El Colegio de la Frontera Sur

Modelación computacional de procesos sociales agroecológicos

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Con orientación en Agroecología y Sociedad

Por

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Tabla de Contenido

Resumen

La masificación de la agroecología ha sido estudiada profundamente con un enfoque social y se han llegado a apuntar distintos factores claves que aparecen en varios casos emblemáticos de difusiones masivas de los principios agroecológicos en familias campesinas y urbanas. Dado que las ciencias de la complejidad han permitido formular modelos que nos dan un mayor entendimiento sobre la dinámica y fuerzas de distintos procesos ecológicos y sociales, pensamos que es posible crear modelos para obtener mayor entendimiento de los procesos de masificación. Por ello, nuestro objetivo fue formular dos modelos de procesos agroecológicos y estudiar con ellos dos posibles escenarios. Diseñamos un primer modelo que considera el componente de la racionalidad campesina, esto es, las consideraciones que hacen los campesinos al tomar decisiones, que es sustancialmente diferente de la racionalidad capitalista. El segundo componente es la dinámica impuesta sobre la parcela derivada de esas decisiones sobre sus prácticas (ya sean agroecológicas o agroquímicas). El segundo modelo que diseñamos fue sobre la difusión de prácticas utilizando métodos pedagógicos intencionados (extensionismo técnico y Campesino a Campesino. CaC) sobre una estructura social preexistente (la Asociación Nacional de Agricultores Pequeños de Cuba). Con estos modelos estudiamos dos casos particulares, los subsidios a agroquímicos y el Movimiento Campesino a Campesino (MACaC) de Cuba. Con ello, fue posible dar argumentos de una manera sistematizada acerca del empobrecimiento ecológico y económico de las familias campesinas por la presencia de subsidios agroquímicos, y por otro lado, sobre las ventajas de CaC para masificar la agroecología en comparación con el extensionismo clásico. También encontramos propiedades emergentes al combinar la influencia de vecinos con la labor de los facilitadores de CaC. En general, consideramos que nuestro trabajo es una herramienta

que permite ampliar nuestro entendimiento sobre las interacciones de los componentes de los procesos de la masificación agroecológica y cómo se combinan para acelerar o detener la adopción de la agroecología.

Palabras clave

Racionalidad campesina, Campesino a Campesino, complejidad, masificación de la agroecología, prácticas agroecológicas

Capítulo 1: Introducción

Masificación de la agroecología y complejidad

La agroecología es una alternativa ante el modelo de producción industrial agrícola basado en la acumulación de capital (Vandermeer y Perfecto, 2018; Sevilla Guzman, 2006). La agroecología busca el cuidado de la biodiversidad y recursos naturales mientras cultiva, cosecha y transforma alimentos sanos y accesibles para los pueblos (LVC, 2018). Es importante recalcar que la agroecología no se reduce a un tema de producción, sino que como movimiento se sustenta en el conocimiento ancestral del campesinado (Altieri y Toledo, 2011, Daza y Vargas, 2012). Esta revalorización de los saberes populares se enriquece en un diálogo horizontal con la ciencia (Altieri y Toledo, 2011). Ejemplo de ello lo vemos en el libro *Ecological Complexity and Agroecology* de Vandermeer y Perfecto (2018) donde señalan múltiples formas en las que el conocimiento tradicional campesino aporta al entendimiento de los agroecosistemas estudiados desde la complejidad ecológica y viceversa. Aún más, ellos concluyen que la complejidad ecológica debiera ser la base científica en la agroecología (Vandermeer y Perfecto, 2018).

La complejidad ecológica estudia los ecosistemas reconociendo que son sistemas complejos, esto quiere decir que, si uno aplica los principios mecanicistas del siglo XIX (Morin, 1994), de separar en partes un ecosistema para tratar de entenderlo, fracasará.

Lo que ocurre es que a partir de la interacción de las partes de un proceso (o sistema), emergen propiedades nuevas, que a su vez cambian el comportamiento que presentan las partes aisladas (Levins y Lewontin, 1985). Los procesos sociales agroecológicos ocurren dentro de diversos ecosistemas y conviene estudiarlos desde la perspectiva de la complejidad.

Existe investigación amplia que ha permitido entender diferentes aspectos de los procesos sociales agroecológicos desde un enfoque de las ciencias sociales (Mier y Terán et al., 2018; Giraldo y Rosset, 2016), sin embargo, cada vez más se reconoce el potencial que presenta la modelación computacional fundamentada en las ciencias de la complejidad para simular escenarios de estos procesos (Rivera-Núñez et al, 2021), visualizar las interacciones de las variables identificadas en las investigaciones y hacer análisis que contribuyan al entendimiento de los procesos sociales agroecológicos.

En esta investigación abordamos precisamente esta intersección de la complejidad ecológica y los procesos sociales agroecológicos. Aunque la mayor parte de los modelos en complejidad ecológica no tratan directamente el comportamiento humano, existen algunos que abordan temas económicos. Por ejemplo Vandermeer y Perfecto (2018) mencionan un ejemplo de manejo del agroecosistema, en particular la decisión de sembrar o no jitomates por parte de los campesinos considerando el precio del mercado. Al modelar esta intuición es posible ver el comportamiento caótico del precio del tomate a lo largo del tiempo. Otro ejemplo, en donde se aborda un proceso socio-ecológico es el artículo de Villegas-Gonzales et al. (2015) titulado “Modelación integrada de sistemas socio-ecológicos complejos”. Este trabajo presenta un modelo donde se integran dos componentes: uno de la hidrodinámica de las inundaciones y otro referente a las decisiones sociales. Concluyen que la modelación integrada permite asistir en el diseño de políticas, así como en procesos educativos. Estos dos modelos, ya sea que los veamos como ejemplos de la complejidad ecológica o de la integración de sistemas socio-ecológicos complejos, manifiestan el potencial que ya mencionamos, y brindan un entendimiento sobre los socio-ecosistemas e incluso se pueden utilizar para incidir en el diseño de políticas y la educación. Precisamente ese entendimiento y búsqueda de incidencia fue lo que nos motivó a hacer la presente investigación.

En esta investigación aplicamos este enfoque a procesos sociales agroecológicos que entran dentro del área de la masificación, territorialización o escalamiento de la agroecología, la cual según Giraldo et al. (2021), puede definirse como:

> …un proceso que lleva a un número cada vez mayor de familias a practicar la agroecología en territorios cada vez más amplios, y que involucra a más personas en el procesamiento, distribución y consumo de alimentos producidos de forma agroecológica, tanto en el campo como en la ciudad.

En los dossieres *Scaling agroecology* (2019) y *Territorialización de la agroecología* (2021), los autores presentan un compendio de investigaciones, que han realizado desde 2014, para analizar los procesos organizativos, pedagógicos y políticos que consideran fundamentales para la difusión de las prácticas agroecológicas y el crecimiento del movimiento. En estos trabajos es posible reconocer factores claves (Mier y Terán et al., 2018) y al mismo tiempo distintos beneficios que conlleva. Por ejemplo, con los procesos pedagógicos como Campesino a Campesino promovidos por la Asociación Nacional de Agricultores Pequeños (ANAP) en Cuba y la Coordinadora Latinoamericana de Organizaciones del Campo (CLOC-Vía Campesina) en Latinoamérica, también se manifiesta una integración y formación política campesina (Val et al, 2019; Rosset et al., 2019). Otros beneficios incluyen: identificación de medios descolonizadores a partir de inventarios de prácticas agroecológicas (Ferreira et al, 2021), el arraigo territorial, las identidades indígenas y la importancia de la soberanía alimentaria a través de la presencia de redes de semillas criollas y nativas (García et al, 2019), formación de personas críticas en la Universidad Bolivariana de Venezuela que llegaron a ocupar cargos institucionales y plantear proyectos que avanzan la agroecología en el campo y la ciudad (Domené y Herrera, 2019), entre muchos otros que se pueden consultar en las publicaciones.

Estos procesos en la masificación ocurren a lo largo de muchos años, por lo cual no es común estudiarlos desde un enfoque en el que se decide realizar experimentos. También es difícil determinar cuáles variables debemos observar y es realmente un reto darles seguimiento a lo largo del tiempo. Considerando que estos procesos son complejos, muchas veces lo que observamos son las propiedades emergentes, precisamente por ello es difícil distinguir qué variables están contribuyendo a que surja ese comportamiento. Además, en las investigaciones puramente sociales no es usual explorar las interacciones de los procesos sociales con las variables y dinámica ecológica de los ecosistemas. Con una modelación que se fundamenta en el entendimiento que ya han aportado las investigaciones sobre masificación es posible hacer una especie de laboratorio para probar ideas, teorías y estrategias. De la misma manera, será posible incorporar la dinámica ecológica usando la perspectiva de la complejidad.

El propósito de estos experimentos no es la predicción. Más bien, a través de simulaciones en donde es fácil cambiar parámetros, agregar o quitar variables e incluso modificar los componentes o reglas de un modelo, comprender las interacciones entre variables y sus implicaciones para la manifestación de comportamientos complejos. La modelación de los procesos de la masificación de la agroecología puede ser de gran ayuda para entender las interacciones subyacentes y sinergias entre componentes que permiten propiedades emergentes, que favorezcan o detengan la difusión de la agroecología a través de los movimientos campesinos. También podemos esperar que estos modelos puedan incidir en el diseño de políticas y en la educación como concluyeron Villegas-Gonzales et. al (2015) con su modelo de inundaciones.

En este trabajo de investigación planteamos dos modelos para estudiar la masificación de la agroecología retomando algunos de los factores clave señalados en el trabajo de Mier y Terán et al (2018). El primer modelo, se enfoca en la dinámica de la adopción y abandono de la agroecología considerando los factores de prácticas ecológicas efectivas y políticas (des)favorables. Para ellos nos centramos en las decisiones de los campesinos incorporando las ideas de Alexander Chayanov (1966) y Jan Douwe van der Ploeg (2015) sobre la racionalidad campesina y las dinámicas ecológicas que se establecen por el tipo de prácticas implementadas en la parcela (agroquímicas o agroecológicas). En el segundo modelo consideramos los factores de la organización social y los procesos de aprendizaje constructivista. Esto lo hicimos tomando el caso del proceso de masificación agroecológica del Movimiento Agroecológico Campesino a Campesino (MACaC), que impulsó la revolución agroecológica en Cuba (Machin et al, 2011) utilizando la estructura de la ANAP y el proceso de aprendizaje de Campesino a Campesino.

En las siguientes secciones presentamos una síntesis de las investigaciones dentro de las ciencias sociales que han estudiado los temas que abordamos en nuestros modelos y nos motivaron a plantearlos. Después incluimos una sección sobre nuestra metodología, en donde exponemos nuestra postura sobre la modelación y planteamos el propósito de nuestra investigación. También mostramos cuáles son los pasos que hacemos al plantear un modelo y cómo lo implementamos en un algoritmo computacional. Posteriormente incluimos una sección que hace una síntesis de trabajos de modelación que motivaron y aportaron elementos que usamos al hacer nuestros modelos. Al final de este capítulo introductorio cerramos con la estructura de la tesis.

Marco Teórico Social

La racionalidad campesina Marco teórico social

Las decisiones de qué prácticas utilizar en la parcela son procesos complejos que llevan a cabo las familias campesinas. Los intentos por entender estos procesos realizando analogías entre la familia campesina y la empresa capitalista han fracasado rotundamente (Chayanov, 1966). El fracaso se debe a que las analogías son muy reduccionistas en dos formas. La primera es que las personas toman decisiones parcialmente racionales (Simon, 1957) cuando se trata de problemas complejos. La segunda es que las decisiones de las familias campesinas no siguen los mismos paradigmas de la economía clásica (Chayanov, 1966). La Teoría de la Economía

Campesina de Chayanov (1966) ofrece un marco conceptual centrado en la familia campesina, la cual propone como Unidad Económica Campesina (UEC). Esta teoría, apoyada por evidencia empírica obtenida por el mismo Chayanov en Rusia, se caracteriza por afirmar que la UEC no es una unidad capitalista, es decir, no funciona centrada en la generación de lucro. La UEC tiene un funcionamiento más complejo que es mejor descrito por una serie de balances dinámicos, subjetivos e influenciables por el contexto.

> [aunque la UEC está] influenciada por el contexto capitalista en el que opera, no está directamente gobernada por éste. Más bien por balances …[que] son principios de orden. Ellos forman y reforman la manera en que se trabajan los campos… y cómo se desenvuelven y materializan identidades y relaciones mutuas (Van der Ploeg, 2015:21)

De modo que la UEC no aplica una fórmula estática para conocer los costos y producción que habrá, sino que se genera en una dinámica compleja por la interconectividad que existe entre los balances involucrados buscando un "todo funcional". Chayanov, probablemente por esto, también se refiere al quehacer campesino como el "arte de la agricultura" (Van der Ploeg, 2015).

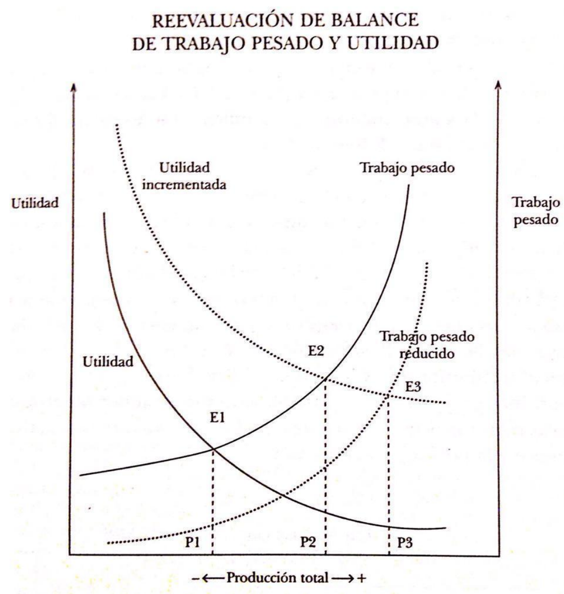
Hay dos balances propuestos en la teoría que tienen potencial para modelar la toma de decisiones de la familia campesina ante esta complejidad de interacciones en la que se encuentra. Al pensar en estos balances debemos considerar que en una UEC los diferentes miembros tendrán una fuerza de trabajo y nivel de consumo diferente, por ejemplo, un bebé, un adulto y un anciano difieren en esos dos aspectos. El primer balance se expresa en términos de trabajo/consumo, donde la UEC usa su fuerza de trabajo hasta que se cubran las necesidades de consumo de toda la familia. El segundo balance es expresado en términos de trabajo pesado/utilidad. El trabajo pesado tiene que ver con la carga individual de cada trabajador en la familia, éste aumenta con la producción total. La utilidad tiene que ver con el beneficio extra que se obtiene al aumentar la producción y va disminuyendo conforme aumenta la producción. Ambos elementos del balance pueden ser modificados por intercambios culturales y por el contexto. Podemos aclarar lo que esto significa con el siguiente ejemplo del libro *El Campesinado y el arte de la agricultura* (2015) de Van der Ploeg:

> "... si la utilidad aumenta más allá de las necesidades de consumo familiares

inmediatas (por ejemplo, para la creación de una 'granja hermosa'…) se define otra 'curva de utilidad'... Sólo entonces, la familia granjera…[emprende] la formación de capital (construir los ingredientes de la 'granja hermosa' del futuro) ...

