people, and favor land degradation by weed-infestation.

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1. Introduction

Shifting cultivation is an ancient agricultural system currently practiced in marginal areas in the tropics (van Vliet et al., 2012). Compared with the modern shifting cultivation practiced by colonizers, the traditional shifting cultivation consists in the slash-and-burn of a small piece of forested land (Watters, 1971). The resulted ashes and soil organic matter are the main source of nutrients for growing food crops in polyculture, usually during few years (1–3 years). Weed infestation and soil depletion are indicators to leave the fields in fallow for decades for forest and soil regeneration (Watters, 1971; de Rouw, 1995). During the fallow stage, cultivation is started in other pieces of forest land to ensure the continuity of crop production. Traditional shifting cultivation is considered a sustainable agro-forestry system because it does not depend upon external inputs (Kleinman et al., 1995). Soil erosion and permanent deforestation tend to be less severe in comparison with more intensive agricultural systems. The *milpa* system is the most remarkable shifting cultivation in Mesoamerican tropical areas. This system harbor important landraces of maize (*Zea mays* L.), bean (*Phaseolus* spp.), and squash (*Cucurbita* spp.), which have been domesticated and diversified in this region (Watters, 1971). Indeed, maize diversification and the coexistence of important non-crop and non-timber species in the weedy vegetation appear to be closely associated with the *milpa* system (Ortega-Paczka, 2003; Finegan and Nasi, 2004). In contrast to modern cultivation systems, such weed species are usually of great value to the

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farmers (Chacón and Gliessman, 1982), and seeds for the next cropping period are obtained by selection of locally harvested seeds (Ortega-Paczka, 2003). As such, the *milpa* system plays an important role in preserving agrobiodiversity.

The replacement of shifting cultivation by intensive agriculture practices and its expansion into tropical forest areas is a global trend (van Vliet et al., 2012). The consequences of such a substitution are expected to be multifarious. Agrobiodiversity, in particular, is expected to decline with such changes (Finegan and Nasi, 2004; van Vliet et al., 2012). The risk is higher for centers of origin and diversification of cultivated plants as has been demonstrated with the loss of several traditional varieties of rice in Southeast Asia (Rerkasem et al., 2009; Xu et al., 2009). In Mesoamerica, the *milpa* shifting cultivation (MS) is being replaced by more sedentary agricultural systems, but the effects of such a substitution in agrobiodiversity have been little explored in particular in tropical mountainous areas (van Vliet et al., 2012). The Sierra Norte, in the southern state of Oaxaca, Mexico is one of the regions were such a substitution is taking place (González, 2001; Ramos-García, 2007). MS is being gradually substituted by a more semi-permanent system (SP) of native maize production, hereinafter referred to as 'milpa sedentarization'. SP consists in cultivation of maize on the same piece of land. In contrast to MS, SP requires soil tillage, weed hoeing, and the use of synthetic fertilizers. MS substitution by SP was implemented due to local regulations initiated in the early 2000s and motivated by government economic incentives purportedly to protect forest areas (Ibarra et al., 2011; Martin et al., 2011).

The shift of maize-based cropping systems presupposes important changes in the diversity of crops and weeds. The substitution of MS by SP has been slow in Sierra Norte in such a way that several plots managed under MS or SP are in close proximity to each other, and under the same ecological conditions. This mixture of farmlands with contrasting methods of cultivation provides a unique opportunity to explore how such changes affect the crops and the associated weeds. In this study we evaluate the effects of the *milpa* sedentarization on the varieties and species of crops, and the composition and abundance of the associated weeds.

2. Methods

2.1. Study area

The study was conducted in Juquila Vijanos municipality, Villa Alta District, Oaxaca State, in the Sierra Norte mountain range, Mexico (Fig. 1). The climate is temperate-humid influenced by the Gulf of Mexico moist winds. Rain is common throughout the year, but peaks during summer (June–September). The average annual precipitation ranges between 1500 and 2000 mm (INEGI, 2008). The average annual temperature at the nearest meteorological station (station 20145) is 18.7 °C (SMN, 2010). The soil lies on a bedrock of schist and slate from Cretaceous period (INEGI, 2008). Soils of maize fields are Inceptisols and those of forest areas are Entisols (Bautista-Cruz et al., 2005). The original vegetation is an upper tropical montane cloud forest (del Castillo and Blanco-Macías, 2007). The municipality total area is 62.93 km². The territory is steep (19–95%). Agricultural areas comprised 20% of the municipality area, whereas 78% of the territory is secondary forests of different development stages and primary forests (INEGI, 2008). This region is inhabited by Zapotecs, an ethnic group with its own
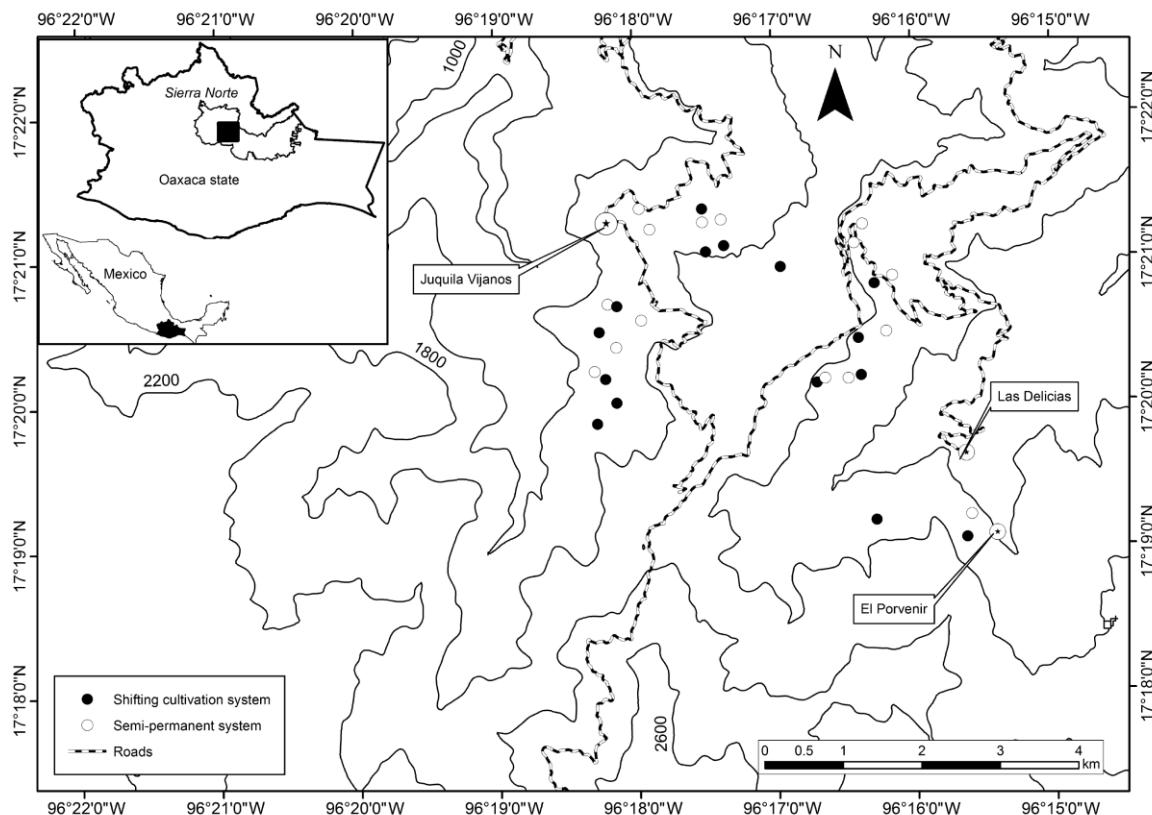

Fig. 1. Map of San Juan Juquila Vijanos, Oaxaca, Mexico and the plot location of the two cropping systems used for agrobiodiversity evaluations.

language and cosmovision, that use maize as staple food (González, 2001). The land is communal and administrated by agrarian authorities elected by the people of the community and recognized by the federal government (González, 2001).

2.2. Characteristics of the cropping systems management

Our study was conducted in the *zona fría* (cold zone) of the study area, an agroecological zone between 1400 and 1900 m a.s.l., which is where both MS and SP are still practiced. The *zona fría* encompasses well-preserved areas of native forests, including the tropical montane cloud forest (del Castillo and Blanco-Macías, 2007). In this zone, both cropping systems are preferentially cultivated following a spring-winter cycle under rainfed conditions. Crop fields of the two cropping systems are small in extension, usually 0.50–1.5 ha. Maize is sown in holes using a dibble. The two cropping systems differ in land preparation, cropping and fallow period, weed control, and crop nutrition (Table 1). Soils in cropping areas are structurally simpler, devoid of litter layer, and are less acidic, with lower effective cation-exchange capacity, lower content of soil organic matter, and higher N/P than those of the adjacent forests (Bautista-Cruz and del Castillo, 2005; Bautista-Cruz et al., 2005).

2.3. Field methods

We studied a total of 30 different farmlands in the *zona fría* agroecological zone, 15 of which were managed under MS, and 15 under SP. All farmlands of MS and SP were located at close distance between each other (average distance of 410 m), and with similar altitude, location in the landscape, and slope steepness (Fig. 1). For crop diversity management assessment, a 10×10 m quadrat was placed in the center of each farmland and at least 10 m from the border of the field, pathways or streamflows. The height of 10 maize plants was measured and averaged: two plants on each corner of the quadrat and two plants at the center. Slope steepness was measured with a clinometer. A 5×5 m sub-plot was set at the center of the main quadrat to record the density of maize, bean, and squash. Two mature maize ears were collected in each sub-plot for landrace identification. Identification was based on ear characteristics (length, diameter, row number and arrangement, shape, texture and kernel color) and plant height, following Sánchez et al. (2000). Bean and squash species were identified according to field guides based on Debouck (1994) and Lira and Montes-Hernández (1994) respectively.

Weed species richness, total and classified by life cycle, was estimated by the total number of species of reproductive individuals found in the five 50×50 cm quadrats placed one on each corner, and one placed at the center of the 10×10 m quadrat. In the five 50×50 cm quadrats we also estimated weed density. Total weed cover percentage was estimated with the line interception method (Canfield, 1941). For this purpose, a 10 m

line was placed at the middle of each 10×10 m quadrat. The percentage of the line intercepted by weeds, crops, bare soil or litter was recorded. The field work was carried out from October to December 2013, after the weed control period and before harvesting. The specimens collected were identified, categorized by life cycle, annual and perennial, and deposited at the CIIDIR-IPN-Oaxaca herbarium, Mexico (OAX). Taxonomic nomenclature follows the classification of the Association Phylogenetic Group (APG III) (Bremer et al., 2009).

2.4. Statistical analysis

To look for possible associations between the weed species composition of the two cropping systems, we conducted a McQuitty cluster analysis based on squared-Euclidean distance using presence-absence values. We also explored which crop and weed species are associated with each cropping system, by conducting two indicator species analysis, with the Dufrêne and Legendre (1997) method, one for crop species, in the 5×5 m sampling plots, and the other for weed species, in the five 50×50 cm quadrats. To choose the indicator species, the farmland sites were classified into two groups using K-means partitioning. This method assigns each observation to the cluster whose mean yields the least within-cluster sum of squares (MacQueen, 1967). The statistical significance was determined with permutations of species-site group associations using the indicator value index (IndVal, Dufrêne and Legendre, 1997). This index is the product of two quantities, A and B. Quantity A is the relative frequency of the species in the target site group divided by the sum of the relative frequencies of all groups. Quantity B is the relative frequency of occurrence of the species inside the target site group. We used the function *HClust*, from the base package of R for the cluster analysis; the package 'indicspecies' and the function *indvalori* for the indicator species analysis (De Cáceres and Legendre, 2009) of R (R Development Core Team, 2013).