Esto podría llevar a la redefinición del trabajo pesado: cuando se sabe que el acto de producir patatas también abre la posibilidad de mejorar las condiciones de vida…" (Van der Ploeg, 2015:62)

Figura 1. Reevaluación de balance de trabajo pesado y utilidad



Fuente: Van der Ploeg, 2015: 63

En la Figura 1 se puede apreciar a lo que se refiere Van der Ploeg en la cita anterior, esto es, que el aumento de la producción en una familia campesina se puede vincular a la revalorización de lo que es necesario, así como al cambio de percepción de la carga que implica el trabajo. De la misma manera, agentes externos que tengan incidencia sobre los recursos que utilizan las familias, pueden generar un cambio de percepción. En nuestro modelo exploramos este caso, donde una política pública que subsidia las prácticas agroquímicas puede llegar a distorsionar los balances campesinos. Este proceso de reevaluación de la utilidad y el trabajo pesado marcan las pautas para la propuesta del modelo, ya que buscamos simular cualitativamente la diversidad en el acervo de saberes de las familias en una red social campesina y las incidencias de agentes externos.

La teoría original de Chayanov ha sido criticada por no incorporar elementos relevantes hoy en día como la alta dependencia de insumos y las alternativas de trabajo para el campesino, sin embargo, es posible incorporar estos elementos en el balance trabajo pesado/utilidad.

En su libro Van der Ploeg presenta otros balances relevantes hoy en día, por ejemplo:

a) hombre/naturaleza viva
b) producción/reproducción
c) recursos internos/externos
d) autonomía/dependencia
e) Escala/ intensidad

Hay quienes cuestionan el valor del aporte de estos balances basándose en la subjetividad mencionada (Ploeg, 2015), sin embargo, al contrario de restar valor, la subjetividad nos guía a la hora de construir un modelo, ya que advierte que una sobre simplificación de la racionalidad campesina podría resultar en resultados totalmente desproporcionados. Sin duda alguna, es más simple contar horas de trabajo y capital, pero eso no debe ser motivo para omitir las variables culturales involucradas, aunque esto implique complicaciones al trabajo y muy probablemente complejidad analítica. Además, precisamente el que no dependa de un cálculo reduccionista entre horas de trabajo y capital, es lo que permite a la UEC sobrevivir en situaciones donde una empresa capitalista simplemente no podría (Van der Ploeg, 2015).

Por último, otra razón por la que se escoge la teoría de Chayanov para nuestro primer modelo es porque parte de una postura donde el campesinado no es una figura obsoleta o destinada a desaparecer dando lugar a una clase capitalista y una obrera del campo, como se pensaba desde la perspectiva de la economía clásica y neoclásica, así como desde la perspectiva de Marx (al menos su postura inicial) y algunos de sus seguidores como Kautsky y Lenin (Thorner, 1966) . Al contrario, éste viene a ser un punto de partida para la transformación social. Este punto de vista es compartido por millones de campesinos en movimientos internacionales campesinos como La Vía Campesina (LVC, 2013).

Para el primer modelo también consideramos la investigación sobre los efectos de las prácticas agroecológicas y las prácticas agroquímicas en las parcelas campesinas. Las investigaciones de Gliessman (2015), Altieri (2009), Epstein (1997) Pretty (2008), Graber et al. (1995) entre muchos otros, registran los efectos a largo plazo de las prácticas agroquímicas y las agroecológicas. Estos resultados determinaron las ecuaciones con las que modelamos el componente ecológico en nuestro primer modelo, esto es, nuestra representación de las familias campesinas toma en cuenta la situación ecológica de la parcela dentro de su balance con el cual toman decisiones. En el artículo se encuentra con mayor detalle los supuestos que hicimos a partir de esas investigaciones.

En esta sección presentamos una síntesis de la teoría social-económica que sustenta y motiva nuestro primer modelo. En la siguiente queremos seguir el mismo formato, pero para nuestro segundo modelo, el cual se refiere a la difusión de las prácticas agroecológicas.

La difusión en movimientos agroecológicos

La difusión de la agroecología existe desde los años 70 y se ha dado a través de diversos movimientos sociales (Holt-Giménez 2008, Mier y Terán et al. 2018). Debido al gran cambio que propone en cuanto a la manera de hacer agricultura y al sistema social, ha sido nombrada revolución agroecológica (Machín et al. 2011, Altieri y Toledo 2011). Este movimiento no está limitado a una nación, al contrario, campesinos alrededor del mundo se han unido a la revolución agroecológica y forman parte del movimiento campesino global La Vía Campesina (LVC), que cuenta con más de 200 millones de campesinos (LVC, 2013) y cuyo slogan es “Globalicemos la lucha, globalicemos la esperanza”. Esta lucha es en contra de la “revolución verde”, la producción agrícola industrial y las metodologías anti dialógicas para extenderla (Giraldo y Rosset, 2021), que han recrudecido las diferencias en el sistema social a través de la generación de dependencias de insumos (George 1977, Freebairn 1995) y de la negación del valor del conocimiento tradicional (Altieri, 1990; Altieri, 2004). LVC se compone de varias organizaciones, las cuales han sido factores clave en la masificación de la agroecología (Mier y Teran et al., 2018; Val et al., 2019; Rosset et al., 2019; Ferreira et al, 2021; Khadse y Rosset; 2017). Las organizaciones campesinas miembro de la LVC ofrecen una estructura desde la cual se puede acelerar la difusión de la agroecología al interior de los países y al mismo tiempo al ser miembros de LVC se benefician del conocimiento y apoyo de otras organizaciones. Un ejemplo donde vemos un proceso donde ocurrió algo similar es el Movimiento Agroecológico Campesino a Campesino (MACaC) en Cuba, donde a partir de la metodología Campesino a Campesino (CaC) que aprendieron de una escuela campesina de Tlaxcala en México, lograron difundir prácticas agroecológicas a lo largo de todo el país en muy poco tiempo.

El caso de Campesino a Campesino

Uno de los procesos más estudiados en cuanto al escalamiento o masificación de la agroecología es el movimiento Campesino a Campesino (CAC), cuya metodología se originó en los años 70s en el altiplano maya de Guatemala de un intercambio entre la ONG "Vecinos Mundiales", la clínica Behrhorst y los campesinos Kaqckiqueles. Más tarde en los años 80s, algunos de los campesinos huyeron del ejército guatemalteco hacia México donde al lado de ejidatarios del municipio Vicente Guerrero en Tlaxcala, formaron una escuela internacional de campesinos. Ahí asistieron campesinos miembros de cooperativas de Nicaragua, los cuales organizaron en su país el primer taller Campesino a Campesino y eventualmente se consolidó el Movimiento Campesino a Campesino (MCAC) que, aprovechando la estructura de la Unión Nacional de Agricultores y Ganaderos UNAG, logró difundirse ampliamente en Nicaragua. El desarrollo de MACaC en Cuba también tiene sus orígenes con la escuela internacional de campesinos de Vicente Guerrero. A partir del intercambio entre los campesinos mexicanos y cubanos se empezaron a difundir las prácticas agroecológicas en la periferia urbana de La Habana. La ANAP desde ese primer encuentro fue la que impulsó la difusión y eventualmente estableció el MACaC. Dada la estructura de la ANAP y la creatividad cubana, el MACaC hizo dos aportaciones (la figura del Coordinador y la estrategia de Banes) a la pedagogía que generó un éxito sin precedentes (Machín et al., 2011). El número de familias que se incorporó al movimiento sobrepasó los 300,000 en un tiempo relativamente corto. Igualmente, es importante considerar que el logro no fue solo una cuestión temporal sino también espacial, ya que el movimiento se extendió a lo largo de toda la isla.

El movimiento Campesino a Campesino parte de un esquema de pedagogía horizontal, donde los mismos campesinos imparten talleres o hacen visitas a las parcelas de sus compañeros para mostrar alguna práctica y a través de la constatación directa de resultados positivos los campesinos deciden emular, apropiarse, y hacer innovaciones de los principios agroecológicos[1] (Holt-Giménez 2008, Machín et al. 2011). En Cuba se generó una red con diferentes actores que coordinan actividades desde un nivel de comunidad hasta uno de orden regional y nacional. Los principales actores del movimiento son los promotores (campesinos agroecológicos con ánimo de compartir); los facilitadores (cuadros de las cooperativas a las cuales están asociados los campesinos[2]); y los coordinadores (en distintos niveles: municipal,

1 En Cuba se dice: "Cuando el campesino ve hace fe"

2 Existen cooperativas de dos tipos: las CPA (cooperativas de producción agropecuaria) y las

provincial o nacional). Sin lugar a dudas, la estructura organizativa vinculada a la ANAP ha sido un factor fundamental del éxito en el crecimiento tan rápido de la agroecología en Cuba.

Pensamos que un enfoque desde la modelación puede ayudar a entender de qué forma es que las distintas figuras que conforman el método CaC, así como la estructura de la ANAP son efectivas, especialmente al compararlas con el extensionismo clásico. Además, puede mostrar interacciones entre los componentes de la pedagogía del método CaC que aceleran de una forma no lineal el aprendizaje (es decir, la difusión de las prácticas). No hemos encontrado algún intento por modelar el proceso dinámico de difusión que ocurre con los movimientos agroecológicos utilizando una estructura pre-existente y procesos pedagógicos intencionales. De la misma manera, no encontramos un modelo que estudie una dinámica que incluya los componentes de racionalidad campesina y dinámica ecológica de la parcela. Por ello, pensamos que nuestra investigación hace un aporte original a la búsqueda de entendimiento en los procesos de masificación agroecológica.

Ahora queremos expresar cuál es nuestra perspectiva sobre la modelación y sus limitaciones. Asimismo, presentamos cómo es nuestro proceso de modelación, es decir, cómo planteamos un modelo y cómo lo estudiamos.

Metodología

Perspectiva y propósito de la modelación en nuestra investigación

No es difícil pensar que cualquier persona en el mundo se ha enfrentado a un modelo, ya que cualquier conceptualización de la realidad es un modelo. Incluso las personas llamadas “modelos”, lo son en cuanto a la conceptualización de belleza, moral, etc. Las maquetas también son modelos que nos permiten imaginar cómo va a ser una construcción real. Básicamente los modelos nos ayudan a señalar, apuntar, resaltar, representar ciertas características que hemos conceptualizado de la realidad. Los motivos para modelar pueden ser muy variados, desde contemplarlos, reflexionar sobre ellos o estudiar implicaciones lógicas, incluso compartirlos y construir significado. Asimismo, todos los modelos parten de un conjunto de supuestos, axiomas o paradigmas. En particular, en este trabajo los modelos que nos

CPS (Cooperativas de Crédito y Servicio). Todos los campesinos cubanos están asociados a alguna de estas dos formas organizacionales, las cuales a su vez, se distribuyen localmente por todo el territorio nacional.

interesan son modelos matemáticos, esto implica que usando la lógica matemática clásica podemos estudiar las implicaciones de los supuestos que propongamos para estudiar la difusión de la agroecología. Los supuestos tienen que ver con lo que hemos escrito de los factores y la racionalidad campesina e incluso con supuestos de otros modelos que veremos más adelante relacionados con las redes sociales. Nuestra expectativa no es hacer modelos predictivos de los procesos sociales, dado que reconocemos la complejidad inherente a estos. Por ello, lo que esperamos del modelo matemático[3] es que sus implicaciones sean cualitativa y estadísticamente congruentes con las observaciones de la realidad. Otra forma de expresar esta postura es que los algoritmos y modelos que propondremos son heurísticos.

Algo que es importante y muchas veces se olvida en el ámbito académico, es que la reflexión y construcción es sobre la conceptualización y no sobre la realidad, es decir la realidad no está obligada ni limitada por los modelos que nosotros construyamos. Esto aplica para cualquier modelo humano, incluidos todos los modelos científicos. Esto, definitivamente es importante recordarlo porque gran parte del trabajo en ciencia es estudiar los modelos para ver sus implicaciones, de modo que si no tenemos cuidado, terminamos por hacer aseveraciones sobre la realidad cuando nuestro trabajo fue sobre la conceptualización. Lo que es factible esperar de la simulación a partir de los modelos es encontrar comportamientos análogos entre la realidad y nuestras explicaciones de los modelos, precisamente eso es lo que esperamos en esta investigación. También lo visualizamos como un laboratorio donde haremos simulaciones de los conceptos teóricos alrededor de los procesos sociales, donde podremos poner a prueba diferentes ideas e hipótesis a través de experimentos pensados. Así podremos ver las consecuencias lógicas y compatibilidad de esas hipótesis con las observaciones hechas en las investigaciones sociales.

Ahora que hemos expuesto nuestra perspectiva de la modelación, también queremos exponer brevemente los pasos que seguimos para construir un modelo, esto es, una vez que hemos estudiado las investigaciones sociales y ecológicas sobre un tema, ¿cómo construimos un modelo?

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[3] También buscaremos aplicar el principio de parsimonia, es decir quitar la mayor parte de supuestos, de manera que las predicciones sigan reproduciendo las observaciones. La complejidad muchas veces es modelada siguiendo este principio, un ejemplo tiene que ver con el modelo del movimiento de una parvada. A pesar de que en la realidad se observan patrones complejos en el vuelo de una parvada, un modelo de agentes con dos reglas presenta el mismo tipo de patrones. De modo que se intentará seguir este principio en lo posible.

¿Cómo construimos los modelos?