To compare the total species richness of weeds between the two cropping systems under the same number of individuals, we performed an individual-based rarefaction and extrapolation curves with EstimateS 9.1 (Colwell, 2013). To compare differences in densities of crops, and richness and densities of annual and perennial weeds, total weed cover, and slope steepness between the two cropping systems, first we tested for the normality of the response variables using the Shapiro-Wilks procedure. The data of richness and density of annual weeds were rank transformed, whereas the data of weed cover were logit transformed to improve normality. The differences of these response variables between the two cropping systems were tested with one-way ANOVAs. Please note that by being only two groups to be compared, this test is equivalent to a *t*-test (Sokal and Rohlf, 1981: 222–229). Owing to the sensitivity of weed abundance to slope steepness in tropical agricultural areas (Klanderud et al., 2010), we explored the associations in annual and perennial weed species richness and

Table 1
Farm management of the *milpa* shifting cultivation and the semi-permanent system practiced in the cold zone (1400–1900 m a.s.l.) in Juquila Vijanos, Oaxaca, Mexico, based on interviews with local agrarian authorities and farmers.

	Cropping systems	
	Milpa shifting cultivation	Semi-permanent
Land preparation	Slash (December to April) and burn (May) of secondary forests	Plowing soil two times in April using a team of two oxen
Maize sowing	May	May
Cropping period	2–5 years (normally 3 years)	4–10 years
Weed control	Pulled by hand and/or cut with a machete	Hoeing
Crop nutrition	From ashes, soil organic matter, and N-fixing crops (*Phaseolus* spp.)	From synthetic fertilizers: urea and diammonium phosphate
Harvesting	November or December	November or December
Fallow period	>a decade	2–5 years (normally 3 years)

density with cropping systems, slope steepness, and cropping systems by slope steepness interaction through multiple regression tests. Prior to multiple regression analyses, the categorical variables of the cropping systems were coded as +1 (SP), and as −1 (MS). Non-significant terms were removed from the model if their joint effect was not significant using a backward elimination procedure and the extra sums of squares principle (Draper and Smith, 1981). The Infostat package was used for ANOVAs (Di Rienzo et al., 2013). For multiple regression analyses we used the base package of R, function *lm*; the package and function 'visreg' were used for the visualization of fitted multiple regressions (Breheny and Burchett, 2015) of R (R Development Core Team, 2013).

3. Results

3.1. Crop species composition, number of species and varieties, and density

We found evidence that change in cropping system affect the crop species, density of cultivation, and composition. The maize *Nal-tel de altura* was the only landrace found in the study area. This landrace has three color varieties in MS: yellow, white, and blue, and two varieties in SP: yellow and white. The yellow variety was recorded in thirteen plots of MS, while both the white and blue varieties were recorded in only one plot respectively. In SP, the yellow variety was recorded in ten plots, while the white variety in five plots. This difference in composition was statistically confirmed by the indicator species analysis. The yellow maize variety was associated with MS (IndVal = 1, P = 0.001), and the white maize variety with SP (IndVal = 0.93, P = 0.001). Both the yellow and the white maize varieties were found in similar slope steepness ($F_{1,16}$ = 2.5, P = 0.133).

The cultivation systems appear to influence both maize density and the presence of climbing bean species (*Phaseolus vulgaris* L. and/or *Phaseolus coccineus* L.). Maize density was significantly lower in MS than in SP (Table 2). Maize was more frequently intercropped with bean species in MS than in SP: in MS, 53% of the plots were maize-bean intercropping compared to 27% of the plots in SP. The rest of the plots of both cultivation systems were maize monoculture. In addition, two species of squash (*Cucurbita ficifolia* Bouché and *Cucurbita moschata* Duchesne) could only be detected in one plot of MS and one plot of SP.

Table 2
Mean values ± standard error of crop density, weed species richness and density by life-cycle, and weed cover recorded in the two cropping systems in Juquila Vijanos, Oaxaca, Mexico. n = 15 fields per cropping system with exception of density of bean (n = 8 shifting cultivation fields, n = 4 semi-permanent fields). Rank and logit transformation of data to improve normality are indicated in parentheses. Statistical tests were based on standard one way ANOVA (see methods for details). Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system.

	Cropping systems	
	MS	SP
Crop species		
Density of maize 25 m^{-2}	82.6 ± 5.7 b	102.7 ± 5.7 a
Density of bean 25 m^{-2}	9.1 ± 1.8 a	5.3 ± 2.6 a
Weed species		
Richness of annual weed species (rank)	9.2 ± 1.5 b	21.8 ± 1.5 a
Richness of perennial weed species	3.1 ± 0.4 a	2.1 ± 0.4 a
Density of annual weeds m^{-2} (rank)	9.0 ± 1.5 b	22.0 ± 1.5 a
Density of perennial weeds m^{-2}	5.5 ± 0.6 a	2.9 ± 0.6 b
Weed cover (logit)	1.6 ± 0.3 b	2.7 ± 0.3 a

Different letters indicate significant statistical differences between the two cropping systems (P < 0.05).

Table 3
The first four families with the highest species richness of weeds in the two cropping systems (MS = *milpa* shifting cultivation, SP = semi-permanent, C = two cropping systems combined), and their proportional contribution (%) to the overall number of species and individuals in Juquila Vijanos, Oaxaca, Mexico.

Family	Number of weed species			Number of weed individuals		
	MS	SP	C	MS	SP	C
Asteraceae	8	10	13	56	342	398
Poaceae	7	6	9	47	36	83
Rubiaceae	2	5	5	9	79	88
Lamiaceae	5	4	5	11	16	27
Contribution (%)	63.6	66.7	66.6	62.7	83.5	78.2

3.2. Weed species composition, richness, and density

We detected 48 species and 757 individuals of weeds in total, of which 193 individuals and 33 species were found in MS, and 564 individuals and 36 species in SP (Appendix A). Within each cropping system we detected 12 families (Appendix A). Four families accounted for more than 60% of all species and individuals of weeds in the two cropping systems (Table 3): Asteraceae was the most abundant family, followed by Poaceae, Rubiaceae, and Lamiaceae.

We detected that weed species composition differs between the two cropping systems (Fig. 2). Two major clusters of weed species could be differentiated by the cluster analysis. Nearly all of the plots (13 out of 15 plots) belonging to MS were grouped in the same cluster (I). Most of the SP plots (11 out of 15 plots) were grouped
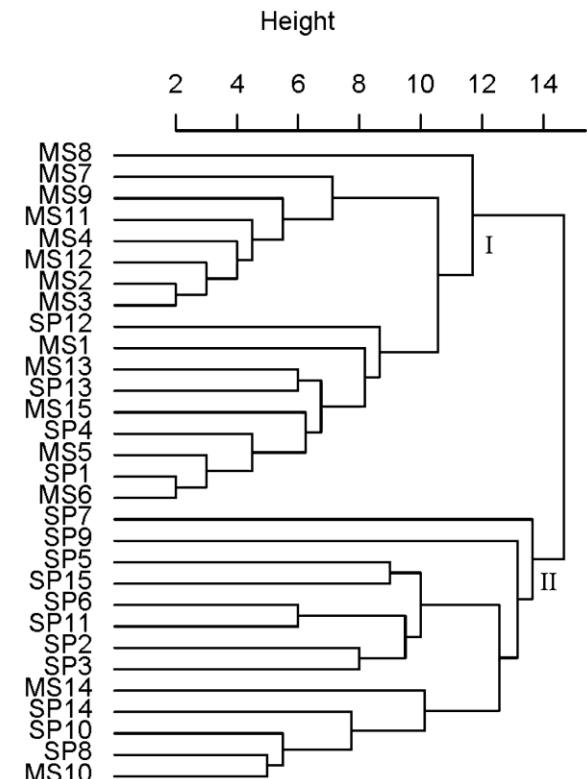

Fig. 2. Cluster dendrogram (McQuitty method and squared-Euclidean distance) based on the presence-absence of weed species in the two cropping systems in Juquila Vijanos, Oaxaca, Mexico. Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system, 1–15 = number of fields per cropping systems.
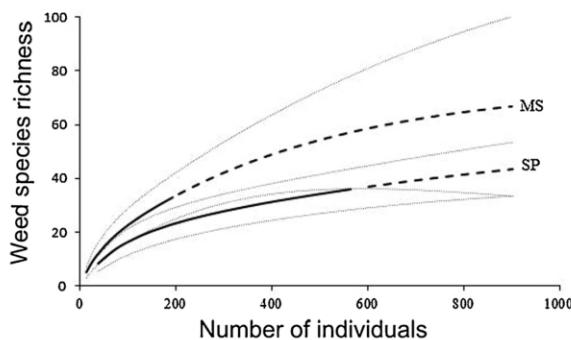
Fig. 3. Rarefaction (solid line) and extrapolation (dashed line) curves for the total weed species richness in the two cropping systems in Juquila Vijanos, Oaxaca; Mexico. Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system. Dotted lines represent 95% confidence intervals.

Fig. 4. Significant interaction of cropping systems by slope steepness on density of annual weeds. Result from significant model of multiple regression $Y = 27.2 + 26.8X_1 - 35.8X_2 - 43.7X_1 \cdot X_2$, where Y = density of annual weeds, X_1 = cropping systems, X_2 = slope steepness, $X_1 \cdot X_2$ = interaction between cropping systems and slope steepness. *Milpa* shifting cultivation: open circles and dashed regression line. Semi-permanent system: filled circles and solid regression line.

into another cluster (II). The two exceptions observed, the MS10 and MS14 plots, were positioned into the cluster composed mostly by SP plots. We found that these two plots were managed following shorter fallows than those of the other MS plots, which may favor weed species typical of SP. The other exceptions were the SP1, SP4, SP12, and SP13 plots, which were grouped into the MS cluster. The recently change from MS to SP in these four plots could explain the presence of weed species typical of MS.

The indicator species clearly distinguished the weed species proper of both MS and SP. The perennial fern weed *Pteridium aquilinum*, (bracken fern, Dennstaedtiaceae), was the only weed species significantly associated with MS (IndVal = 0.76, P = 0.007). The weed species *Galinsoga parviflora*, *Melampodium longifolium*, and *Sigesbeckia jorullensis* (Asteraceae); *Digitaria ciliaris* and *Setaria parviflora* (Poaceae); *Crusea hispida* (Rubiaceae); and *Ipomoea cholulensis* (Convolvulaceae) were associated with SP (IndVal > 0.57, P < 0.05). Most of these weeds were annuals with the exception of *S. parviflora* which was perennial.

The richness and density of weeds, classified by life-cycle, and the cover of weeds were different between MS and SP. The richness and density of individuals of annual weed species were lower in MS than in SP (Table 2). Also, the density of perennial weeds was higher in MS than in SP. In addition, weed cover was significantly lower in MS than in SP. The richness of total weed species did not show significant differences between the two cropping systems at 95% confidence as shown in the rarefaction-extrapolation curves (Fig. 3).

According to the multiple regression analyses, the relationship between the density of annual weeds and the slope steepness was conditioned by the cropping system ($F_{3,26}$ = 10.38; P_{model} = 0.0001; adjusted R^2 = 0.49). As slope steepness increased, the density of annual weeds decreased sharply in SP, and increased slightly in MS ($P_{interaction}$ = 0.014) (Fig. 4). We did not find any significant relationship between the richness of annual weed species, and the richness and density of perennial weed species with cropping systems, slope steepness, and cropping systems by slope steepness interaction.

4. Discussion

Our results provide evidence that the replacement of MS by SP leads to a simplification of the diversity of crops and weed species. More specifically, such changes are associated with alterations in the composition of the varieties of the local landrace of maize, increases in the density of annual weeds, and reductions in the frequency of maize-bean intercropping and in the density of

perennial weeds. Furthermore, we have found evidence that this change in agricultural practices requires a higher intensity of management.

4.1. Crop species composition and structure

With the *milpa* sedentarization, the white maize variety is encouraged, while the colored varieties become reduced, as in the case of the yellow variety, or undetectable, in the case of the blue variety. Also, maize intercropped with climbing beans tends to disappear. Squash species are practically non-existent in the two cropping systems.

The yellow and blue maize have been recognized as common varieties of maize landraces among indigenous communities in mountainous areas of southern Mexico (Brush and Perales, 2007; Ramos-García, 2007). This is in line with our results in MS. The establishment of SP can discourage the production of colored maize varieties by favoring the white maize, as has been reported in other localities in Mexico (Vielle-Calzada and Padilla, 2009). The preference of the white variety appears to be associated with the *milpa* sedentarization and may involve socio-economic and ecological factors. First, the food policy of the Mexican government has promoting the consumption and monoculture of the white variety through the government store DICONSA, and the PRO-CAMPO assistance program (Zahniser and Coyle, 2004). Second, the white variety is more marketable than the colored varieties. The maize produced in the SP system, at least in some plots, is not only for self-consumption but for commercial purposes. By contrast, the colored maize varieties in traditional milpa systems in southern Mexico are used exclusively for home-use and special uses, and are inherent to the way of life of indigenous communities (Ortega-Paczka, 2003; Brush and Perales, 2007). Third, the prohibition of slash-and-burn practices by the local authorities imposes a more restrictive use of forest lands for agricultural purposes. This prohibition implies a landscape homogenization, which decreases the number of isolated agricultural sites bordered by forests (Robson and Berkes, 2011). By contrast, MS practices

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usually maintain cropping areas surrounded by fallows of different stages of development, and spatially separated from other cropping areas (e.g., del Castillo, 2015). Such kind of sites helps to maintain the integrity of maize varieties through the avoidance of cross pollination with pollen from other *milpa* fields (Ortega-Paczka, 2003). Indeed, the rare blue maize variety was found only in MS in an isolated field surrounded by *Pinus chiapensis* forests, and farmers prefer isolated areas surrounded by forests to cultivate this variety of maize. Our results therefore, support the point that shifting cultivation agriculture helps to preserve agrobiodiversity (Finegan and Nasi, 2004; Boege, 2008).

Two factors can be ascribed to the decline of the maize-bean intercropping system in the study area. First, bean species are appreciated in maize based intercropping systems due to the nitrogen fixation (Seran and Brintha, 2010). However, with the common practice of applying synthetic fertilizers in SP, maize-bean intercropping probably is perceived as unnecessary (Debouck, 1994). Second, the high maize density in SP may be incompatible for intercropping systems as suggest Seran and Brintha (2010). The increase of maize density and continuous monocropping, however, is increasing the dependency on synthetic fertilizers, as noticed in SP. This cropping system can increase the productivity of maize but also can reduce the availability of important companion food crops. Clearly, the implementation of SP brings about not only the reduction of the diversity of maize varieties but also the diversity of *Phaseolus* beans. This implementation certainly contributes to explain the observed reduction in agrobiodiversity detected in Southern Mexico (Ibarra et al., 2011; Robson and Berkes, 2011).

The scarcity of squash species (*Cucurbita* spp.) in both cropping systems is noteworthy and suggests that the tendency of agrobiodiversity reduction, although exacerbated in SP, can be detected also in MS. Squash species are characteristic companion crops of the traditional *milpa* (Lira and Montes-Hernández, 1994). The causes of the decline of squash species in the studied cropping systems deserve further research. However, in SP some farmers acknowledge that the presence of squash obstructs hoeing. The observed decline in squash species appears to be a common trend. Currently, squash is seldom intercropped with maize and bean in polyculture systems in subsistence farmers of Africa and Latin America (Postma and Lynch, 2012).

Maize monoculture and the replacement of colored maize varieties by white maize as observed in our study have been identified elsewhere (Ortega-Paczka, 2003; Vielle-Calzada and Padilla, 2009). This tendency can be explained by the substitution of MS by SP in our study area. The consequences for human nutrition of such changes deserve detailed studies, but may be detrimental. In contrast with the white maize variety, the yellow and blue maize varieties are important sources of carotenoids and anthocyanins, respectively, which are important sources of vitamin A and antioxidants for human health (Salinas-Moreno et al., 2005; Menkir et al., 2008). *Phaseolus* is the main source of protein for indigenous communities (Worthington et al., 2012). Thus, our results suggest that the substitution of MS by SP may imply losses of important sources of nutrients for the local human population, which may require the search of alternative sources that compensate such losses.

4.2. Weed species composition and structure

The substitution of MS by SP is associated with important changes in the accompanying weeds. These include dramatic changes in weed species composition; a markedly increase in the richness and density of annual weeds at the expense of the density of perennial weeds; an increase in total weed cover; and alterations in the relationships between annual weed density

and slope steepness. Most of such changes appear to be closely related with the drastic differences in cultivation practices observed between the two cropping systems. MS is characterized by a minimum disturbance of soil and weeds through no-tillage and manual weeding (Table 1). With this relaxing weeding practice, perennials weeds, which tend to be larger and with deeper roots than annual weeds, are likely more difficult to eradicate. Contrastingly, with the frequent soil tillage and weed hoeing in SP (Table 1), only short-lived weeds match the time and space to reproduce and persist, as has been detected in other similar cropping systems (de Rouw, 2001; Nichols et al., 2015). Indeed, no-tillage farming and relaxed weeding practices tend to favor perennial weeds (Bàrberi, 2002; Nichols et al., 2015). Changes in weeding practices and soil preparation may also contribute to explain why most of the weeds selected by the indicator species analyses as distinctive of SP are annuals, whereas the only species found to be distinctive of MS is perennial. The observed shift of weed species composition by *milpa* sedentarization is consistent with other studies that have revealed a strong influence of crop management on weed composition in farming fields (Nichols et al., 2015).

With the increase of annual weed density and total weed cover in SP, the weed infestation is evident in this system. Both, weed density and weed cover are widely-used indicators of weed infestation levels in crops (de Rouw, 1995, 2001). The annual weed infestation observed in SP can be explained, in addition to the frequent soil tillage, by the absence of long forest fallow periods and the reduction of polyculture practices, since both management strategies have been proven as effective methods of weed control (de Rouw, 1995, 2001). Although the perennial weeds density was higher in MS than in SP, this weed abundance is suppressed during forest fallow periods (del Castillo and Blanco-Macías, 2007). At least in the study area, tree species such as *Liquidambar styraciflua* and *Clethra* spp. resprout from living stumps at the beginning of fallows accelerating forest cover that suppress weeds in MS (del Castillo and Blanco-Macías, 2007).

Our results suggest that weed infestation, particularly by annual weeds, tend to be higher on gentle slopes as revealed by our regression analyses, which shows that the density of annual weeds tend to increase in SP. Under steeper slopes perhaps the weed hoeing commonly practiced in SP, is less frequently needed, because the torrential rains common in the study area help to eliminate annual weeds by surface runoff. The sensitivity of weed abundance to slope steepness in shifting cultivation areas was observed by Klanderud et al. (2010) in tropical rain forest areas of Madagascar. However, these authors did not differentiate between annual and perennial weeds.

Resprouting from tree roots or stems accelerates forest regeneration (Chazdon, 2014). Thus, the tillage practices observed in SP likely reduce the probabilities of fast forest regeneration during fallows by the removal of stumps. Indeed, perennial weeds observed in SP can have an important role as facilitators of forest regeneration. Some of the perennial weed species observed in our study sites have been identified as early successional species, such as *Phytolacca icosandra*, and the bracken fern, *Pteridium aquilinum* (e.g., Rejmanek et al., 1982). The bracken fern, a distinctive weed of MS, is considered as a cosmopolitan noxious weed (Gliessman, 1978). However, in our study area this fern species precedes the colonization of shrubs and trees and is associated with the initial stage succession just after the field is left fallow (del Castillo and Blanco-Macías, 2007). The role of the bracken fern as facilitator of forest regeneration has been reported elsewhere (Marrs et al., 2000). Thus, by affecting the abundance of perennial weeds some which are also important species during succession in fallow. The consequences of the replacement of MS by SP may have important consequences in forest dynamics, and deserve further studies.

5. Conclusions

The substitution of the traditional *milpa* system cultivation by a semi-permanent system in humid highlands of southern Mexico is associated with important changes in agrobiodiversity including the companion weeds. The semi-permanent system tends to favor the white maize variety at the expense of colored maize varieties, and climbing bean species. The total cover of weeds increases. Annual weeds become most abundant and perennial weeds decline. The traditional *milpa* shifting cultivation is a better reservoir of agrobiodiversity and less prone to weed infestation than the new semi-permanent system. The consequences of such a substitution may increase the probabilities of weed infestation, the dependence on agrochemicals, reduce the nutritional apportionment of the crops to the human population, and reduce the capability of the land to regenerate during the fallow periods. Finally, any alternative management aimed to restrict shifting cultivation agriculture should include strategies that ensure the conservation of agrobiodiversity as well as the prevention of land degradation associated with weed infestation.

Appendix A.

Weed species recorded in the two cropping systems (MS = *milpa* shifting cultivation, SP = semi-permanent system) in Juquila Vijanos, Oaxaca, Mexico, and their life cycle (A = annual weeds, P = perennial weeds) and number of individuals.

Taxa	Life cycle	No. of weed individuals in the cropping systems		Total
		MS	SP	
Pteridophyta				
Dennstaedtiaceae				
Pteridium aquilinum (L.) Kuhn	P	25	12	37
Dicotyledoneae				
Asteraceae				
Aldama dentata La Lave ex La Llave	A	0	14	14
Bidens odorata Cav.	A	0	1	1
Bidens sp.	A	0	2	2
Erechtites hieraciifolius (L.) Raf. Ex DC.	A	0	1	1
Galinsoga parviflora Cav.	A	12	72	84
Heliopsis aff. *buphthalmoides* (Jacq.) Dunal	A	0	7	7
Jaegeria hirta (Lag.) Less.	A	29	149	178
Lactuca graminifolia Michx.	P	1	0	1
Melampodium longifolium Cerv. ex Cav.	A	2	45	47
Piqueria trinervia Cav.	P	3	2	5
Sigesbeckia jorullensis Kunth	A	7	49	56
Smallanthus maculatus (Cav.) H. Rob	P	1	0	1
Trigonospermum melampodioides DC	P	1	0	1
Caryophyllaceae				
Drymaria villosa Schltdl. & Cham.	A	1	3	4
Commelinaceae				