Una de las ventajas de hacer un modelo matemático es que es una representación que todos entendemos de la misma manera [Vandermeer y Perfecto, 2018], esto es por el lenguaje formal que usa. En particular nosotros estamos interesados en estudiar procesos a lo largo del tiempo. Para modelar un proceso primero escogemos cuales son las variables de interés dentro del proceso, las cuales pueden tomar distintos tipos de valores (binarios, numéricos, vectoriales, etc…). y proponemos unas reglas de cambio para ellas. Estas reglas, también llamadas funciones u operadores, establecen la dinámica que seguirán las variables a través del tiempo. Esto se escribe formalmente de la siguiente manera

Eq 1. Expresión formal general de los modelos que planteamos

Sea $\hat{x} \in E$ entonces tenemos que:

$$\frac{d\hat{x}}{dt} = \hat{f}(\hat{x})$$

donde $\hat{x}$ es una notación simplificada que representa todas las variables de interés, esto lo podemos ver como si fuera un vector que tiene como entradas cada variable: $\hat{x} = (x_0, x_1, ..., x_n)$ donde cada variable x_i puede tomar valores de un espacio diferente E_i de modo que el espacio E de la ecuación 1 es la conjunción de todos esos espacios, $E = E_1 X E_2 X ... X E_n$

La derivada temporal $\frac{d\hat{x}}{dt}$ representa el cambio de las variables en el tiempo y la función $\hat{f}(\hat{x}) = (f_1(\hat{x}), f_2(\hat{x}), ..., f_n(\hat{x}))$ también es un vector que contiene las reglas de cambio f_i de cada variable x_i y nos indica que cada regla de cambio puede depender de todas las demás variables:

$$\frac{dx_i}{dt} = f_i(\hat{x})$$

De esta manera en cada modelo quedarán claros cuáles son los supuestos de los cuales partimos, ya que quedan explícitas las reglas que asumimos que gobiernan a cada variable. Cabe mencionar que hay modelos donde las funciones pueden depender de derivadas espaciales y de mayor orden, sin embargo, esto no aplica para los modelos que hicimos. Un modelo de agentes sobre una red también lo podemos representar de esta forma, considerando que una de las variables sería el identificador del nodo sobre la red, de modo que las reglas de cambio sobre un nodo puedan depender de las variables de otros nodos.

Dentro de las funciones también definimos parámetros que junto con las condiciones iniciales representan distintos escenarios del modelo, los cuales al variar pueden presentar comportamientos completamente diferentes. Un ejemplo muy utilizado para mostrar esto es el mapeo logístico, que es un modelo de una variable x que cambia en un tiempo discreto, es decir en vez de que el tiempo cambie de una manera continua en los números reales, lo hace a pasos como los números naturales. El mapeo logístico se expresa de la siguiente manera:

$$x_{n+1} = rx_n(1 - x_n)$$

donde x_n, x_{n+1} son los valores de la variable x al tiempo n y un paso después el tiempo $n + 1$. r es un parámetro del modelo. En la siguiente sección vemos cómo se explora un modelo y ahí retomaremos este ejemplo del mapeo logístico para entender la importancia de los parámetros y las condiciones iniciales en modelos complejos.

¿Cómo exploramos los modelos?

Existen algunos modelos que se pueden estudiar de manera analítica y dar la integral de la del cambio temporal de las variables, con lo cual se puede saber el estado de todas las variables en cualquier tiempo, este es el caso de cualquier modelo lineal, es decir, un modelo donde las variables dependen de manera directamente proporcional. Sin embargo, muchos otros modelos son no lineales, que es donde entran las ciencias de la complejidad. En estos modelos, en vez de buscar la integral de forma analítica, se hace un algoritmo computacional que explore la dinámica para diferentes condiciones iniciales y parámetros del modelo. Esto ayuda a explorar de forma cualitativa las dinámicas que puede presentar el modelo sin la necesidad de tener la función predictiva de los valores a cada momento.

Retomando el mapeo logístico de la sección anterior, la manera de explorar el modelo, consistiría en los siguientes pasos:

a) Establecer valores de los parámetros del modelo
    i) Pasos opcionales para entender la dinámica: Representar de manera gráfica el modelo.

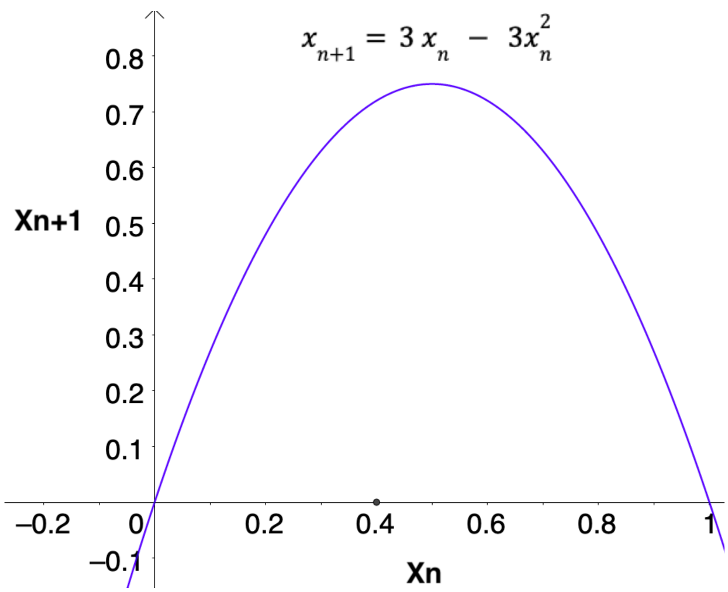
No es posible para todos los modelos pero en el caso del mapeo logístico, dada una r, podemos dibujar la gráfica de la función logística de la siguiente manera:

$$r = 3$$

$$x_{n+1} = rx_n(1 - x_n) = 3x_n - 3x_n^2$$

La gráfica de esta función poniendo a x_{n+1} en el eje horizontal y a x_n en el vertical se vé en la figura 2.

Figura 2: Gráfica generadora del mapeo logístico

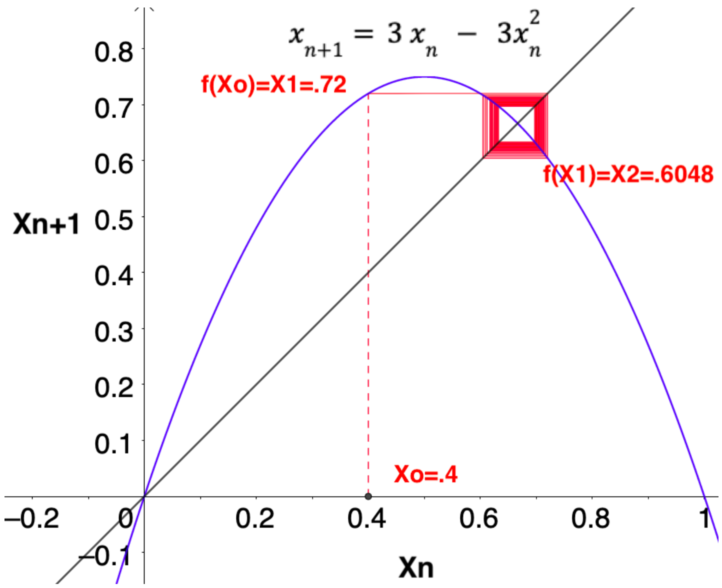


b) Hacer simulaciones para distintas condiciones iniciales a lo largo de cierto tiempo, es decir de cierto número de iteraciones y registrar los valores tomados por las variables

   i) Paso opcional: Agregar elementos que ayuden a visualizar la dinámica.

   En el caso del mapeo logístico se puede agregar la función identidad para poder visualizar qué valores toma la variable dada una condición inicial. Por ejemplo, en la figura 3 se ve que agregamos la función identidad (en negro) y visualizamos la trayectoria (en rojo) cuando empezamos la variable con el valor de $x_0 = 0.4$.

Figura 3: Una trayectoria del mapeo logístico

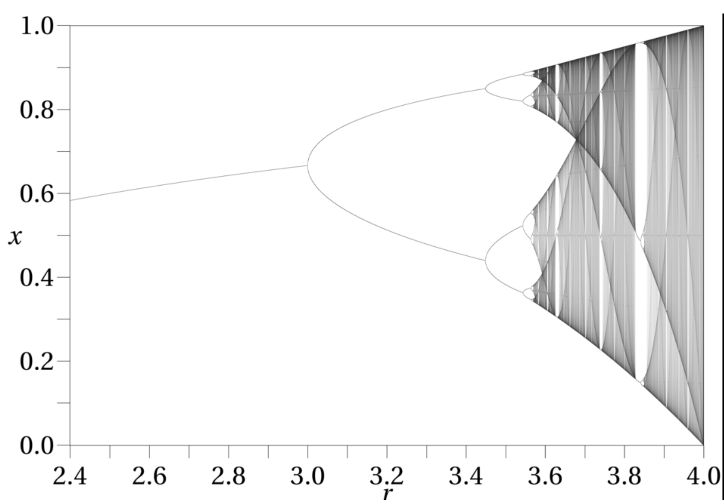


c) Repetir los dos pasos anteriores para otros valores de los parámetros. Hacer esto repetidas veces y registrarlo.

d) Analizar y estudiar cómo cambian los resultados al cambiar los parámetros del modelo

   i) Paso opcional: Hacer una gráfica de resultados y parámetros.
   En el caso del mapeo logístico se puede dibujar los valores adquiridos al final de las iteraciones para cada condición inicial dado un valor al parámetro r. De este modo se obtiene gráfica en la figura 4.

Figura 4: Cambiando el parámetro r en el mapeo logístico



Fuente:

https://es.wikipedia.org/wiki/Aplicaci%C3%B3n_log%C3%ADstica#/media/Archivo:Logistic_Bifurcation_map_High_Resolution.png

En la figura 4 se puede ver cómo el modelo tiene un comportamiento muy diferente para distintos valores de r, si este parámetro es menor a 3 todas las condiciones iniciales llegarán a un mismo punto. Pero después vemos que para ciertas r hay 2 valores límites o más adelante 4. Incluso aquí podemos ver el concepto de caos, ya que hay regiones donde prácticamente se toma cualquier valor posible, de modo que el modelo tiene alta sensibilidad a condiciones iniciales.

Ahora que hemos compartido la forma general en la que trabajamos para proponer y estudiar los modelos, queremos hacer una síntesis de algunos de los modelos que ya se han hecho y están relacionados al trabajo de investigación que hacemos aquí. Existen diferentes modelos computacionales para fenómenos sociales, en particular nos interesa el área de la toma de decisiones y la difusión en redes. A continuación presentamos una síntesis de los principales modelos que inspiraron nuestro trabajo.

Marco Teórico de Modelación

CONSUMAT: Incorporando teorías del comportamiento humano en simulaciones sociales

En el trabajo de Jager et al. (2000) se hace una revisión de teorías psicológicas “relevantes para el entendimiento de los procesos cognitivos que guían el comportamiento de un consumidor” [*ibidem*]. El término consumidor aparece en esta teoría porque su propósito era la simulación de dilemas de comunes, que tratan sobre el comportamiento humano respecto a un recurso en común. En este trabajo, nos interesa la síntesis que hace de estas teorías, englobándolas en cuatro procesos cognitivos diferentes: repetición, imitación, deliberación y comparación social. Estos procesos describen la toma de decisiones de una persona respecto a su comportamiento frente a un recurso, esto está vinculado al modelo que se propone en este trabajo, ya que nosotros simulamos la toma de decisiones de los campesinos respecto a la forma en que utilizan su parcela.

La repetición consiste en repetir el comportamiento anterior, es un proceso individual y automatizado. Las teorías que describen este comportamiento son la teoría del condicionamiento clásico y la del condicionamiento operante. Estas teorías señalan que cuando un comportamiento tiene una consecuencia o resultado favorable, entonces se refuerza, en otras palabras, se seguirá repitiendo el mismo comportamiento (Jager et al., 2000).

La imitación consiste en imitar el comportamiento de otros consumidores que tengan características deseables o que sean “modelos a seguir”. La imitación es un proceso cognitivo social y aunque requiere un poco de razonamiento para entender el comportamiento de otros podemos considerarlo prácticamente automatizado. Las teorías que entran en esta categoría son la teoría del aprendizaje social y la teoría de la conducta normativa (Jager et al., 2000).

La deliberación consiste en la evaluación de alternativas al comportamiento anterior y la elección de la más satisfactoria. Este proceso depende fuertemente de las habilidades cognitivas de las personas para hacer la evaluación. En particular la teoría del comportamiento planeado dice que en la evaluación de las oportunidades existe una tendencia por las opciones menos dependientes de recursos externos. La deliberación es un proceso individual y razonado. Las teorías que entran en esta categoría son la teoría del comportamiento planeado, la teoría del comportamiento razonado y la teoría de decisión y elección (Jager et al., 2000).

La comparación social consiste en buscar a otros consumidores similares en cuanto a sus habilidades y opiniones para conocer su comportamiento, posteriormente se pasa a una evaluación de esos comportamientos. La comparación social es un proceso cognitivo social y razonado. Las teorías dentro de esta categoría son la teoría de la comparación social, la teoría de la carencia relativa y también entra la parte de normas sociales de las teorías de comportamiento planeado/razonado (Jager et al., 2000). En el cuadro 1, se puede apreciar a manera de resumen las características de los diferentes procesos cognitivos.