Taxa	Life cycle	No. of weed individuals in the cropping systems		Total
		MS	SP	
Commelina diffusa Burm.f.	P	0	1	1
Tripogandra purpurascens (Schauer) Handlos	A	3	8	11
Convolvulaceae				
Ipomoea cholulensis Kunth	A	0	5	5
Ipomoea purpurea (L.) Roth	A	0	2	2
Fabaceae				
Crotalaria sagittalis L.	A	0	1	1
Desmodium sp.	A	2	0	2
Lupinus elegans Kunth	P	1	0	1
Lamiaceae				
Hyptis atrorubens Poit.	P	3	11	14
Hyptis mutabilis (Rich.) Briq.	P	2	3	5
Hyptis urticoides Kunth	P	1	1	2
Salvia lasiocephala Hook. & Arn.	A	4	1	5
Salvia tiliifolia Vahl	A	1	0	1
Lythraceae				
Cuphea aequipetala Cav.	P	1	5	6
Onagraceae				
Lopezia racemosa Cav.	A	18	44	62
Phytolaccaceae				
Phytolacca icosandra L.	P	10	2	12
Rubiaceae				
Crusea calocephala DC.	A	6	35	41
Crusea hispida (Mill.) Rob.	A	0	13	13
Richardia scabra L.	A	0	16	16
Spermacoce laevis Lam.	A	0	5	5
Spermacoce ocymoides Burm.f.	A	3	10	13
Monocotyledonae				
Cyperaceae				
Cyperaceae sp. 1	P	1	0	1
Cyperus esculentus L.	P	5	0	5
Kyllinga pumila Michx.	P	1	0	1
Poaceae				
Arthraxon hispidus (Thunb.) Makino	A	0	1	1
Digitaria ciliaris (Retz.) Koeler	A	0	17	17
Panicum commutatum Schult.	P	21	0	21
Panicum dichotomum L.	P	4	1	5
Panicum laxiflorum Lam.	P	12	2	14
Panicum stramineum Hitchc. & Chase	P	8	0	8
Panicum viscidellum Scribn.	P	0	1	1
Paspalum humboldtianum Flüggé	P	1	0	1
Setaria parviflora (Poir.) M.Kerguelen	P	1	14	15
Unknown species				
Sp. 1	A	2	8	10
Total		193	564	757

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Capítulo 2. Shifts in swidden agriculture may alter the diversity and capacity of tropical montane cloud forest regeneration in very early fallows areas of southern Mexico

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2.1. Abstract

For centuries, *milpa* shifting cultivation (MS) has been part of the landscape dynamics in tropical montane cloud forests (TMCF) areas managed by Mesoamerican indigenous communities. Presently, this agroforestry system is being substituted by a semi-permanent system (SP), characterized by tillage, fire suppression, application of synthetic fertilizers, and short fallow periods. In the TMCF area of Sierra Norte, Oaxaca, Mexico fallows of both MS and SP cultivation systems are intermixed in the landscape. In this area, we compared the composition, richness, and diversity of vascular plant species of 2-3 year old SP and MS fallows, and explored the possible role of the forestlands adjoining the fallows on the fallows' vegetation properties. The tree and herb species composition was clearly separated into two clusters, one belonging to MS and the other to SP fallows. Pioneer and late-successional TMCF tree species were distinctive of MS fallows, whereas, native perennial grass and forb species were distinctive of SP fallows. The composition of other life forms could not be separated based on the cultivation system. The species richness and diversity of trees, tree seedlings, shrubs, and vines were higher in MS fallows; whereas the richness and diversity of herbs was similar in MS and SP fallows. The richness and diversity of herbs was similar in both fallow types. In MS and SP fallows, the richness of tree seedlings increased with the proportion of adjoining forestlands older than 20 years,

but not with forestlands younger than that age. Tree seedling density increased with the proportion of forests older than 20 years adjoining the fallows in SP but not in MS fallows. We conclude that the replacement of MS by SP reduces greatly biodiversity in early fallows and their potential for TMCF regeneration by altering the composition and structure of the vegetation, favoring the substitution of trees by grasses and forbs, and increasing the fallows' dependence on adjoining forests as seed sources. Our results show the importance of land-use legacies and the vegetation adjoining early fallows to the regeneration and conservation of TMCFs.

Keywords: Forest restoration, Land-use legacy, *Milpa* shifting cultivation, Restoration ecology, Secondary succession, Young fallows, Weeds.

2.2. Introduction

Agricultural fallows are important for biodiversity conservation, forest regeneration, ecosystem services, and the sustainability of traditional agricultural systems (see Chazdon, 2014 for a recent review). Fallows are stages of secondary succession and a passive method of forest recovery in traditional agroforestry systems in tropics (Finegan and Nasi, 2004). Given the common trend of declining of mature forests, particularly in tropical areas, secondary forests are becoming increasingly important as biodiversity reservoirs, including those derived from agricultural practices (e.g., Ochoa-Gaona et al., 2007; Chazdon et al., 2009). Furthermore, agricultural fallows are instrumental for soil and forest regeneration, pest and weed control, and the generation of forest products and services (Kleinman et al., 1995; Styger and Fernandes, 2006; Ribeiro-Filho et al., 2013). Such crucial roles contribute to explain why traditional shifting cultivation systems have been practiced for centuries and still are commonly practiced in marginal areas in the tropics (Styger and Fernandes, 2006; van Vliet et al., 2012). The *milpa* shifting cultivation (MS), for instance, has coexisted for centuries in areas of tropical montane cloud forest (TMCF) in Sierra Norte, Oaxaca in southern Mexico, one of the most vulnerable ecosystems to land use change (del Castillo and Blanco-Macías, 2007; del Castillo and Pérez-Ríos, 2008; Mulligan, 2010). As a result, this ancient system of land management is considered

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as a successful way of biodiversity conservation and environment management (e.g., Anta and Pérez, 2004; Boege, 2008). This agroforestry system consists of the slash-and-burn of a small piece of forest land for growing a polyculture of maize, bean, and squashes during few years, followed by long-fallow periods in which forest is regenerated. Cultivation is shifted to another piece of forest land to ensure local food crop supply. This spatial and temporal dynamic of land use generates a heterogeneous landscape composed by a mosaic of diversified crop fields, fallows of various ages including secondary forests, and primary vegetation (Finegan and Nasi 2004; del Castillo and Blanco-Macías, 2007; del Castillo, 2015, Plate 1). Thus, MS as an agroforestry system should be considered as a method of landscape management in which crop fields interact with the fallows that surround them. Consequently, any cropping system alteration should affect the entire landscape, including the fallows that develop after the land was cultivated.

New local environmental policies, motivated by government economic incentives tend to replace MS with a semi-permanent system (SP) (Ibarra et al., 2011; Martin et al., 2011). The changes in land use are apparently subtle as both are maize-based cropping systems associated with fallows. In contrast to MS, SP is characterized by a longer cropping phase, shorter fallow periods, a native maize monoculture, soil tillage, and exhaustive mechanical weed control. As a result, during the cropping period, weed species composition change dramatically compared to that found in MS fields, the richness and abundance of annual weed increase, and the abundance of perennial weeds decreases (Pérez-García and del Castillo, 2016). However, the impacts of such a substitution on the fallows as biodiversity reservoirs, and on their capacity for forest regeneration in TMCF areas have not been studied yet. This kind of studies provides an example of how changes in cultivation practices affect post-cultivation stages.

The capacity of the fallows as biodiversity reservoirs and for forest regeneration in the tropics can be related to the availability of regeneration of the native species from the soil seed bank, seed rain, and sprouts, and the degree of environmental disturbance linked to agricultural practices of the cropping phase (Pickett and White, 1985; Martínez-Ramos and García-Orth, 2007; Chazdon, 2014).

Thus, different kinds of land use and the inherent intensity, frequency, and scale of disturbance can affect varyingly the capacity of regeneration of the native vegetation (Foster et al., 2003). In this regard, the classification of fallows' vegetation by life forms facilitates detecting how previous cropping management practices acts as a habitat filter during the colonization process of the post-cultivation period (Kammesheidt, 1998; Klanderud et al., 2010, HilleRisLambers et al., 2012). The presence of adjoining forests, should be particularly important for the fallow's revegetation, since seed dispersal of TMCF and secondary forests are limited (Holl et al., 2000; del Castillo and Pérez-Ríos, 2008). Thus, we expect that seed sources adjoining the fallows would be those with the highest contribution to the fallows' seed rain.

Since the substitution of MS by SP is still not complete in TMCF areas of Sierra Norte in Oaxaca, fallows derived from both management systems coexists at short distances between each other. As a result, such areas are convenient for studying the effects of replacing the traditional MS with SP systems. In this study, we compared the vegetation that develops in early fallows resulted from both cultivation systems. We hypothesize that longer cultivation periods and frequent tillage in SP fallows will decrease woody species and increase herb species compared with MS fallows. Tilling contributes to eradicate living stumps of woody species, which are the main propagule source of trees in traditional shifting cultivation areas (de Rouw, 1993; Kammesheidt, 1998; Finegan and Nasi, 2004). By reducing competition with woody plants, tilling is expected to favor the establishment of opportunistic species of herbs and grasses. However, the presence of adjoining forestlands can ameliorate such effects in early fallows through the provision of seeds of native species, in particular of tree species, the dominant life form. Thus, the apportionment of seeds from the seed rain should be more important for SP than for MS fallows. Furthermore, as older forests are expected to produce more seeds than younger forests, we expect that such apportionment increase with the age of the adjoining forestlands (del Castillo and Pérez-Ríos, 2008).

2.3. Methods

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2.3.1. Study area

The study was conducted in Juquila Vijanos municipality, Villa Alta District, Oaxaca State, in the Sierra Norte mountain range, Mexico (Fig. 1). The original vegetation was an upper tropical montane cloud forest (*sensu* Webster, 1995), which is still abundant at the study area (del Castillo and Blanco-Macías, 2007; Toledo-Aceves et al., 2011). The climate is temperate with 18.7°C of average annual temperature of and 1500-2000 mm of average annual precipitation (INEGI, 2008; SMN, 2010). Soils of maize fields are Inceptisols and those of forestlands are Entisols (Bautista-Cruz et al., 2005). The land area devoted for cropping occupies approximately 20% of the municipality's total area (62.93 km^2), while the rest is mostly secondary forest of different development stages and primary forest (INEGI, 2008).
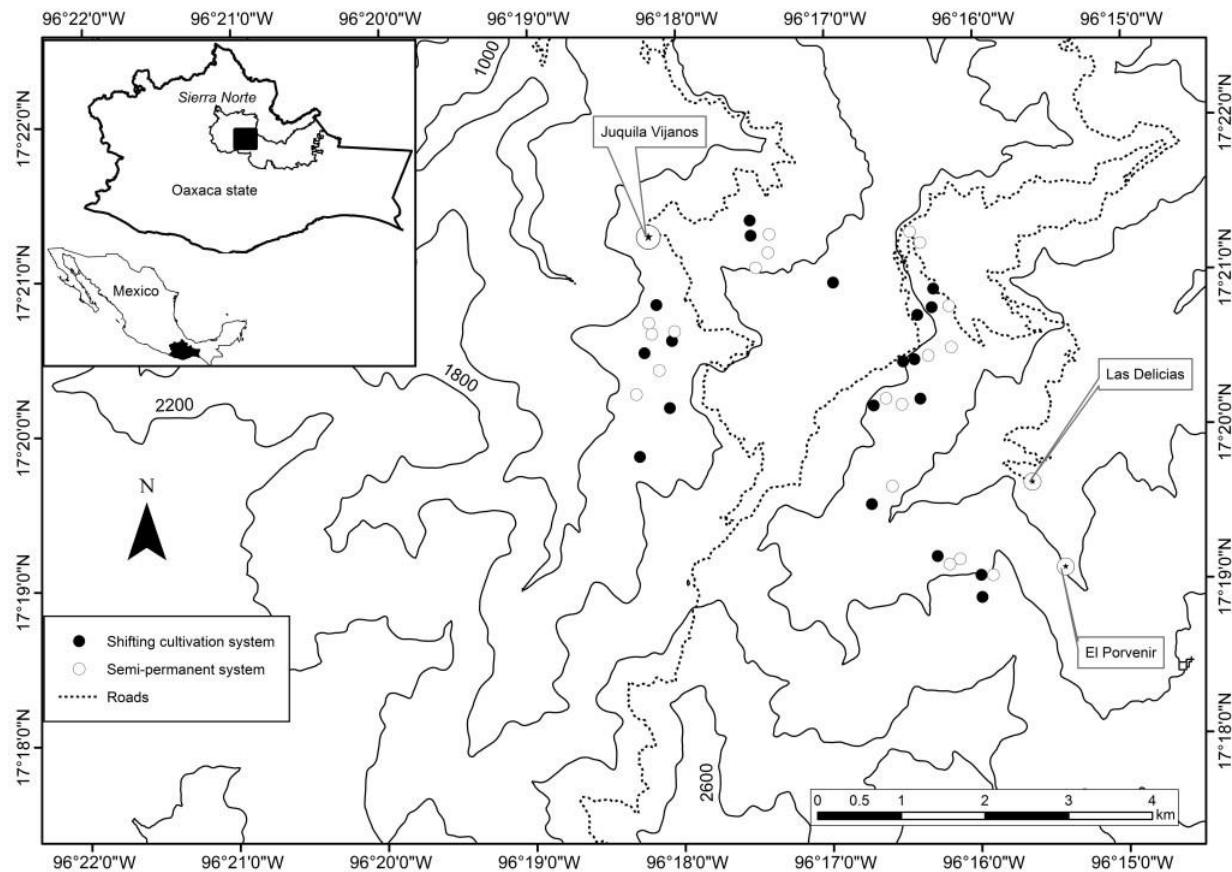

Fig. 1. Map of San Juan Juquila Vijanos, Oaxaca, Mexico and the plot location of the two cropping systems used for the vegetation of initial fallows evaluation.

2.3.2. Field methods

During February and March 2016, we studied 38 2-3 years age fallows, 19 of which were managed under MS, and 19 under SP. The MS and SP fallows were located at short distances between each other, at 1400-1900 m a.s.l, and with a similar steepness (Fig. 1). The age of the fallows was obtained from local agrarian records kept by the local authorities. Crop fields of the two cropping systems were small in extension, usually 0.50 to 1 ha.

The assessment of the composition, richness, density of individuals, and diversity of tree, shrub, vines, and herb species of fallows was conducted in temporary plots. For large trees, a 10×40 m plot was placed at the center of each fallow site. Shrubs and vines were recorded in a 2×40 m subplot placed at the center of the main plot. As in the case of the main plot, the longest side of the plot was set perpendicular to the direction of the slope. Herbs and tree seedlings were assessed in eight 50×50 cm quadrats distributed along the longest borders of the main plot, four on each border, and arranged in such a way that the distance between two contiguous quadrats along the border were the same. We tallied the individuals of all species within plot and subplots in order to estimate species richness and the density of individuals of trees, shrubs, vines and herbs in their respective sampling units. Tree, shrub, vine, and herb species were identified in the field with the aid of a field guide elaborated from a preliminary species inventory of young fallows of the two cropping systems, and a previous floristic research conducted in fallows of the shifting cultivation system (del Castillo and Blanco-Macías, 2007). Doubtful and uncommon species were identified at the CIIDIR-IPN-Oaxaca herbarium, Mexico (OAX). Voucher specimens were deposited at the CIIDIR-IPN-Oaxaca herbarium, Mexico (OAX). We followed the Angiosperm Phylogeny Group for the assignment of genera into family (Bremer et al., 2009). A pilot study revealed that two groups of trees could be clearly distinguished in the fallows: tree seedlings characterized by young short trees with slender stems and < 1.3 m height, which were derived from seeds; and large trees > 1.3 m height, most of which were derived from sprouts as evidenced by the living stumps or stems left commonly in MS fields. According to the local agrarian authorities, it was possible that in the group of large trees some plants were indeed derived from seeds

naturally or planted by farmers such as domesticated fruit trees in particular in SP fallows. Although not perfect, our classification of trees provides an appraisal of the two main sources or origins of the trees in the fallows.

We recorded the vegetation type adjoining the sampling fallows and its stage of development. The age of the adjoining forestlands was provided by the local agrarian authorities. We georeferenced the limits of fallows and the segment of the adjoining forests using a DigitalGlobe aerial image in order to estimate the current proportion of the surrounding forests. The adjoining forestlands were classified according to its stage of development into two categories: forests of 10-20 years old and forests of 20-40 years old. We did not find forests older than 40 years of age adjoining the fallows. This forest classification is justified because previous studies have shown that the composition and abundance of the species change dramatically with forest age (del Castillo and Blanco-Macías, 2007).

2.3.3. Statistical analysis

To look for possible associations between the species composition of trees, tree seedlings, shrubs, vines, and herbs of the two cropping systems, we conducted a Ward cluster analysis based on species abundance and the Euclidean distance. We also explored which tree, shrub, vine, and herb species are associated with the two cropping systems, by conducting indicator species analyses, with the Dufrêne and Legendre (1997) method. The statistical significance was determined with permutations of species-site group associations using the indicator value index (IndVal, Dufrêne and Legendre, 1997). This index is estimated by the following formula: IndVal = (A $\times$ B) 100, where A is the mean abundance of a single species in a single group compared to all groups in the study, and B is the relative frequency of occurrence of a single species inside the target site group. We used the function *HClust*, from the base package of R for the cluster analysis; the package 'indicspecies' and the function *indvalori* for the indicator species analysis of R (De Cáceres and Legendre, 2009; R Development Core Team, 2013).

We compared the tree, tree seedling, shrub, vine, and herb species richness and diversity (exponential of Shannon-Wiener index (*H'*)) of the two cropping systems. We rarefied species richness

based on the number of species as a function of the cumulative number of samples using the EstimateS 9.1 software (Colwell, 2013). The exponential of *H'* has the advantage over other diversity indices that it weights species exactly by their frequencies, without favoring rare or common species, and allowing comparisons of diversity among communities (Jost, 2006). We compared the exponential of *H'* between the MS and SP fallows with the exact Mann-Whitney test, which is suitable for non-normal data, using the package 'coin' and the function *wilcoxtest* of R (Hothorn et al., 2006, 2008).

We conducted Poisson regression models to explore the relationship between the tree, tree seedling, shrub, vine, and herb species richness and density of individuals with the cropping system type and the proportion of secondary forests adjoining the fallows. For analyzing the species richness of trees and vines, and the density of trees and shrubs, which were over-dispersed, we used negative binomial regressions, following Zeileis et al. (2008). For testing the effect of the cropping system, we coded 0 the MS, and 1 the SP fallow types. Non-significant terms were removed from the model if their joint effect was not significant using a backward elimination procedure. For such regression analyses we used the base package of R, function *glm*, and the packages 'mass' and 'visreg'of R (Venables and Ripley, 2002; R Development Core Team, 2013; Breheny and Burchett, 2015).

2.4. Results

2.4.1. Tree, shrub, vine, and herb species composition

A total of 141species of vascular plants were recorded at the studied fallows of which 118 were found in MS fallows and only 74 in SP fallows (Appendix 1). Asteraceae (31 species) was by far the most diverse family in both fallow kinds followed by grasses (Poaceae, 12 species). Typical families of Mexican TMCF areas were virtually exclusive of MS fallows (cf. Rzedowski, 1996). These include species in the Brunelliaceae, Chloranthaceae, and Altingiaceae (before Hamamelidaceae) families (Appendix 1). The legume family (Fabaceae) was rather diverse in MS (11 species) compared with only two species in SP fallows. Oaks (Fagaceae, 5 species) were rather abundant in MS fallows, whereas in SP fallows only one species with a single individual was found (Appendix 1). By contrast,

Apiaceae, Commelinaceae, Myrtaceae, and Polygonaceae were families exclusive of SP fallows, most of which species were weeds.

Cluster analyses revealed that most of the differences in species composition between MS and SP fallows are concentrated in two life forms: trees and herbs. Indeed, MS fallows were grouped in a single cluster of tree species and neatly separated from those of SP, which, in turn, were grouped in a distinct cluster (Fig. 2a). Herb species, on the other hand, were also separated by the cropping system into two clusters (Fig. 2d). The composition of tree seedlings, shrubs, and vines were similar in both fallow types and could not be distinguished in the cluster analyses (Fig. 2). In addition, several tree, shrub, vine, and herb species were found to be indicator species of initial fallows of MS (Table 1). Contrastingly, only herb species were indicators of SP fallows (Table 1).
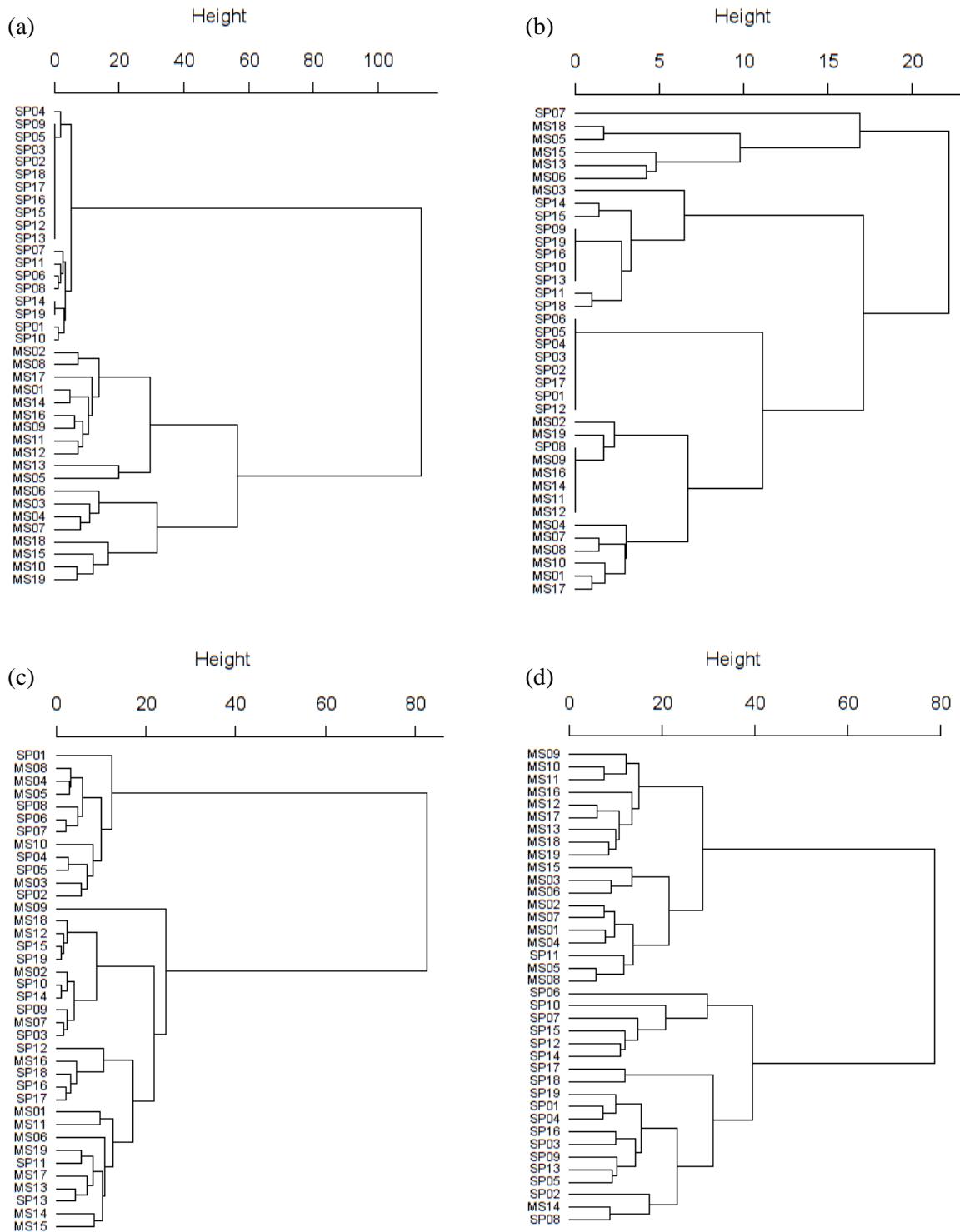
Fig. 2. Cluster dendrograms (Ward method and Euclidean distance) based on the abundance of (a) tree, (b) tree seedling, (c) shrub-vine and, (d) herb species in the two cropping systems in Juquila Vijanos, Oaxaca, Mexico. Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system, 1–19 = number of fields per cropping systems.