Cuadro 1. Características de los procesos cognitivos

	Automatizado	Razonado
individualmente	repetición	deliberación
socialmente	imitación	comparación social

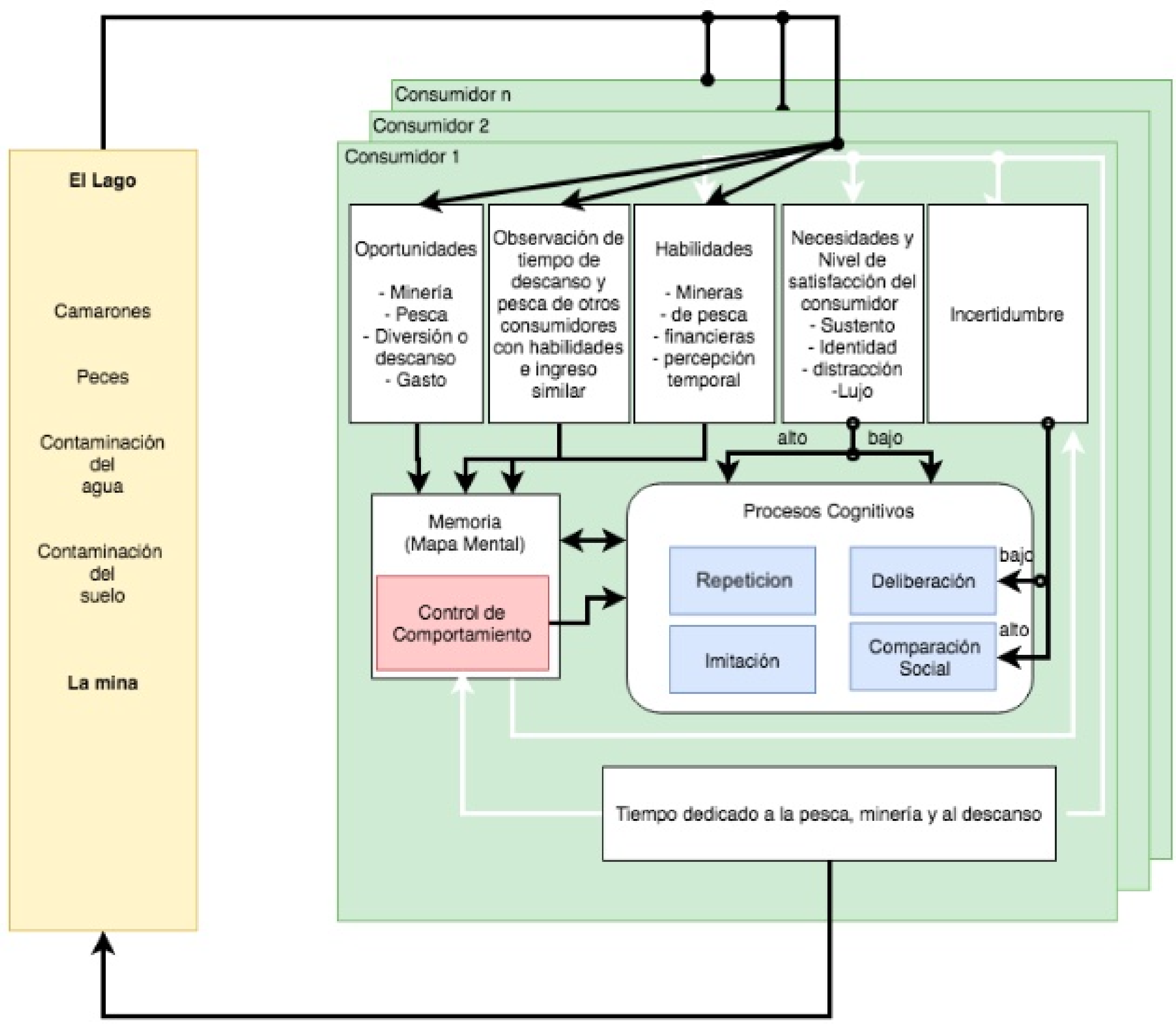
El modelo CONSUMAT

La propuesta de Jager et al. (2000) para modelar los dilemas de comunes fue el modelo CONSUMAT. En los dilemas cada individuo determina sus estrategias de aprovechamiento del recurso en común, sin embargo, estas estrategias afectan la disponibilidad del recurso para todos los demás. El modelo describe en qué situaciones se activa cada proceso cognitivo del cuadro 1 con base en dos parámetros: la incertidumbre (IC) y el nivel de satisfacción del consumidor (NSC). La incertidumbre está relacionada a las expectativas del consumidor respecto a cierta estrategia de aprovechamiento de un recurso. Si no se cumple su expectativa la incertidumbre aumenta. El NSC, se refiere a las necesidades del consumidor, no solo materiales sino también sociales, mentales y de cualquier otro aspecto.

El modelo de CONSUMAT usa agentes para representar a los consumidores, los cuales tienen ciertas necesidades, habilidades y memoria (donde se almacena las estrategias que sigue la persona). Por otro lado, también se modela el recurso en común de los consumidores y las oportunidades o estrategias que pueden tomar, de modo que los consumidores interactúan con el recurso y con otros consumidores. Los procesos cognitivos se activan con base en esa interacción que se traduce en un NSC y IC para el consumidor. La repetición se activa con un alto NSC y baja IC. La imitación ocurre cuando está alto el NSC pero la IC también es alta, de modo que, las expectativas del consumidor no se están cumpliendo. La deliberación ocurre cuando son bajo el NSC e IC, en ese caso el consumidor necesita reevaluar su estrategia. Por último, cuando la NSC es baja y la IC es alta, se activa la comparación social, donde busca la mejor estrategia de los consumidores parecidos a sí mismo, las evalúan y escoge una suficientemente buena. Como resultado de los procesos de imitación, deliberación y comparación social puede ocurrir un cambio de habilidades o estrategias. A su vez, las estrategias de los consumidores afectan al recurso en común. Esto se ejemplifica en el siguiente mapa conceptual, que muestra el caso de un lago donde pescan varios consumidores.

En la figura 2 se puede apreciar que, por un lado, tenemos los recursos compartidos, el lago (donde se incluye todo lo que contiene) y la mina. Por otro lado, están los consumidores del 1 al n, los cuales interactúan con los recursos. Hasta arriba del recuadro del consumidor vemos que sus habilidades, oportunidades y observaciones dependen de los recursos presentes. Éstas a su vez actualizan el mapa mental del consumidor (donde se encuentra el control del comportamiento). Este mapa interactúa con los procesos cognitivos, ya que las evaluaciones que ocurren cuando se activan algunos de ellos necesitan la información de las habilidades y observaciones. A su vez los procesos cognitivos pueden requerir de cambios en las habilidades del mapa mental y también determinan el tiempo dedicado a las distintas actividades (incluido el descanso). Por un lado, esas decisiones afectan los recursos cerrando un ciclo y, por otro lado, forman parte de ciclos de retroalimentación modificando el mapa mental y afectando el nivel de satisfacción del consumidor (NSC), la incertidumbre y las habilidades. A su vez la NSC y la IC determinan qué proceso cognitivo se ha de emplear.

Figura 5. El modelo CONSUMAT en el caso de un lago.



Fuente: Jager et al, 2000

El modelo CONSUMAT lo utilizamos cómo guía del primer modelo que estudiamos sobre la racionalidad campesina. Específicamente consideramos los procesos cognitivos de repetición y deliberación, tomando en cuenta si se cubrían las necesidades de la familia campesina. Sin embargo, no alcanzamos a desarrollar en este modelo los procesos cognitivos sociales, ya que nos enfocamos en modelar la toma de decisiones individual y cómo un agente externo usando subsidios puede distorsionar las necesidades del campesinado. A continuación, presentamos algunos modelos que tratan el tema de difusión en redes, los cuales sirvieron de inspiración para el segundo modelo que desarrollamos.

Modelación de difusión

Los modelos que a continuación presento han contribuido al análisis de la difusión de enfermedades, ideas, opiniones, prácticas entre otras cosas, en una red. Cada uno de ellos aportó alguna innovación al modelo anterior. Algunos de estos contribuyeron a precisar mejor las características que incorporamos en nuestra simulación, como son:

1. La inclusión de un factor para la innovación y uno para la imitación
2. La forma en que los vecinos influyen en la adopción de una práctica
3. La estructura de la red

El modelo de Bass y la teoría de difusión de innovaciones de Rogers

La difusión de los movimientos agroecológicos involucra la difusión de prácticas e innovaciones. Han existido diferentes teorías al respecto de ese tema, de las cuales resalta la Teoría de Difusión de Innovaciones de Everett Rogers (1962), quien sintetizó el trabajo de varias investigaciones sobre la difusión de innovaciones y ha repercutido inmensamente hasta el día de hoy en la mercadotecnia, especialmente a través del modelo que Frank Bass hizo unos años después. Esta teoría asume que toda la población termina por incorporar una innovación y describe que la curva de adopción es logística, lo cual se apega bastante a la realidad. En realidad, esta teoría se enfoca en categorizar a la población donde se difunde una innovación con base en el tiempo que tardaron en adoptar la innovación y hacer un análisis de la mentalidad de cada uno de esos grupos. En 1969 Bass, influenciado por esa teoría hizo un modelo matemático con la intención de describir la adopción de un nuevo producto por una población a lo largo del tiempo. Tiene un supuesto, que es dividir a la población en dos tipos de personas, los que espontáneamente deciden adoptar el nuevo producto y los que por imitación lo adoptan. Esto lleva lógicamente a la siguiente ecuación:

$$\frac{dF(t)}{dt} = (p + qF(t))(1 - F(t))$$

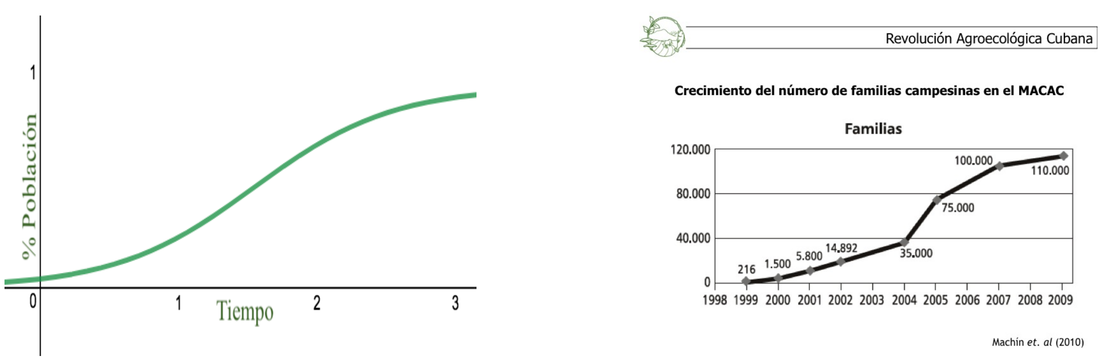
Donde F(t) es la fracción de personas que adoptaron el producto al tiempo t, de modo que (1-F(t)) es la fracción que no lo ha adoptado. Así pues, el cambio en el tiempo de F(t) está dado por el aumento de la porción p de los que no han adoptado más la porción de imitadores que depende de una taza q y de la fracción de personas que ya adoptaron el producto, esto es en cuanto más personas adopten la taza de imitación aumentará. La solución a esta ecuación es:

$$F(t) = \frac{1-e^{-(p+q)t}}{1+\frac{q}{p}e^{-(p+q)t}}$$

Que describe una gráfica sigmoidea como se observa a la izquierda de la Figura 3. Este tipo de curvas también se puede ver en ejemplos dentro de la agroecología, como se puede ver en la gráfica de la derecha de la Figura 3, que corresponde a las familias incorporadas al Movimiento Agroecológico Campesino a Campesino (MACAC) en Cuba.

Figura 3. a) Gráfica Sigmoide que corresponde a la adopción por parte de una población de un producto o práctica nueva. b) Incorporación de campesinos al MACAC en Cuba

Figura 6. Comparación de curva sigmoide con la incorporación de campesinos a MACAC



a) b)

Fuente de b): Machín et al. 2010

Este modelo es interesante y bastante práctico, sin embargo, tiene varias limitaciones.

Empezando porque la adopción de prácticas sólo se explica por dos elementos: la innovación y la imitación. Esto deja de lado cualquier aportación por la presencia de una estructura pre-existente o de un proceso pedagógico intencionado, que es precisamente el caso de CaC y la ANAP.

Difusión simple

Podemos obtener la misma gráfica con forma de S si tomamos en cuenta la estructura de la red y suponemos una difusión simple. Este modelo parte de un contexto epidemiológico de modo que tenemos una enfermedad que un nodo contagia a todos los nodos a los que está enlazado. Así, los supuestos son que todos los nodos son susceptibles y que una vez adquirida la enfermedad, permanece. En este caso podemos ver cómo la estructura de la red influye mucho en la velocidad en que se propaga la enfermedad. Para una red de malla observaremos que se propaga linealmente, en una red de pequeño mundo observaremos la gráfica con forma de S y para una red conectada al azar la S es mucho más vertical y empieza antes. De hecho, sabemos en este modelo que el máximo número de pasos que le llevará a la enfermedad cubrir toda la red es el diámetro de esta.

Si quitamos el supuesto de susceptibilidad de toda la red, es decir pensamos que algunos nodos son inmunes, también la estructura empieza a tomar un rol más importante. Muchas veces ocurre que en una red social no existe ruta entre dos nodos, esto es porque no forman parte del mismo grupo o alguno de ellos es un nodo aislado. Cuando tomamos en cuenta la inmunidad de los nodos, puede ocurrir que una red que antes formaba un solo grupo quede dividida. Usualmente lo que ocurre es que queda un componente principal que contiene a la mayoría de los nodos y algunos otros grupos pequeños o nodos aislados. En este caso se empiezan a usar herramientas estadísticas para saber cuál es la probabilidad de que se infecte el componente principal, ya que eso conduciría a una epidemia. Esa probabilidad está relacionada a la probabilidad de estar conectado al componente principal, de manera que usando la distribución de grados es posible encontrar relaciones entre el grado esperado en la red y la probabilidad de que ocurra la epidemia, entre más conectada la red más probable que ocurra.

Modelo Susceptible-Infectado-Susceptible (SIS)

Este modelo elimina el supuesto de que se quede infectado por siempre, de modo que los nodos pueden estar oscilando entre los estados infectado y susceptible. Se definen dos parámetros, uno es la tasa de infección (i) y otro la tasa de recuperación (r). Con este modelo se encuentra un límite para la proporción de i con r, debajo del cual no se queda la infección. Este límite depende de la distribución de grado de la red.

Modelo de DeGroot

El modelo (1974) de DeGroot simula una población en la que hay comunicación. Cada persona tiene diferentes valores de confianza con sus vecinos, y una opinión inicial binaria (1,0). Con este modelo se puede analizar si la población converge a una opinión o no.

Aportaciones desde la modelación a nuestro trabajo

Resumiendo, los modelos presentados han ayudado al entendimiento de la difusión de información y aprendizaje en redes sociales, así como del comportamiento humano. En el presente trabajo se toma como referencia el modelo de CONSUMAT para la toma de decisiones de los agentes, claro que lo modificamos para incorporar la racionalidad campesina y nos limitamos a los procesos cognitivos individuales. La teoría de Rogers y el modelo de Bass nos apuntaron a utilizar un parámetro para la probabilidad de adoptar de forma autodidacta la práctica (lo que representaría un innovador) y otro parámetro para la probabilidad de adoptar por influencia de los vecinos. El modelo de difusión simple nos sugiere la elección del tipo de red (pequeño mundo) para las simulaciones que realizaremos. Al mismo tiempo los últimos dos modelos nos señalan cómo surge un comportamiento logístico si los agentes en la red transmiten el conocimiento. El modelo SIS nos señala una forma de mejorar nuestro trabajo para poder incorporar la tasa de deserción. Por último el modelo de De Groot nos señaló una forma de incorporar la confianza en los distintos agentes, por un lado los campesinos y por otro los técnicos.