Table 1. Significative indicator species and their indicator value (IndVal) of the vegetation of fallows of the two cropping systems recorded in Juquila Vijanos, Oaxaca, Mexico.

Especies	IndVal
Milpa shifting cultivation system	
Trees	
Saurauia scabrida (Actinidaceae)	0.65**
Liquidambar styraciflua (Altiginaceae)	0.76***
Alnus acuminata (Betulaceae)	0.61**
Clethra occidentalis (Clethraceae)	0.94***
Quercus candicans (Fagaceae)	0.60*
Persea liebmannii (Lauraceae)	0.51*
Morella cerífera (Myricaceae)	0.73**
Myrsine coriaceae (Primulaceae)	0.65**
Tree seedlings	
Myrsine coriaceae (Primulaceae)	0.95***
Shrubs	
Senecio oaxacanus (Asteraceae)	0.59*
Moussonia deppeana (Gesneraceae)	0.56*
Vines	
Canavalia villosa (Fabaceae)	0.61**
Clitoria mexicana (Fabaceae)	0.56*
Rubus adenotrichus (Rosaceae)	0.64*
Rubus glaucus (Rosaceae)	0.59*
Herbs	
Iresine diffusa (Amaranthaceae)	0.56*
Ageratina sp. (Asteraceae)	0.83***
Alloispermum integrifolium (Asteraceae)	0.56*

Fleischmannia pycnocephala (Asteraceae)	0.61*
Tithonia longiradiata (Asteraceae)	0.76***
Pseudognaphalium aff. altamiranum (Asteraceae)	0.51*
Pteridium aquilinum (Dennstaedtiaceae)	0.92***
Tibouchina scabriuscula (Melastomataceae)	0.64*
Coccocypselum cordifolium (Rubiaceae)	0.56*

Semi-permanent system

Herbs

Daucus montanus (Apiaceae)	0.51*
Acmella repens (Asteraceae)	0.83***
Ageratum houstonianum (Asteraceae)	0.81***
Galinsoga parviflora (Asteraceae)	0.51*
Jaegeria hirta (Asteraceae)	0.55*
Commelina diffusa (Commelinaceae)	0.56*
Kyllinga pumila (Cyperaceae)	0.89***
Geranium seemannii (Geraniaceae)	0.60*
Hypericum silenoides (Hypericaceae)	0.85***
Sisyrinchium micranthum (Iridaceae)	0.71**
Hyptis atrorubens (Lamiaceae)	0.91***
Cuphea aequipetala (Lythraceae)	0.59*
Plantago major (Plantaginaceae)	0.74**
Axonopus sp. (Poaceae)	0.68**
Paspalum conjugatum (Poaceae)	0.79***
Setaria parviflora (Poaceae)	0.79**

$* = P < 0.05$, $** = P < 0.01$, $*** = P < 0.001$

2.4.2. Tree, shrub, vine, and herb species richness and diversity

With the exception of herbs, MS fallows were more rich and diverse in species of all life form of plants including tree seedlings, and the differences were highly significant (Fig. 3a-d; Table 2). In agreement with those results, the rarefaction curves indicate that MS fallows are richer, per sample unit, in species of trees, tree seedlings, shrubs, and vines than those derived from SP (Fig. 3a-d). Indeed, the tree species based on the exponential of *H'* index was almost fourfold higher in MS than in SP and the difference was highly significant (Table 2). The exponential of *H'* of tree seedling, shrub, and vine species were nearly twice as high in MS as in SP. Only the richness and diversity of herb species of fallows were similar and not significantly different in the two cropping systems (Fig. 3e; Table 2).
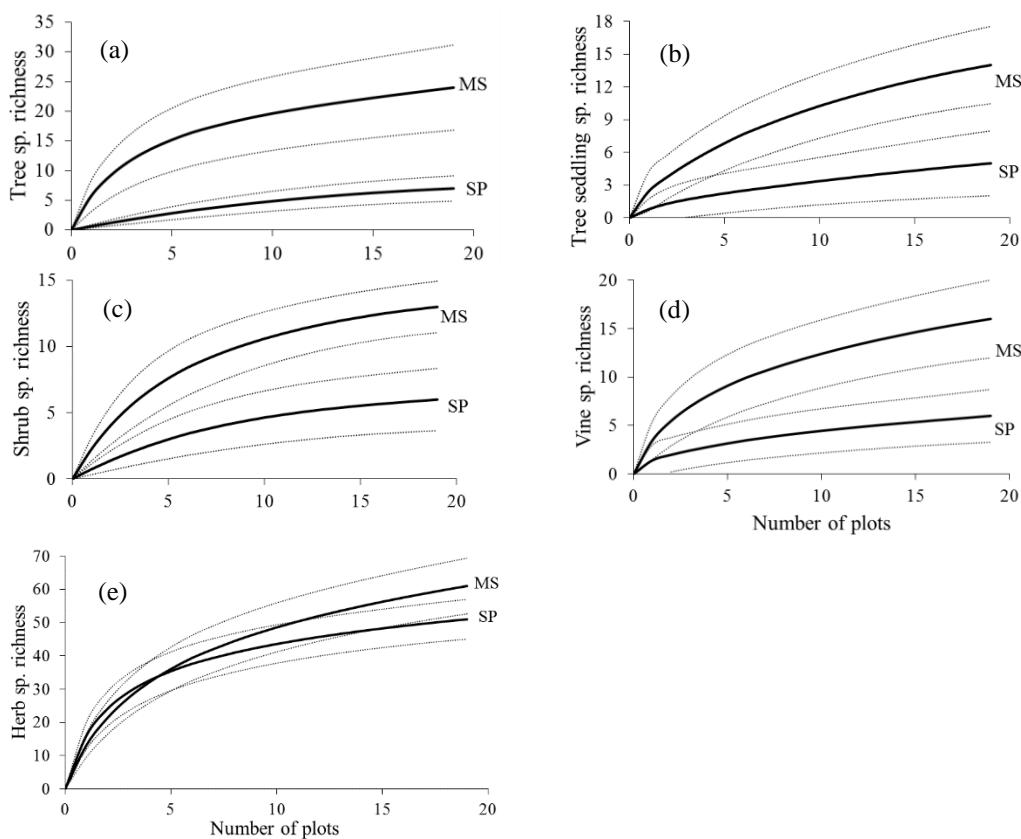

Fig. 3. Sample-based rarefaction curves for the (a) tree, (b) tree seedling, (c) shrub, (d) vine, and (e) herb species recorded in 19 plots in each of the two cropping systems in Juquila, Vijanos, Oaxaca, Mexico. Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system. Solid lines represent rarefaction curves, and dotted lines represent 95% confidence intervals.

Table 2. Mean values ± standard error of diversity based on the exponential of Shannon-Wiener index of plant species by life form recorded in Juquila Vijanos, Oaxaca, Mexico. The statistical test was based on exact Mann-Whitney test (Alpha = 0.05). Cropping systems: MS = *milpa* shifting cultivation, SP = semi-permanent system.

	Cropping system		Exact *P*-value
	MS	SP	
Trees	4.5 ± 0.5	1.2 ± 0.1	0.0000
Tree seedlings	2.2 ± 0.3	1.2 ± 0.1	0.0003
Shrubs	2.1 ± 0.3	1.2 ± 0.1	0.0018
Vines	2.8 ± 0.3	1.3 ± 0.1	0.00001
Herbs	10.6 ± 0.8	12.2 ± 0.8	0.1519

2.4.3. Relationship between the richness and density of plant life forms of early fallows with the surrounding forests

The GLM analyses revealed that the proportion of forestland surrounding early fallows can affect species richness and density of individuals in the fallows but on a life form-specific basis, depending on the age of the adjoining forestlands, and the cropping system from which the fallows were derived (Table 3). In particular, the richness of tree seedling species of fallows of both cropping systems increased with the proportion of adjoining forest fallows of 20-40 years old (Table 3; Fig. 4b). Also, the density of tree seedlings in SP fallows increased sharply with the proportion of 20-40 years old forests, but in MS fallows the presence of adjoining forestlands appear to have no effect (Table 3; Fig. 4g). Conversely, the density of vines decreased in fallows of both cropping systems with the proportion of adjoining 20-40 year old forestlands (Table 3; Fig. 4i). By contrast, there were no significant relationships between the proportion of adjacent forestlands of 10-20 years old and the species richness and density of any life form in early fallows in any of the two cropping systems studied (Table 3).

Finally, the differences in richness of tree, shrub, vine, and herb species, and the density of individuals of tree, shrub, and herb species of fallows were related to the cropping system regardless on the proportion of adjoining forestlands (Table 3; Fig. 4).

Table 3. Generalized Linear Models with the log link function exploring the relationship between the cropping system and the proportion (%) of adjacent vegetation bordering fallows with the species richness and densities of trees, tree seedlings, shrubs, vines, and herbs recorded in fallows in Juquila Vijanos, Oaxaca, Mexico.

Predictors	Trees	Tree seedlings	Shrubs	Vines	Herbs
Species richness					
Intercept	1.765***	0.551*	0.817***	1.245***	2.573***
A: Cropping system	-2.225***	-1.29***	-1.122***	-0.789***	0.200*
B: Forest fallows of 10-20 yr	NS	NS	NS	NS	NS
C: Forest fallows of 20-40 yr	NS	0.008*	NS	NS	NS
A × B	NS	NS	NS	NS	NS
A × C	NS	NS	NS	NS	NS
Density of individuals					
Intercept	3.290***	0.882***	1.670***	2.730***	2.697***
A: Cropping system	-3.595***	-2.043***	-1.150**	-0.463***	0.494***
B: Forest fallows of 10-20 yr	NS	NS	NS	NS	NS
C: Forest fallows of 20-40 yr	NS	NS	NS	-0.006***	NS
A × B	NS	NS	NS	NS	NS
A × C	NS	0.030***	NS	NS	NS