Pregunta de investigación, Objetivos y Estructura de la Tesis

Considerando el potencial que tiene la modelación desde las ciencias de la complejidad para estudiar los fenómenos socio-ecológicos y la falta de modelos sobre los procesos de la masificación de la agroecología, nos hicimos la siguiente pregunta:

¿Qué modelos se pueden proponer para estudiar los procesos de la masificación de la agroecología y qué aportaciones se obtienen de ellos?

Para responder a esta pregunta planteamos los siguientes objetivos.
Objetivo 1:

a) Crear un modelo de la dinámica ecológica en la parcela que resulta de la interacción de la toma de decisiones por parte de las familias campesinas y las consecuencias ecológicas de esas prácticas. Este modelo debe incorporar las ideas de la economía campesina de la tradición Chayanoviana y los hallazgos de las investigaciones sobre los efectos ecológicos de las prácticas agroquímicas y agroecológicas.
b) Usar el modelo para estudiar de qué forma un agente externo puede alterar esta dinámica, en particular el caso de una política que subsidia la agricultura química.

Objetivo 2:

a) Crear un modelo para estudiar la difusión de las prácticas agroecológicas que considere métodos pedagógicos intencionados y una estructura pre-existente como lo que ocurrió en el Movimiento Agroecológico Campesino a Campesino.

En esta investigación construimos los dos modelos computacionales. Estos modelos se encuentran desarrollados en forma de artículos científicos en esta tesis. En el siguiente capítulo, se encuentra el primer modelo, referente a la racionalidad campesina, desarrollamos un modelo cualitativo que combina los balances campesinos descritos por Chayanov y van der Ploeg con la dinámica simplificada de la capacidad ecológica (la cual describimos en el artículo) en una parcela cuando se usan practicas agroecológicas o agroquímicas. Con este modelo estudiamos el caso en que se subsidian los insumos agroquímicos.

En el anexo 1 incluimos el segundo artículo, donde abordamos nuestro segundo objetivo, referente a la difusión usando la metodología Campesino a Campesino. Este es un modelo de agentes que representan a las familias dentro de cooperativas. Estas cooperativas están organizadas en una malla cuadrada para reflejar la ANAP que es una red geográfica de cooperativas. Aquí también implementamos las figuras de CaC (promotores, facilitadores y coordinador) así como el técnico del extensionismo clásico, de modo que pudiéramos comparar ambas metodologías y analizar de dónde provienen los beneficios en CaC.

En el capítulo 3 respondemos a la pregunta de investigación resumiendo los resultados de nuestros artículos y dando nuestras conclusiones generales sobre la experiencia al modelar los procesos sociales agroecológicos en los artículos que presentamos.

Capítulo 2: Artículo "Building an agroecological model to understand the effects of agrochemical subsidies on farmer decisions"[4]

Building an agroecological model to understand the effects of agrochemical subsidies on farmer decisions

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Abstract

We present a simple simulation model whose purpose is to explore qualitatively and heuristically the effects that agrochemical subsidies could have on the type of decisions farmers make about their plots (keeping other variables fixed). We use elements of Chayanovian thinking and ecological complexity as a basis, considering that this decision is made by families with heterogeneous preferences in a context with a dynamic that, on the one hand, is non-linear for ecological cycles, and, on the other hand, is chaotic in terms of the interaction with the market. The model describes the relationship between the ecological-productive potential or capacity of

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a plot and the total production, as well as the effect of management (agroecological or agrochemical) on the ecological capacity. We explore the effect of agrochemical subsidies on this decision and discuss the consequences of these public policy instruments on the lives of farming families. The model shows that by using agrochemicals, both the economy and the ecological balance of the plot enter an unstable pattern with harmful long-term consequences, as there could be a significant reduction in household savings. The same effect is observed on production, since the ecological capacity tends to decrease throughout the simulation.

Keywords

Choice dynamics, peasant, subsidies, rationale, modeling, fragile system

Introduction

The policy of subsidizing agrochemicals is an essential part of the strategy of corporations and states to expand the Green Revolution around the world. It is so important that it is estimated that about half of fertilizer consumption today receives some form of subsidy (UNEP, 2020). Although the global North countries started eliminating these subsidies in the 1990s, and a process of taxation has begun (Rougoor et al., 2001), in Latin America, Asia and Africa public subsidy policies continue to be defended (Katto-Andrighetto et al., 2017). The excuse is the alleged need to maintain incentives to increase agricultural yields and productivity and thus ensure food security (Lappe et al, 1998)). This discourse continues to be used, despite the growing recognition that this type of instruments has led to their use and abuse (FAO et al, 2021; UNEP, 2020; Carrignton, 2021; Rosset, 1987) , causing crops to become vulnerable to pests that are increasingly resistant, and creating decreasing yields that force farmers to continually increase doses to maintain the same results (Kotschi, 2013; Ray, 2012).

There is evidence that promoting agrochemicals has negative consequences on biodiversity (Hendrickx et al., 2007), which in turn makes crops susceptible to weed infestations, various diseases, and the effects of climate change (Altieri et al., 2015). There is also evidence that these policies have made farmers dependent, while discouraging them from finding agroecological alternatives (Rosset, 1987). Moreover, overuse of pesticides is generating harmful effects on the health of agricultural workers (Nicolopoulou-Stamati et al., 2016; Corsini et al., 2008) and consumers (Lisolette, 2005), and causes environmental damage such as contamination of water bodies and soil, eutrophication in rivers, lakes and ocean coasts (MEA, 2005), functional extinction of insects (Sánchez-Bayo, 2019), ozone layer depletion, and an increase in greenhouse gas emissions, among many other ecological impacts (Lin et al., 2011; Campbell et al., 2017; ETC Group, 2017).

The papers we cite link these adverse consequences to the excessive use of agrochemicals, which are promoted, among other means, through subsidies that affect farmers' decisions about their farming practices. However, the way in which this occurs, especially in the case of peasant households, may not be explainable as a purely economic issue. Using an economic rationale, it could be argued that due to agrochemicals' high price elasticity of demand, a direct consequence of introducing subsidies is increased consumption (Katto-Andrighetto et al., 2017). Nevertheless, peasant rationale does not only respond to rational choices based on price variability but is based on a series of factors that escape the logic of supply and demand and the calculation of means and ends for profit maximization (Chayanov, 1966; van der Ploeg, 2013; da Silva, 2014). The issue of the numerous factors that peasants must balance to make decisions is complex and non-linear, and it lies outside the economic assumptions with which analysts usually predict their behavior (Vandermeer, 2020).

Alexander Chayanov is known for being the first to have spoken about the radical difference between peasant and capitalist rationales. His theory asserts that the peasant household's way of working and search for general wellbeing leads to decisions that are vastly different from those of a capitalist enterprise (Chayanov, 1966). Chayanov's main observation is that while peasant households are influenced by the capitalist context, they are not completely governed by its logic. Rather, the peasant economy is explained by a series of balances that link it to the capitalist system in a way that is complex and hard to predict (van der Ploeg, 2013).

Chayanov's starting assumption is that, with some exceptions, the peasant economy is not based on paid labor, but on family labor. Since no wages are paid, or at least part of the work is based on the family's own labor, profits can hardly be calculated. Therefore, the classical economic criteria are replaced by the permanence of the family unit over time and across generations, through the constant adjustment of a series of balances that obey a different logic. The two main balances identified by Chayanov are the labor/consumption and hard labor/utility balances, which express the amount of labor that a family is able or willing to do in relation to its concrete needs (Chayanov, 1966). However, van der Ploeg (2013) points out other balances that should also be considered within the Chayanovian approach: the family/nature balance (which has to do with the interrelation and mutual transformation between people and ecosystems), the balance between internal and external resources, the balance between autonomy and dependence, and the balance between scale and intensity. For this author, the peasant economy is based on the capacity of small farmers to creatively evaluate, refine, and combine all these balances so that different equilibria can be creatively achieved (van der Ploeg, 2013; Santiago Vera et al. (a) (b), In press).

The family/nature balance is especially useful for analyzing the impact of subsidies on peasant decisions. This balance consists of the ability of the peasant household to produce enough to cover its needs without altering the ecological reproduction of its plot (van der Ploeg, 2013:48). As the agroecological literature has assiduously described, many peasants, and especially indigenous peoples, have developed diverse knowledge systems that allow them to transform agroecosystems without the need to reduce ecological wealth (Vandermeer and Perfecto, 2012). However, Green Revolution agriculture has thrown this relationship out of balance through chemical, mechanical and genetic technologies that are promoted, among other ways, through public input subsidy policies. These instruments contribute to the decontextualization of each village's endogenous knowledge and incorporate farmers into a uniform system based on external knowledge that gnaws away at the natural reproduction of the plot and the larger territory where it sits (Giraldo, 2018).

Indeed, agrochemical subsidies have distorted the family/nature balance and have caused peasants to make decisions contrary to the reproduction of life on their own plots and territories. As Herbert Simon (1957) has described, this is because people are only partially rational when it comes to solving complex problems. Peasant households, far from finding optimal solutions, look for solutions that satisfy their needs, even if this sometimes means choosing practices that upset the ecological balance and therefore harm their own benefit in the long term. What must be understood is that peasants try to harmonize balances in a complex scenario, since they not only have to consider ecological factors (whose behavior is non-linear) but also market elements (which exhibit chaotic behavior) (Vandermeer, 2020). In addition, public policies in the form of fiscal subsidies to inputs tip the balance so that families decide to adopt practices (FAO et al, 2021; UNEP, 2020; Carrignton, 2021) that degrade their plots ecologically in the long term and, in many cases, cause them to incur debts, while the real beneficiaries end up being the corporations producing agrochemical inputs.

The heart of the matter is the way in which peasants make decisions and maintain their balances in a complex context. The objective of this article is precisely to interpret how distortions caused by subsidies affect peasant's decisions, taking into account the considerations of the Chayanovian model reviewed by van der Ploeg (2013), which includes the family/ecosystem balance. We propose a qualitative model that allows us to use a limited rationale that includes not only the economic component but also the family/ecosystem balance, as well as the ecological dynamics of a farming plot, whose natural reproduction is affected by peasant practices. In this article, we will call this natural reproduction "ecological capacity". We use this model to study the case in which subsidies are introduced, and we analyze the effects on the behavior of families. We do not intend for the model to be predictive. The purpose is to carry out a heuristic exercise aimed at creating and simulating scenarios that help us evaluate complex contexts. We believe that this model can be useful to study how external factors (we focus specifically on agrochemical input subsidy policies) can change peasant's choices, which is important now that the need to repurpose agricultural support has been acknowledged (FAO et al, 2021).

Model

Overview

We developed the model in the Julia programming language. It consists of first-order dynamic equations qualitatively representing observed relationships between ecological capacity, total output, and net gain. These relationships are different, according to the agricultural style that is practiced (agrochemical or agroecological). We chose the style approach since it is non-site-specific, in line with our aim of qualitative modeling and, therefore, adaptable to the needs of other researchers (Lloyd and Chalabi, 2021; Van der Ploeg, 2013). To represent external agents subsidizing Green Revolution agriculture, we parameterized expenses in the net-gain function of agrochemical practice. We used a weighted sum to represent the diversity of rationales. How much importance is given to each variable by a specific peasant family is abstracted into a fraction. All the fractions add up to 1. Each day the variables will change according to the production practice and are recorded for further analysis.

We present a model not with the intention of predicting reality based on quantitative evidence. Our model is a tool for qualitatively exploring different scenarios, aiming to understand peasant rationale when choosing farming practices and how certain factors interact with that rationale. It is a space for experimentation. For the sake of a simple, heuristic model, we have abstracted some “stylized facts” from the literature on agroecology. We in no way claim that they apply in every case. Instead, they create a modeling environment in which to carry out thought experiments, which would otherwise be impractical to implement as real experiments. In this way, we can tell how the results of the model applied in particular scenarios qualitatively resembles the behavior of peasants in real scenarios.

This model was strongly influenced by the work of Chayanov (1966) and van der Ploeg (2013). They discuss the complexity of peasants’ rationale and how mistaken economists have been who reduce peasant rationale to a capitalist one. This is the reason why we outline a modular model that can be adapted to several scenarios. Here, we utilize the elements we consider necessary for the study of subsidies.

The following is a concise summary of the explicit assumptions we have made for this model:

1. A farm’s ecological capacity increases with greater use of agroecological practices and decreases with higher degrees of Green Revolution practices.
2. Total output increases as the farm’s ecological capacity increases.
3. For low values of ecological capacity, agroecological production is higher than with agrochemical practices. For intermediate values, the opposite occurs, and for high capacity, they are similar.

To be able to portray these assumptions in the model, we take into consideration the following variables: ecological capacity, total output, and peasants’ net gains. The three variables are also essential for the different balances that peasants use while making decisions concerning the administration of their farms (Chayanov, 1966; van der Ploeg,2013). The external agent, on the other hand, provides subsidies that reduce costs (leading, therefore, to a net gain) in industrial agriculture practices. The next sections go into greater depth about why these assumptions were made, and these variables chosen to portray them. We know they do not always hold in real-world situations. The model is meant to be used as an exploratory tool, and could eventually assist peasant organizations, policymakers, and agricultural schools in their discussions about production practices and their consequences.

Evidence for the first assumption

Ecological variables, such as crop diversity, biodiversity, natural fertility of the soil, susceptibility to pests, and climate change, are fundamental to understand long-term effects on the production, economy, and health of farms (Epstein, 1997; Pretty, 2008; Graber et al., 1995). The ecological capacity (EC) of a farm is its ability to restore and reproduce its current state, and it is directly dependent on these variables. For the sake of simplicity, we choose to only use the EC variable because it qualitatively encompasses all the other ecological variables. It is also necessary in the model to represent that peasant choices are affected by the environmental variables as van der Ploeg (2013) suggests.

The EC of a farm is not static, it is a dynamic variable dependent on different factors. One factor is the agricultural practice, which is the focus of our research. There are several categories of techniques that farmers adopt. However, in this paper, we are interested in two specific types: agroecological (meaning polyculture, non-chemical, non-GMO, promoting soil ecology) and industrial agriculture (referring to monoculture, chemical, artificial fertilizers, Green Revolution's input dependent). The effect of both sets of practices over ecological variables has been studied in depth and is well known (Gliessman, 2015). Eroded or degraded farms have a low ecological capacity; however, with adequate farming practices or care, its ecological capacity can be increased (Holt-Giménez, 2006). A farm with higher EC is less susceptible to pests or climate changes, and it will be able to recover or maintain its usual reproduction after a disturbance (Durmont et al., 2013; Gliessman, 2015; Epstein, 1997). When the soil fertility originates from natural processes, it has a highly interconnected ecology, and it will be able to restore crops more easily (Gliessman, 2015), therefore it will have a higher EC. Agrochemicals have a negative effect on soil ecology because it breaks many connections in its network, resulting in soil erosion and a long-term loss of natural fertility (Altieri, 2009; Epstein, 1997; Graber et al., 1995), these also means it will have a lower EC. Considering agroecological farms promote natural processes to recover soil fertility, this constitutes the first motivation for our first assumption.

A second motivation comes from the evidence of an increase in a farms' vulnerability to pests and climate change derived from the practices of the Green Revolution (Epstein, 1997). There is an example of a comparison regarding the resistance of both types of farms to huracan Mitch (Holtz, 2001) showing agroecological practices helped farmers suffer fewer losses. That supports our assumption that EC increases with greater use of agroecological practices. There is still more evidence that Green Revolution practices deteriorate farms' ecological capacity (Epstein, 1997; Altieri, 2009; Pretty, 2008). Some questions may arise concerning yield increments in a crop cycle after implementing industrial agriculture methods, such as the use of fertilizers. Note, however, that this is artificial/temporary fertility, which affects the ecological capacity and therefore the yield of future crop cycles. So, to dispel those doubts, we assess the long-term effects.

One more piece of evidence that supports this assumption relies on agroecological understanding of practices. 'Importantly, "agroecology promotes principles rather than rules or recipes" (Nichols et al., 2016). These principles are environmental, political, economic, and social (Nichols et al., 2016; Rosset and Martínez-Torres, 2013; Altieri, 1995). In particular, environmental principles have to do with minimizing loss of resources, recycling nutrients, promoting functional diversity, and increasing biological interactions and synergies (see Fig. 0). Another aspect to ponder is the landscape, given that in agroecology, it is as important as the farm itself. The objective of an agroecologist is to design and manage a diverse ecological system (farm-landscape) that replaces external inputs with natural processes (Rosset and Altieri, 2017). Each farm has different conditions and consequently different needs, so the principles are adapted in practice to address these issues.

Some examples of agroecological practices are: compost, cover crops, mulching, insectary flowers, animal integration, agroforestry, among many others (see Fig. 0) (Nichols et al., 2016). Mulching and cover crops (covering the soil with dead or live organic matter) increase soil humidity, and thus also increase microbial activity and ecological interrelationships (Wang et al., 2020; Gliessman, 2015). The presence of this organic matter also decreases soil erosion and the presence of weeds. Polycultures and crop rotations preserve soil nutrients by allowing biological complementarity between crops (Altieri, 1995; Gliessman, 1998). They also reduce farms' vulnerability to pests (Iqbal et al., 2020; Kremen and Miles, 2012). Agroforestry arrays and animal-crop integration help to get an optimal recycling of nutrients and allow modifications of the microclimate to protect the annual crops from harsh weather. Trees also allow nutrients from deeper soil levels to become available, thus promoting soil fertility. Thus, it is possible to appreciate how each practice embodies certain principles mentioned above (see Fig. 0) and promotes natural processes that increase farms' health, productivity, fertility and resilience (Altieri, 1995; Gliessman, 1998); in other words, they increase farms' ecological capacity (EC).

Nevertheless, there are limitations we had to take into account. Specifically, the soil will not lose its EC completely or increase it ad infinitum. So, it was necessary to include these limitations in our model. We chose to represent them by allowing EC to vary in a fixed range of 0.1 to 1. Considering all these specifications, we propose the following dynamic equations for EC according to each practice.

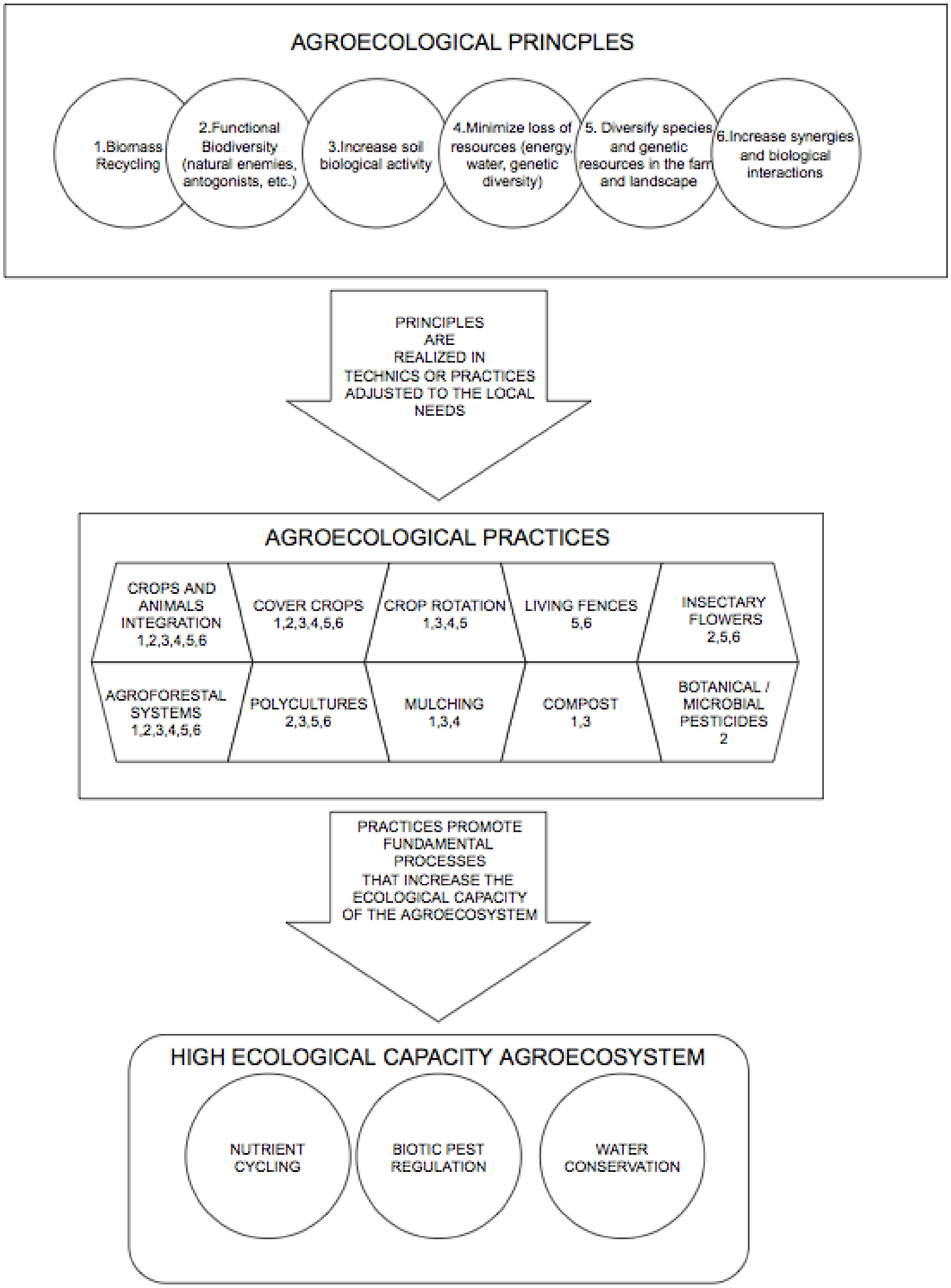


Fig. 0 The agroecological style is based on principles (top box), which are realized in techniques or practices (middle box) adapted to particular needs of a farm, which in turn promote the fundamental processes (lower box) that increase the ecological capacity of the farm. (Rosset and Altieri, 2018; Nichols et al., 2016; Altieri, 1995; Gliessman, 1998)

Implementing the first assumption into the model

For the agroecological set of practices we want the EC of the farm to increase over time, we can achieve this with a growth rate I, and multiplying it with the term (1 - EC) to account for the limit stated above.

$$\frac{dEC}{dt} = I * EC * (1 - EC), \qquad (1)$$

Likewise, changes in the EC for agrochemical practices are given by

$$\frac{dEC}{dt} = - D * EC * \left(EC - EC_{min}\right), (2)$$

where D is the rate of loss of EC due to agrochemical practices and EC_{min} is the minimum of ecological capacity.

Now, let us consider the relationships between ecological capacity and the other variables.

Evidence for the second assumption

We start with a farm's total output, which we call total output. This variable is important when peasants make choices. We do not use yield, because in an agroecological farm, production is not limited to the main crops' yield. It is more accurate to refer to the total output per unit area in a year (Rosset, 1999), which considers the produce of several crops and animals. In particular, we are not analyzing the size of the farm, so we will use only the total output. The nitrogen efficiency curve points to a reduction in yield through the years in farms where fertilizers are applied. Research has shown that this is a result of the erosion of the soil. In other words, as the ecological capacity decreases, total output also decreases (this is our second assumption, though in the negative form). There is more evidence of an increasing relationship between these two variables, for example (Rosset and Martínez-Torres, 2013; Altieri, 2009):

- A decrease in ecological capacity leads to an increase in vulnerability to pests and climate condition, which in turn leads to a total output decrease.
- Total output increases with an increase in biodiversity and soil ecological relationships.

The third assumption

The third assumption is actually not evident because comparing agroecological and agrochemical farms is not a simple task (Lloyd and Chalabi, 2021), especially if we consider farms in different parts of the world. However, in our model we posit a conservative scenario, where agroecological farms give better results for low EC values. Industrial production will overcome the agroecological for medium EC values, and for high EC values the total output will be similar for both types (Pretty, 2008; Altieri, 2009) This scenario is optimistic in terms of Green Revolution agriculture results, considering agroecological farms' total output is higher for all EC values in some locations. With these factors in mind and considering that this is a stylized model, we propose the total output as a function of EC in the next section.

Implementing the second and third assumptions

For the agroecological set of practices we have that

$$\frac{dP}{dt} = P_{Amin} + B_A * EC^4, \qquad (3)$$

where P_{Amin} is the agroecological production with a minimum EC, B_A is the maximum production increment achievable at EC=1 . The reason EC is to the 4th power in agroecological practices and to the 2th power in agrochemical is to portray our third assumption for EC ϵ [0,1].

For agrochemical practices, changes in the total output are given by

$$\frac{dP}{dt} = P_{Cmin} + B_C * EC^2, (4)$$

where P_{Cmin} is the agrochemical production at minimum ecological capacity.

As stated before, we do not aim to predict reality with our model, and these functions are not a result of quantitative data analysis. Instead, our purpose in choosing these particular functions was to capture the behavior described above.

Net Gain

Another significant factor in peasants' decisions is profit, although we must emphasize it is not the only factor as depicted in some models (Chayanov, 1966). The net gain refers to the difference between the peasants' investment and the total earnings of a production cycle (be it for self-consumption or to be sold). Therefore, a proportionality exists between the total output and the net earnings of a peasant family. However, markets, governments, and other external agents exert influence on that relationship (Mier y Teran et al., 2018). In the model, we account for this influence in the specific case of a subsidy granted to a farm with agroextractivist practices, i.e., a government paying part of the cost of agrochemicals, as UNEP (2020) states, "to enhance food security, income and avoid poverty traps" among other policy objectives, however resulting in “unintended negative socio-economic and environmental impacts.” (UNEP,2020). We show results that align with the observed consequences of such policies.

Diversity in rationalities

As stated before, peasants do not limit their rationality to a single variable (total output, profit, ecological capacity). Instead, peasants’ rationales are diverse. One way this is expressed is in how important each variable is for peasant families and their purposes. We propose to represent this variable’s importance by fractions that total 1. We then multiply the weights by the performance in each of the variables and tally a sum. This sum represents the performance of a crop cycle according to a family’s rationale.

$$R = \Sigma_i w_i v_{i_{norm}}, \Sigma_i w_i = 1 \quad (5)$$

where R is the result of the weighted sum (w_i) of the normalized variables ($v_{i_{norm}}$).

However, note that the variables are in different ranges, so it is necessary to rescale them. To do this, we used the quotient of the minimum over the maximum for the agroecological and agrochemical performances in each of the three variables (ecological capacity, net gain, and total output) used in our model.

$$min_{norm} = \frac{0.5*min}{max} \quad (6)$$

$$max_{norm} = 1 - min_{norm} \quad (7)$$

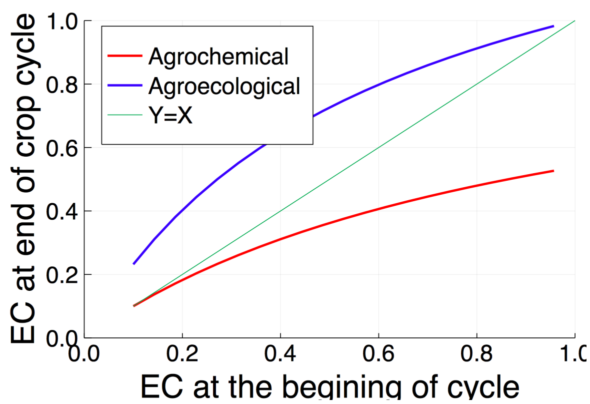
We do this every time a family tries out a practice, allowing us to consider the relative difference between the performances. In this way, if the relative difference increases, it will influence a peasant’s decision in a more significant way, limited, of course, by the weight given by the peasant to each variable. In the results, we show the curves obtained for one particular rationality.

Effects on the peasant economy

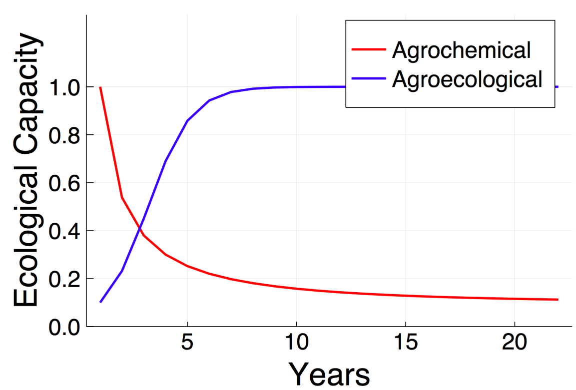
In our last analysis, we parametrize the subsidy intervention and run simulations with a particular rationale throughout 20 cycles. We measure the frequency of Green Revolution farming cycles because it gives us a measurement of how much a peasant family’s economy is affected in the long term. Using resilience analysis, we can also conclude that peasants’ choice regarding farming practices with that particular rationality is fragile to external agents.