NS = non-significant

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$
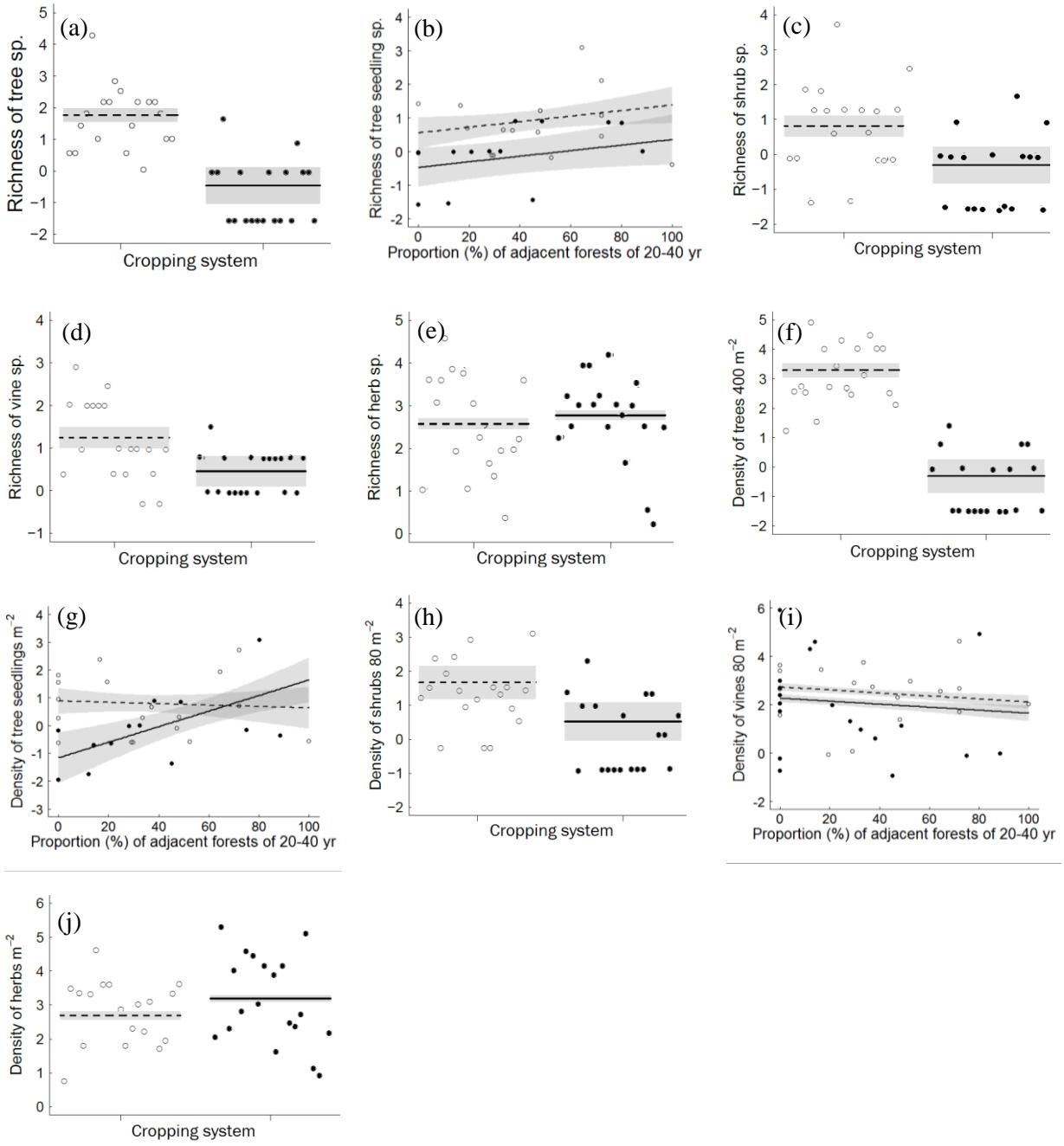
**Fig. 4.** Relationship between species richness and densities of trees, tree seedlings, shrubs, herbs, and vines recorded in initial fallows in Juquila Vijanos, Oaxaca, Mexico, and significant ($P < 0.05$) adjacent vegetation parameters in GLM. See Table 3 for regressions results. *Milpa* shifting cultivation: open circles and dashed regression line. Semi-permanent system: filled circles and solid regression line.

2.5. Discussion

Our results provide a first insight on how apparently subtle changes in cultivation practices affect the dynamics of the landscape in areas originally occupied by TMCFs, and how such change interact with the habitat surrounding the fallows. The replacement of MS by SP alters drastically the vegetation of early fallows and their capacity for TMCF regeneration in TMCFs areas of southern Mexico. This replacement, however, appears to have contrasting effects on different life forms and, in some cases, depends on the proportion and age of the forestlands adjoining the fallows. Of particular importance is the great simplification of woody species richness, density, and diversity in young SP fallows. Trees were by far the most vulnerable life form, whereas herbs were the most favored one by the replacement of MS by SP cultivation practices. The suppression of trees by herbs in fallows when traditional slash-and burn agriculture is substituted by more permanent cropping system has been commonly observed in other regions of the world including Africa and southeast Asia (de Rouw, 1995; de Rouw, 2001; Klanderud et al., 2010). However, in contrast to such studies in which the replacing species in the fallows were mostly exotic species, in TMCF areas, native species were the most commonly observed species in SP fallows (Table 1). This exceptional case could be related to the long-term coevolution of native herbaceous weed species with native maize in crop lands cultivated for centuries by Mesoamerican indigenous groups (Vibrans, 1998; Madamombe-Manduna et al., 2009).

The shift from forest to herbaceous fallows can be ascribed to the observed differences in the cropping system between MS and SP. The combination of long fallow periods, fewer cropping cycles and the reduced intensity of the cultivation management in MS (Pérez-García and del Castillo, 2016), likely accelerates the early recovery of the TMCF. Resprouting of living stumps is probably one the factors that most likely contribute to the rapid recovery of the original vegetation in traditional shifting cultivation agriculture (see Egler, 1954; de Rouw, 1993; Vieira and Proctor, 2007). In MS fallows, the common presence of individuals of *Saurauia scabrida,* an intermediate-successional tree, and the late-successional tree species *Persea liebmannii* and *Quercus candicans* in MS fallows (Table 1) can be explained by the presence of living stumps of these species left during the cultivation period (personal

observation). The presence of intermediate- and the late-successional species illustrate the value of MS fallows as biodiversity reservoirs. By contrast, longer cropping periods with frequent soil tillage and shorter fallow periods in SP can severely decrease the probabilities of occurrence of living stumps of trees and shrubs (de Rouw, 2001). MS fallows may also facilitate a rapid forest regeneration by the common presence of species with N-fixing symbionts, such as *Alnus acuminata* and *Morella cerifera* in the tree stratum (Nair, 1993), and the legume vines *Canavalia villosa* and *Clitoria mexicana* (Table 1). Nitrogen is very limited in TMCF soils (Bautista-Cruz and del Castillo, 2005), and the presence of N-fixing species may facilitate the subsequent establishment of species more vulnerable to N deficiency (see also Glenn-Lewin and van der Maarel, 1992). By contrast, symbiotic N fixing is expected to be rather reduced in SP fallows, as only two small legume herbs at very low abundance were found there (Appendix 1). The dominance of native perennial grasses and Asteraceae forb species in SP fallows (Table 1), has been found in other TMCF areas of Mesoamerica, that have been extremely deforested (Muñiz-Castro et al., 2006; Ortega-Pieck et al., 2011). The intermediate- and long-term successional dynamics of SP and MS fallows warrants further studies. However, the dominance of herb species and the scarcity of trees in early SP fallows lead to the hypothesis that SP fallows may follow a different successional dynamics than MS fallows, in which herbs, not trees, are the dominant life form. This would not be entirely surprising as alternative stable states dominated by either trees or grasses are common in other tropical habitats, such as lowland tropical areas (see Warman and Moles, 2009). Furthermore, native grass species in fallows of SP can persist and even increase in abandoned pasturelands in other TMCF areas (Muñiz-Castro et al., 2006; Ortega-Pieck et al., 2011).

Understanding the effects of changes of cultivation practices on the dynamics of the landscape cannot be understood thoroughly without paying attention to the spatial habitat configuration of the landscape. A correct management of crop lands associated with shifts from periods of cultivation and secondary succession requires paying more attention to the resulting fallows, which dynamics, in turn, is also affected by the quantity and quality of the adjoining vegetation. In agreement with our

predictions, we have found evidence showing that the proportion of forestlands older than 20 years old adjoining the fallows can be a crucial relationship for forest regeneration in SP fallows where such forests are likely the major seed source. As discussed above, stump eradication by tillage and long cropping phases likely decrease the probabilities of forest regeneration from sprouting or seeds stored in the soil in SP fallows. Furthermore, seeds, particularly those of late-successional species, tend to have short lifespans in the seed bank (Chazdon, 2014). Since seed dispersal is often limited, the nearest seed sources are likely those with the highest apportionment of seeds (del Castillo and Pérez-Ríos, 2008). Seed apportionment of young forest should be minimal due to the low density of seed producing trees, thus explaining the lack of effects on the vegetation on the studied fallow types. On the other hand, the lack of detectable effects of the presence of forest surrounding the vegetation of MS fallows suggests that forest regeneration in such fallows depends mostly on *in situ* propagule sources, whereas in SP fallows seed dispersal is the main propagule source. On the other hand, the establishment of herbs and vines depends much more on the open areas since forest fallows tend to suppress herbaceous weed and vine species by the shade cover (de Rouw, 1995; del Castillo and Blanco-Macías, 2007). Thus, these life forms may be benefited by the presence of open areas. The absence of adjacent forest fallows from advanced successional stages can be an additional factor that arrests secondary succession owing to the inexistence of propagules of trees, which is consistent with current views of succession in tropical areas (Finegan and Nasi, 2004; Martínez-Ramos and García-Orth, 2007; del Castillo and Pérez-Ríos, 2008).

Our results therefore, illustrate how habitat configuration (presence of nearby forestlands) and the quality (forest age) of the adjoining vegetation tends to have contrasting effects on the vegetation of early fallows originated from distinct cultivation practices. Changes in cultivation systems do not only affect cropping phase but likely alter the entire dynamics and biodiversity of the landscape. Clearly management of conservation of TMCFs areas in which cropping lands are temporarily and spatially alternated with forest areas requires adopting more landscape-oriented schemes, which consider the entire landscape and the interaction between the different components of the landscape. Such kind of

approach has been successfully applied in other landscapes of the world such as the agricultural landscapes of Northwest Europe (Kleyer et al., 2007).

2.5.1. Socio-environmental implications of fallow transformation by changes in the cropping system

The species depauperation in SP fallows may be detrimental for the livelihoods of local people since shifting cultivation fallow species had a great ecological, economic, and cultural value as suggested by Rerkasem et al. (2009) and Xu et al. (2009). In TMCF areas, the species of MS fallows are important sources of firewood, timber, medicine, ornament, and food to the local people (Aguilar-Santelises, 2007). Also, the higher capacity of MS fallows to regenerate secondary forests can accelerate weed suppression and soil recovery which are crucial for the sustainability of shifting cultivation agriculture (de Rouw, 1995; Kleinman et al., 1995).

In addition to the impact on biodiversity, the substitution of MS by SP may affect ecosystem services and jeopardize ecosystem integrity. The suppression of stumps associated with this practice is likely the major cause of the decrease of trees in SP fallows. The observed reduction in tree density in SP fallows suggests that the capacity for carbon sequestration is greatly reduced relative to those of MS. Indeed, the higher rates of soil carbon sequestration have been detected during the first 15 years after abandonment (Bautista-Cruz and del Castillo, 2005). Such increases coincide with the highest increases observed in tree density and basal area in chronosequences at the study site (del Castillo and Blanco-Macías, 2007). The practice of tillage in SP does not only retard forest regeneration by the removal of stumps in the post-cultivation fallows, but may contribute to increase the risks of erosion, particularly in areas with steep slopes as those of TMCF (see Dale and Polasky, 2007).

2.6. Conclusions

Our data support the hypotheses that the change in the native maize cropping system is associated with changes in the vegetation of initial fallows derived from the tropical montane cloud forest in southern Mexico. The initial fallows shift from tree to perennial grass-forb fallows with the

substitution of traditional *milpa* system by the semi-permanent system. Fallows of the semi-permanent system without contiguous forestlands can arrest the secondary succession and increase the prevalence of herbaceous fallows. The prevalence of herbs in SP may diminish the availability of multiple environmental services provided by tree fallows of the traditional *milpa*. Also, the land degradation can increase even more owing to the eradication of N-fixing, pioneer, and late-successional tree species. Therefore, the prohibition of the *milpa* system should be reconsidered not only because the consequences discussed during the cropping phase but also because during the fallow phase the capacity of the fallows as biodiversity reservoirs is severely diminished, forest recovery is hampered and ecosystem services are reduced.