Results

We obtained the change of the ecological capacity after one cycle by running equations 1 and 2. We did this in our Julia program for EC values in the range of 0.1 to 1. We see in Fig 1 a) that for the agrochemical practice, there is always a degradation of ecological capacity since the curve falls below the identity line (Y=X). Meanwhile, the agroecological practice restores it. These practices happen until they reach the range limit, which practically occurs after five years, as seen in Fig. 1 b). This means that for agrochemical practices, it will take approximately five cycles to have eroded soil. Instead, if we started with an eroded land after five crop cycles of agroecological practices, we can expect to have replenished farm soil. This result is not far-fetched; for example, Holt-Giménez (2006) describes the success of Kakchiquel peasants in Guatemala, where after only one or two years of agroecological practices in an eroded and dehydrated soil, they began to obtain production increases between 100% and 200% . As stated before, we ’do not claim or expect this will always be the case considering the diversity of farmlands and environments. However, to represent other qualitative results, it is possible to fine-tune the model to simulate different scenarios.



a)



b)

Fig. 1 in a) we can see along the X axis the EC at the beginning of the cycle, and along the Y axis the value of the EC at the end of the cycle for agroecological (AE) and agrochemical (AX) practices. b) The EC through time using AX practices starting with EC=1 (red), and AE practices starting with EC=0.1 (blue), both will reach the range limits within 5 years.

Equilibrium points and attractors in the dynamics of choice

Next, we show the relationships between EC and total output after running equations 3 and 4 through one cycle with different EC initial values. In Fig. 2, we added arrows to signal the direction of the dynamic a peasant farm would follow in each practice, although we should note that they do not indicate an actual trajectory of a peasant’s farm.

When studying dynamic equations, it is useful to locate the equilibrium points, which are states of the system where change is equal to zero. In our model, an equilibrium point is a state of the farm where the EC, total output, and net gains would remain constant. We can see in Fig. 2 that if there is no change of farming methods, an equilibrium point appears for each curve. In the agroecological farm, the equilibrium happens at EC = 1, which is the maximum for EC and total output. The opposite occurs for agrochemical practice, where the equilibrium point is at the minimum for both EC=0.1 and total output.

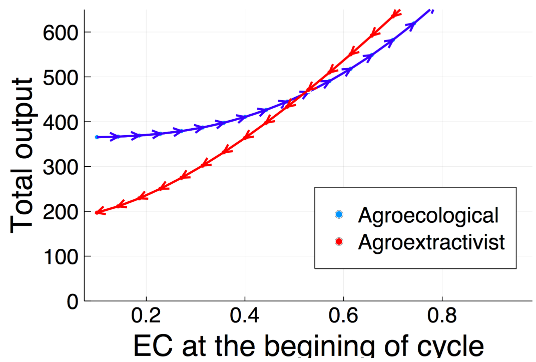
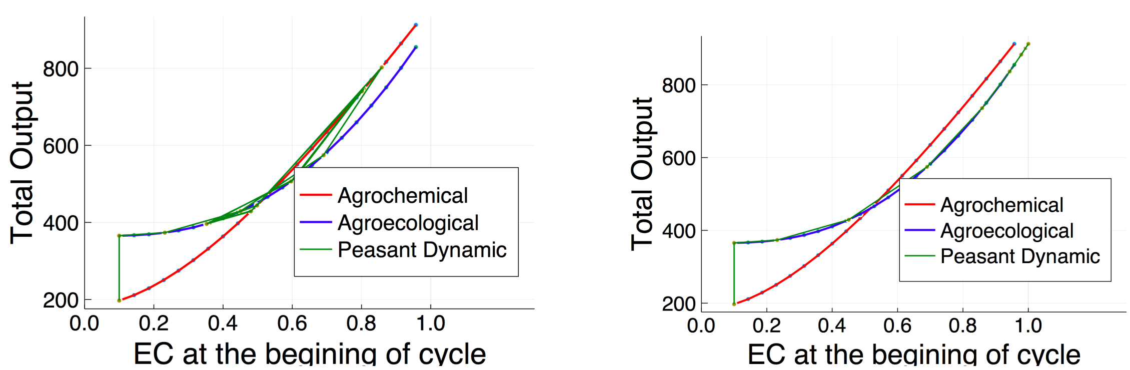


Fig. 2 Total output after a crop cycle for initial values of EC in all the range (0.1,1). This is not the vector field; the arrows simply illustrate the direction of the dynamic over the curves. An equilibrium point exists for each curve; agroecological (AE) is at EC=1 and agrochemical (AX) is at EC=0.1; in terms of total output AE will reach the maximum and AX the minimum.

However, if a farmer could choose the practice based on a rationale, the decision would also affect the dynamic. Thus, there are two forces that guide the peasant trajectory in the curves: the rationale and the practice. In Fig. 3, we have two simplistic rationales: a) shows one focused purely on optimizing total output (which some governments extoled while embracing the green revolution), and b) shows another rationale that is focused solely on ecological capacity.



a) b)

Fig. 3 The curves depict production for each practice; therefore the states of the trajectory will always fall on the curves, and we can perceive which practice is being adopted by the curve it falls on. In a), we see the trajectory of a farmer trying to maximize total output. The farmer's trajectory is cyclical, changing between agroecological and agrochemical practices, and therefore increasing then deteriorating the ecological capacity. This uncommon situation results from assuming that a farmer would only care about total output and is continuously trying the other practice; however, this particular situation is included to illustrate its instability. On the other hand, b) shows a trajectory of a peasant pursuing a higher ecological capacity: It has an equilibrium point at EC= 1, where total output reaches its maximum along the agroecological curve.

Notice that now the first peasant (focused purely on total output) would not reach an equilibrium point. Instead, the intersection of the curves appears to be an attractor of the trajectory. The agroecological practice will improve EC, but when EC > 0.5, then total output is higher for agrochemical practices, leading the peasant to change the practice. Consequently, this decreases EC because of the degradation effect of agrochemical until EC < 0.5, where again total output is higher with agroecological farming.

This behavior results from the two forces mentioned above and the particularity that the curves intersect. The relevance of this result is that it shows that there is a mapping between the curves' geometric properties and the peasant's dynamic choice.

However, short-cycle behavior is uncommon among peasants. Examples do exist, however, of peasants that showed cyclical behavior (traditional-agrochemical-traditional) through an extended period (Machin Sosa et al., 2010). In our model, we can change the period by allowing for some space between trials. In this simulation, peasants were continuously trying and comparing the two practices. We analyze the time between trials in a later section.

One more aspect to point out from this result is that the strategy to optimize total output fails in the long term. A peasant ends up achieving the opposite effect because the equilibrium point reached by a farmer pursuing improved ecological capacity produces more output than the states in the cyclical trajectory of a peasant pursuing an immediate higher output. We also address this in a later section.

Influence of external agents

Now we see how in the model an external agent modifies the geometric properties of the curves. The external agent could be a governmental policy that grants agrochemical subsidies and pays for a percentage of the inputs, making them cheaper or even free for the peasant. Fig. 4 a) has the net-earnings curves for each of the practices. Here we can see that a peasant who is concerned solely with profit would always choose agroecological over Green Revolution practices. Even though the total output and earnings for agrochemical are higher, the investment required is also very high. Thus, the net gain is lower than the one obtained by using agroecological methods. We can see that for low EC (<.2), net earnings under industrial practice are negative. A peasant who implemented this practice would end up losing money. However, if an external agent subsidizes the Green Revolution inputs investment, we get figure 4 b). This time the price paid for the inputs is only 3% of the real cost, and this leads to an intersection between the curves. Therefore, the peasant's dynamic will become a cycle similar to the previous example (total output), leading to the same consequences.

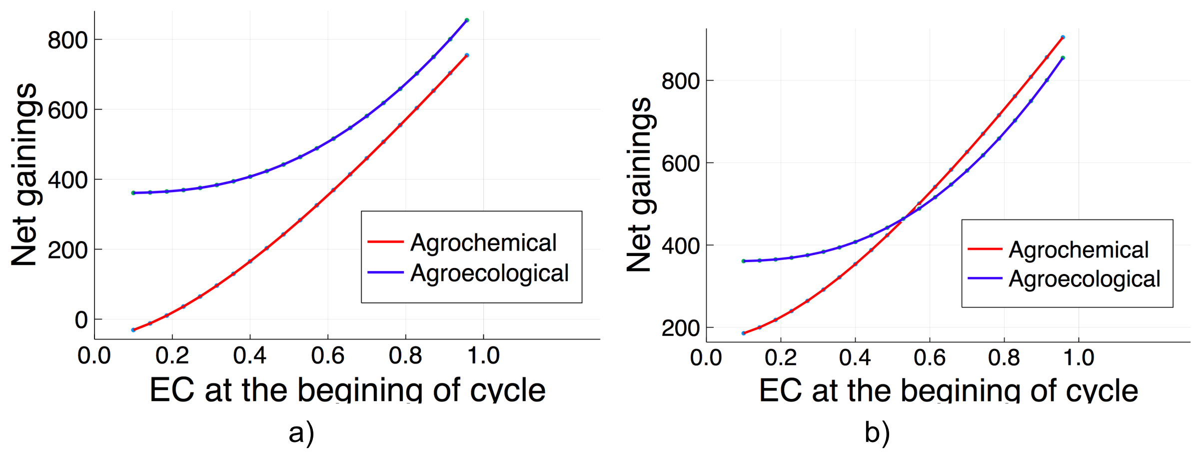
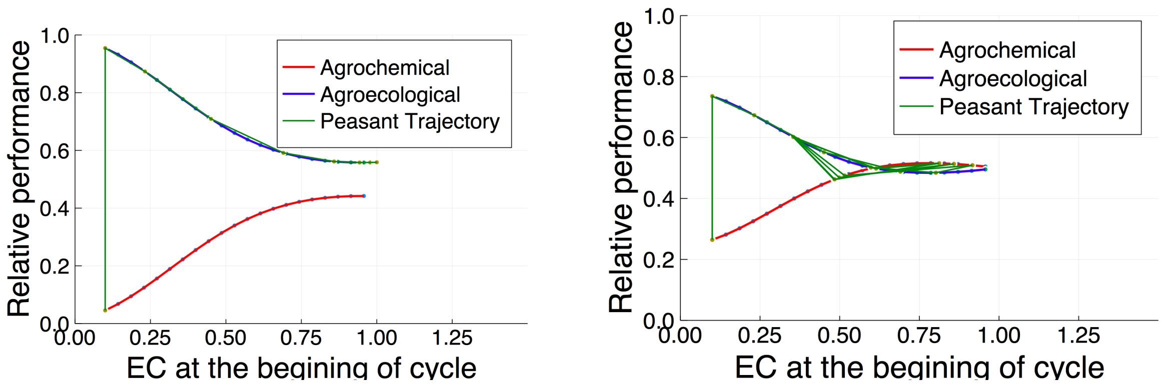


Fig. 4 These curves show a peasant's net earnings at different values of EC and the deformation caused by an external agent. In a), there is no subsidy and the agroecological method is always on top, i.e., net earnings are always higher than the agrochemical method. In b), a subsidy is given to lower the investment costs for agrochemical practices, producing an intersection of the curves. Now the agrochemical curve is above the agroecological one for values of EC > .5.

A particular rationality

We will now show the performance curves of a particular rational outlook. In Fig. 5, we plotted the performance for each value in the EC range. In our model, the rationale is limited to three aspects: ecological capacity, total output, and net gain. In particular, this family gives little importance to ecological capacity, with a weight of 0.1, twice as much to total output with a weight of .2, and the remainder to net gain, that is, .7. We can say this is a particular type of entrepreneurial or desperate family, i.e., a family looking for money. As we can see in Fig. 5 a), even though the family gives almost no importance to EC and quite a bit to net gain, the agroecological curve performance is always higher according to their rationale.



a) b)

Fig. 5 These graphs show the performance of a crop for both agroecological and agrochemical practices according to a particular (entrepreneurial or desperate) family rationale, as well as the trajectory that the family would follow. In a), we can see the family changes from agrochemical to agroecological practices and stays there. In b), we can see the effect of subsidizing agrochemical practices: The curves intersect and cause the family to enter a cyclical dynamic.

However, when the same experiment has an intervention of external agents via a subsidy, we obtain the curves in Fig. 5 b). Now an intersection occurs, leading again to cyclical behavior. This behavior has negative consequences on the family's income.

The impact of subsidies on the income of peasant families

To understand the negative consequences mentioned in these examples, we show the cumulative sum of the net gains after 20 years. In Fig. 6, the highest cumulative net gain is obtained when there is no subsidy. This result occurs because the family will choose the better performance according to their rationale, which, as we saw, is the agroecological practice. This choice will lead to better ecological capacity, higher total output, and improved net gain. However, when cyclical behavior occurs because subsidies changed the rationale, the cumulative net earnings are reduced almost a half after ten years. This reduction happens because the trajectory 'indicates that with a subsidy, net earnings always fall below the net earnings at the equilibrium point' under agroecological practice.

The other subject to address is that changes in practices do not occur every year. In this sense, we used different trial periods so that peasants may choose to change their practice only after every 1, 5, 10, and 15 years. As seen in Fig. 6, the first three periods produce similar results, cutting by almost half the net gain after 20 years. In the case of 15 years, given that only one change occurred in the first years, the increase in loss can be attributed to the continuous practice of Green Revolution agriculture. The lowest net gain, however, is for the agroindustrial practice with no subsidy.