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2.8. Appendix 1. Tree, shrub, vine, and herb species recorded in the two cropping systems (MS = *milpa* shifting cultivation, SP = semi-permanent system) in Juquila Vijanos, Oaxaca, Mexico, and their life form (T = tree, S = shrub, V = vine, H = herb) and number of individuals.

Taxa	Life form	Number of individuals in the cropping systems	
		MS	SP
Actinidiaceae			
Saurauia scabrida Hemsl.	T	20	0
Adoxaceae			
Viburnum hartwegii Benth.	T	5	0
Altingiaceae			
Liquidambar styraciflua L.	T	114	1
Amaranthaceae			
Iresine diffusa Humb. & Bonpl. ex Willd.	H	13	0
Apiaceae			
Daucus montanus Humb. & Bonpl. ex Schult.	H	0	7
Asteraceae			
Acmella repens (Walter) Rich. ex Pers.	H	0	40
Ageratina pazcuarensis (Kunth) R.M.King & H.Rob	H	1	4
Ageratina sp.	H	32	5
Ageratum conyzoides (L.) L.	H	1	6
Ageratum echioides (Less.) Hemsl.	H	1	0
Ageratum houstonianum Mill.	H	3	93
Aldama dentata La Llave ex La Llave	H	0	1

Alloispermum integrifolium (DC.) H.Rob.	H	8	0
Asteraceae sp. 1	H	1	0
Bidens odorata Cav.	H	0	3
Bidens sp.	H	0	6
Conyza canadensis L.	H	0	1
Erechtites hieraciifolius (L.) Raf. ex DC.	H	4	3
Fleischmannia pycnocephala (Less.) R.M.King & H.Rob.	H	13	0
Galinsoga parviflora Cav.	H	0	6
Gnaphalium americanum Mill.	H	7	33
Jaegeria hirta (Lag.) Less.	H	1	17
Lactuca graminifolia Michx.	H	1	0
Melampodium longifolium Cerv. ex Cav.	H	0	2
Mikania pyramidata Donn. Sm.	V	4	1
Mikania sp.	V	1	0
Perymenium discolor Schrad.	H	1	0
Piqueria trinervia Cav.	H	9	28
Podachaenium pachyphyllum (Sch.Bip. ex Klatt) "R.K.Jansen, N.A.Harriman & Urbatsch"	H	3	0
Pseudognaphalium aff. altamiranum	H	8	0
Pseudognaphalium attenuatum (DC.) Anderb.	H	9	13
Schistocarpha longiligula Rydb.	H	1	0
Senecio oaxacanus Hemsl	S	31	6
Smallanthus maculatus (Cav.) H.Rob.	H	7	0
Stevia microchaeta Sch.Bip. ex Sch.Bip.	H	3	0
Tithonia longiradiata (Bertol.) S.F.Blake	H	18	0
Betulaceae			
Alnus acuminata Kunth	T	24	0
Brunelliaceae			

Brunellia mexicana Standl.	T	2	0
Campanulaceae			
Lobelia laxiflora Kunth	H	3	0
Lobelia sartorii Vatke	H	1	0
Caryophyllaceae			
Drymaria villosa Schltdl. & Cham.	H	6	6
Chloranthaceae			
Hedyosmum mexicanum C.Cordem.	T	6	1
Clethraceae			
Clethra lanata M.Martens & Galeotti *(= C. kenoyeri)*	T	2	0
Clethra occidentalis (L.) Kuntze *(= C. integerrima)*	T	147	3
Commelinaceae			
Commelina diffusa Burm.f.	H	0	9
Cyperaceae			
Cyperus esculentus L.	H	12	3
Kyllinga pumila Michx.	H	0	57
Dennstaedtiaceae			
Pteridium aquilinum (L.) Kuhn	H	61	7
Ericaceae			
Bejaria aestuans Mutis ex L. *(= B. laevis)*	T	11	0
Gaultheria erecta Vent.	T	2	0
Lyonia squamulosa M. Martens & Galeotti	T	14	0
Vaccinium consanguineum Klotzsch	T	1	0
Euphorbiaceae			
Acalypha aff. langiana	H	7	1
Acalypha sp.	H	5	0
Fabaceae			
Calliandra grandiflora (L'Her.) Benth.	S	10	0

Canavalia villosa Benth.	V	12	0
Clitoria mexicana Link	V	9	0
Crotalaria sagittalis L.	H	4	0
Desmodium intortum (Mill.) Urb.	V	6	1
Inga latibracteata Harms	T	1	0
Mimosa albida Willd.	S	11	0
Mimosa pudica L.	H	0	5
Rhynchosia longeracemosa M.Martens & Galeotti	V	4	0
Senna pallida (Vahl) H.S.Irwin & Barneby	S	4	0
Stylosanthes sp. Kunth	H	2	0
Vigna speciosa (Kunth) Verdc.	V	2	0
Fagaceae			
Quercus candicans Née	T	33	1
Quercus elliptica Née	T	4	0
Quercus lancifolia Schltdl. & Cham.	T	7	0
Quercus laurina M.Martens & Galeotti	T	1	0
Quercus salicifolia Née	T	18	0
Geraniaceae			
Geranium seemannii Peyr.	H	4	26
Gesneriaceae			
Moussonia deppeana (Schltdl. & Cham.) Klotzsch ex Hanst.	S	6	0
Hypericaceae			
Hypericum hypericoides (L.) Crantz	H	2	0
Hypericum silenoides Juss.	H	1	44
Vismia camparaguey Sprague & L.Riley	T	14	1
Iridaceae			
Sisyrinchium micranthum Cav.	H	1	22
Lamiaceae			

Hyptis atrorubens Poit.	H	26	123
Hyptis mutabilis (Rich.) Briq.	H	0	2
Salvia lasiocephala Hook. & Arn.	H	0	2
Salvia tiliifolia Vahl	H	2	0
Lauraceae			
Litsea glaucescens Kunth	S	2	0
Persea americana Mill.	T	1	3
Persea liebmannii Mez	T	6	0
Lythraceae			
Cuphea aequipetala Cav.	H	3	15
Magnoliaceae			
Magnolia dealbata Zucc.	T	4	3
Malvaceae			
Heliocarpus donnellsmithii Rose	T	2	0
Triumfetta grandiflora Vahl	S	11	2
Melastomataceae			
Conostegia icosandra (Sw. ex Wikstr.) Urb.	S	11	1
Conostegia xalapensis (Bonpl.) D. Don ex DC.	S	0	3
Heterocentron subtriplinervium (Link & Otto) A. Braun & C.D. Bouché	H	9	12
Miconia glaberrima (Schltdl.) Naudin	S	2	3
Tibouchina scabriuscula (Schltdl.) Cogn.	H	29	5
Menispermaceae			
Cissampelos pareira L.	V	5	0
Myricaceae			
Morella cerifera (L.) Small	T	61	0
Myrtaceae			
Psidium guineense Sw.	S	0	17
Onagraceae			

Lopezia racemosa Cav.	H	41	62
Orobanchaceae			
Castilleja arvensis Schltdl. & Cham.	H	2	0
Passifloraceae			
Passiflora biflora Lam.	V	1	0
Phyllonomaceae			
Phyllonoma laticuspis (Turcz.) Engl.	S	4	0
Phytolaccaceae			
Phytolacca americana L.	H	1	0
Phytolacca icosandra L.	H	0	6
Pinaceae			
Pinus chiapensis (Martínez) Andresen	T	13	31
Plantaginaceae			
Plantago major L.	H	2	41
Poaceae			
Agrostis ghiesbreghtii E. Fourn.	H	3	0
Arundinella deppeana Nees	H	2	0
Axonopus sp. *(Sw.)* P.Beauv.	H	0	22
Digitaria ciliaris (Retz.) Koeler	H	0	5
Lasiacis procerrima (Hack.) Hitchc. ex Chase	H	6	0
Panicum commutatum Schult.	H	10	1
Panicum dichotomum L.	H	41	25
Panicum laxiflorum Lam.	H	17	3
Panicum viscidellum Scribn.	H	9	0
Paspalum conjugatum P.J.Bergius	H	1	49
Paspalum sp.	H	0	7
Setaria parviflora (Poir.) M.Kerguelen	H	7	39
Polygalaceae			

Monnina xalapensis Kunth	H	1	0
Polygala paniculata L.	H	0	1
Polygala sp.	S	3	0
Polygonaceae			
Rumex crispus L.	H	0	5
Polypodiaceae			
Polypodium plebeium Schltdl. & Cham.	H	1	0
Primulaceae			
Anagallis arvensis L.	H	0	1
Myrsine coriacea (Sw.) R.Br. ex Roem. & Schult.	T	69	2
Rosaceae			
Prunus persica (L.) Batsch	T	0	2
Prunus serotina Ehrh.	T	1	0
Rubus adenotrichus Schltdl.	V	36	11
Rubus coriifolius Liebm.	V	3	4
Rubus glaucus Benth.	V	21	1
Rubiaceae			
Arachnothryx sp.	S	5	0
Coccocypselum cordifolium Nees & Mart.	H	18	0
Coccocypselum hirsutum Bartl. ex DC.	H	3	0
Crusea calocephala DC.	H	22	21
Spermacoce laevis Lam.	H	14	23
Selaginellaceae			
Selaginella sp.	H	37	5
Smilacaceae			
Smilax glauca Walter	V	128	141
Smilax subpubescens A.DC.	V	2	0
Solanaceae			

Solanum nigrescens M. Martens & Galeotti	H	3	1
Solanum schlechtendalianum Walp.	S	1	0
Verbenaceae			
Lippia myriocephala Schltdl. & Cham.	T	11	2
Vitaceae			
Vitis bourgaeana Planch.	V	1	0
Vitis sp.	V	1	0
Total		1495	1165

Capítulo 3. Conclusiones generales

La sustitución de la milpa tradicional por un sistema semipermanente de producción en áreas ocupadas originalmente por bosque de niebla se relaciona con los cambios detectados en la agrobiodiversidad y diversidad florística de la vegetación de acahuales.

El policultivo tradicional de maíz-frijol es sustituido por el monocultivo de maíz. En particular, los maíces pigmentados de la raza local predominante y dos especies de frijol de hábitos trepadores son reemplazados por el cultivo de maíz blanco de la raza local dominante. Además, la composición de arvenses cambia por completo y se incrementa la cobertura total de arvenses. En particular, las arvenses de vida larga asociadas normalmente con sitios agrícolas con disturbios mínimos del suelo son erradicadas para dar paso al establecimiento de arvenses de vida corta adaptadas a sitios con laboreo frecuente del suelo.

Respecto a los acahuales o vegetación secundaria en la etapa de descanso de los terrenos, los acahuales arbóreos y arbustivos son transformados en acahuales herbáceos dominados por pastos y hierbas. Además, estos nuevos acahuales herbáceos pueden mantener su presencia en el paisaje y detener la sucesión secundaria forestal. Por lo tanto, la capacidad de recuperación de los bosques en los acahuales del sistema semipermanente es prácticamente nula.

Finalmente, la sustitución del sistema milpa tradicional por el sistema semipermanente de producción es un factor adicional que puede disminuir en gran mediada la biodiversidad ligada a las culturas ancestrales ubicadas en el bosque de niebla mesoamericano. Además, este cambio en el sistema de producción incrementa el riesgo de deforestación permanente y degradación de la tierra por la infestación de especies herbáceas en los terrenos cultivados y acahuales.