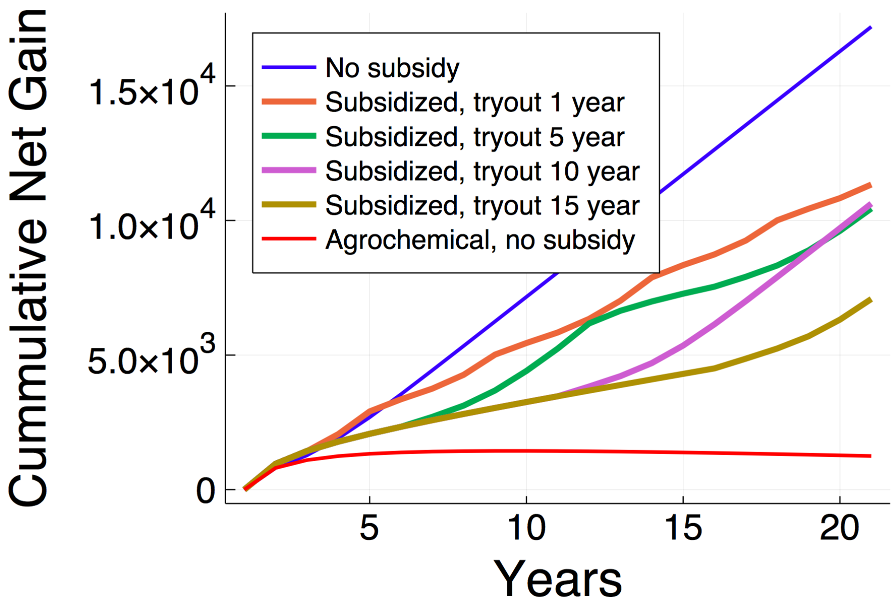


Fig. 6 We can see the effect on farmers' income when agrochemical practices are subsidized. Along the Y axis we can see the cumulative net gain depicting the sum of all the net gains of previous years. The red curve with the lowest cumulative net gain represents what would happen if for all years the practice had been agrochemical. We see that after five years the cumulative effect is actually decreasing, since the farm is losing money. The rest of the curves are for a family with an entrepreneurial or desperate rationale. The highest curve represents the situation when no subsidies are given and the family therefore changes to agroecological practices. In the other curves, an external agent subsidized the agrochemical practice leading the family to spend a different period implementing agrochemical practices, which in the long term almost halved the net gains that would have been obtained if there were no subsidy.

Fragility of families to external agents

The key property of a fragile system is that it responds in a non-linear concave way to disturbances (meaning "a fragile system gets damaged by environmental variability") (Equihua et al., 2020). In our study, the system is the family with an entrepreneurial or desperate rationale. The payoff function is cycles per practice since it is a measure of income loss (as we showed in the previous section). The disturbance is the presence of an external agent. The variability has to do with the subsidized percentage of the Green Revolution inputs investment by the external agent. We parameterized this variability and followed the change in the frequency of farming cycles in each practice. In Fig. 7, note that as the subsidy increases, the agrochemical farming frequency also increases. Thus, we conclude that in our model that the family's income is fragile to subsidies (meaning the family will change its behavior and therefore will be harmed in terms of its income).

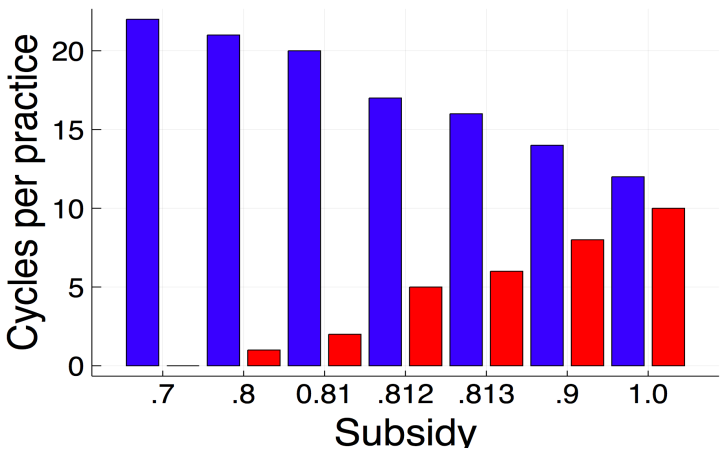


Fig. 7 These are the farming frequencies per practice in a 21-year period, for different amounts of subsidy granted to agrochemical farming. In this case, the family's rationale is either entrepreneurial or desperate (meaning net earnings are the most important driver of their choice of farming practices). As the subsidy increases, the agrochemical farming frequency also increases.

Discussion

As Holt-Giménez (2006) indicated, many governments changed the agriculture of several communities by financing Green-Revolution extensionism. Many peasants are lured by the instant increase in production; however, in the long term, their income drops significantly. In our model we also observe this behavior and its consequences. We see that they are the result of both a particular rationale (which places great importance on net gain) and the presence of an external agent (government policy) that subsidizes a large percentage of agrochemical costs.

The motives for focusing on profit are diverse (debt, health issues, hunger, greed, pressure, threats, etc.). Often, external agents (agroindustry, International Monetary Fund, governments) harass, intimidate, and force peasants to change their mindset. LVC and Grain (2015) demonstrate how industry puts pressure on farmers through seed laws that criminalize them. Our model, however, cannot distinguish between these motives. It would be perfectly possible to approach this fundamental matter when discussing the results generated in a simulation of a particular rural community.

Machin Sosa et al. (2010) also show evidence that some peasants never used this type of rationale, since they always placed greater importance on other variables (Chayanov, 1966; van der Ploeg, 2013), and thus never changed to an agrochemical scheme. We show that in our model when a rationale gives higher importance to ecological capacity, peasants reach an equilibrium point where they will not change to Green-Revolution practices, even though at some EC values production is greater, or even if the presence of subsidies make the net gain (in the short-term) higher for agroindustrial practices.

There may be disagreement with our models' functions describing the relationship between production and ecological capacity. However, the purpose of this paper is to suggest the use of this type of modeling tool as a mathematical parable to accompany agroecological arguments. We discuss the assumptions underlying this model and point to the research that backs them up. We did not design these functions to predict, so their precision is not relevant. We were interested in a qualitative representation.

We also found in our model that a geometric property, in particular, an intersection between the performance curves, implies a change in the peasant's choice trajectory. In other words, it is possible to compute the performance curves for each practice in a specific scenario, identify the intersections of the curves, and use those intersections to visualize the qualitative behavior of the peasants' choice regarding practices. We also pointed out the dynamic forces that drive that choice:

1) rationale
2) effect of a particular practice on a farm's ecological capacity
3) external agents

The variables we chose (ecological capacity, total output, net gain) are what we considered necessary to study the case of subsidies. However, some modifications to the model would make it possible to analyze other phenomena, such as climate change or the effects of a pandemic on peasant choice. Two possible ways to study these factors are to model them as external agents or add a dimension to the model. For this paper, the model is only dependent on ecological capacity. Another future application of the model could include the analysis of a rural community. It would be interesting to use the agroecological matrix coupled with this model. This combination would allow a broader perspective analysis of the political situation and the market's influence on a peasant community's farming choice.

There is evidence that even though subsidies to agriculture have been increasing, they are not improving peasants' lives (Rosset, 1987; López and Galinato, 2006; Fox et al., 2010; Altieri and Toledo,2011; Nikola et al., 2017). Rosset (1987) mentions that in Guatemala, 97% of the cost of agrochemicals was subsidized, promoting Green Revolution practices like the excessive use of pesticides, leading to pest resistance and other undesirable effects (Thrupp, 1990). Our results agree with this study, since we show how subsidies promote these practices, especially for a money-driven rationale. When a family changes farming practices, the net gain can momentarily increase; in the long-term, however, it leads to lower ecological capacity, total output, and net earnings of peasant farms, leaving peasants worse off.

Nikola et al. (2017) point out that stagnation of productivity occurs despite governments investing via agriculture subsidies, which is in tune with our model's results on total output. Evidence exists that the agrochemical industry and mega-farms are the real beneficiaries of this investment (Fox et al., 2010; Rosset, 1987; López and Galindo, 2006). Given our results, we also think this is a possibility, considering that production, peasant income, and the external agent (i.e., government funds) decrease in the long-term.

Another downside of subsidies and Green-Revolution packages is they generate dependency. A tragic example is India's farmer suicide crisis. In the state of Andhra Pradesh, the government withdrawal of subsidies during a drought left peasants extremely vulnerable (Deshpande, 2010). In Cuba, the "Periodo Especial" is another example of how dependency, in this case on agrochemicals, left peasants vulnerable (Machín Sosa et al., 2010). Even though we did not address this topic in our model, it would be possible to recast it to include credit and debt. However, we have argued that our results indicate some peasants' economy is fragile to subsidies.

Conclusion

We discussed building a model that allowed us to assemble and analyze the interrelationship of three concepts that are usually studied separately: the dynamics arising from the interaction between ecological capacity and farm practices, diversity of peasant rationale, and external influence in peasant decisions. We used two farming styles (agroecological and agrochemical) in our model, allowing peasant families to choose between these options. We showed that the behavior of a peasant choice trajectory in the long term (cyclical or reaching an equilibrium point) is related to the geometric properties associated with performance curves. In particular, the intersections of the curves point to a cyclical dynamic. We then included the influence of external agents and the differences arising from the importance peasants give to each of the three concepts. Taking all these elements into account, we showed results that arise when an external agent subsidizes agrochemical practices. This scenario is common among governments that claim to be protecting peasant interests. However, we saw that the long-term effect of such a policy is to lower the income of some (entrepreneurial or desperate) peasants that are more focused on yield or profit than ecological capacity. Even with this latter rationale, if no subsidies were available, families would have chosen an agroecological perspective. This result agrees with our literature review and points to a fragility in those peasants' income if subsidies are present. Finally, we discuss how to modify the model to address other ecological and social situations like climate change or pandemics. We view a practical use of these kinds of models as parables that can accompany policymakers and peasants' arguments when discussing the complex subject of farming.

Declaration of interest statement

Nothing to declare

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Capítulo 3: Campesino to Campesino versus Extensionism: A Comparative Model to Examine Agroecological Scaling[6]

Campesino to Campesino versus Extensionism: A Comparative Model to Examine Agroecological Scaling

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Abstract

In agroecology there is the question of what the most effective social method to achieve its expansion is. Despite the great achievements of the Campesino a Campesino (CaC) (peasant to peasant) methodology to multiply agroecological practices among the peasantry, many experiences continue to use the technical extension model, which consists of hiring several technicians from a public program, an international organization or a Non-Governmental Organization (NGO) to "transfer" agroecological practices to their clients or beneficiaries. CaC, instead, establishes a network of farmers who share their own practices with each other, and the role of the technician changes to that of an organic facilitator in the design and execution of

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the whole process. In this article we made a model in which we simulated the experience of the National Association of Small Farmers (ANAP) in Cuba and compared it with technical extensionism, finding systematically which properties make CaC a more effective, less costly and much more dynamic methodology for **territorializing** agroecology. We identified 3 limitations of extensionism compared to CaC: it does not take advantage of the pre-existing ANAP structure, the number of families reached in each period does not increase, and the logistic behavior of diffusion depends exclusively on how easily influenced each family is. We also recognized that the benefits provided by the facilitator come precisely from the increase in families reached per period due to the increase in organized workshops and that this effect is enhanced in a non-linear way with the presence of influence. On the other hand, we saw that the coordinator's work was the key to scaling the logistical behavior of diffusion at the regional level. Finally, we conducted experiments implementing the Banes method and found that there is a substantial acceleration of diffusion.

Keywords

Campesino a Campesino (peasant to peasant), diffusion of agroecology, technical extensionism

Introduction

Agroecology has become a global movement that seeks to transform the current globalized agrifood system into a fairer, more diverse, healthier, more localized system that is coherent with the ecological conditions of each territory. It also proposes to transform power structures, defend the territory, and put in the hands of the people the control of the means of production, among which the most important are land, water, and seeds. In particular, La Via Campesina (LVC), a movement that brings together 182 organizations in 81 countries and whose members represent more than 200 million peasants, artisanal fisherfolk, nomadic pastoralists, indigenous peoples, urban farmers and landless day laborers, promotes agroecology as a means to achieve peoples' food sovereignty and, through its organizations, is creating strategies for its dissemination such as agroecological training schools (Rosset et al, 2019), localized markets (LVC, 2011; 2015; 2018) and, above all, the *Campesino a Campesino* (CaC; peasant to peasant) methodology (Val et al. 2019). This methodology of knowledge sharing among peasants has in fact proven to be the best strategy to disseminate agroecological practices around the world.

CaC began in Chimaltenango, Guatemala in the 1970s with Cakchiquel indigenous people, where it achieved impressive results that were overshadowed in the context of the war (1960-1996) (Holt-Giménez, 2006). It subsequently sprouted peasant and indigenous community organizations in Mexico (Ramos-Sánchez, 1998, Boege and Carranza, 2009; Miranda, 2019; Royero-Benavides et al. 2019), as well as elsewhere in Honduras, El Salvador and Bolivia. But it was in Nicaragua where the model was able to become more systematic and grow more rapidly in the organizational context created during the Sandinista revolution. Between 1995 and 2012, the movement reported reaching fifteen thousand families throughout the country (Vásquez and Rivas, 2006; Saavedra et al. 2017). Thus, an international network was consolidated, which came to have projects in Brazil and Peru through the organization Bread for the World and extended to Cuba during the difficult crisis known as the Special Period of the 1990s (Rosset and Val, 2018).

The island of Cuba was experiencing an acute food crisis as a result of the fall of the socialist bloc and the intensification of the United States blockade. Cuba had specialized in the production of sugar cane and tobacco, was dependent on imports of food, machinery, spare parts, and agrochemical inputs from the socialist countries, and had bet on industrialization and urbanization that eroded its food self-sufficiency (Machín et al. 2010). Thanks to the fact that part of the traditional peasantry had survived, it was possible to undertake an agroecological transition using the CaC methodology, through the National Association of Small Farmers (ANAP). This organization of the Cuban peasantry—and a member of LVC—first carried out a couple of pilot experiments in some provinces in the center of the country. In 2001, in response to the impressive results obtained, it took on the *Movimiento Campesino a Campesino* (MCAC; peasant to peasant movement) as the central axis of its activity (Rosset et al. 2011). Since then, there has been a spectacular growth: from 216 families in 1999, the movement increased to 110,000 families in 2009—one third of the Cuban peasantry— (Machín et al. 2010). Today the ANAP estimates that 170,000 peasant families—nearly half of the country's peasants—are practicing agroecology as a result of this movement (Roque, 2020). But the impact is even greater if we consider the indirect effect of families who, though they do not participate directly in the movement, have incorporated practices through spontaneous processes of emulation (Val, 2012; 2021).

The success of Cuba has been the basis for expanding the MCAC in the context of the LVC internationalist movement and its organic processes of South-South cooperation, becoming a global phenomenon of training and exchange in agroecological matters. Through multiple meeting spaces held mainly in the Niceto Pérez García comprehensive training center, CaC has spread to other countries, as is the case of Mozambique (Val, 2021), the MST in Brazil (Fernandes et al. 2021; MST-CE, 2019), the Latin American Institutes of Agroecology (IALA) (Rosset et al, 2019), among other experiences, forming a coalescence of processes whose purpose in the LVC is the creation of the agroecological peasantry (Val et al. 2019).

The success of MCAC lies in its simplicity. A peasant called a "promoter," who has successfully tried out an agroecological practice on their plot that solves a specific problem, welcomes other peasants with the same problem, so that, through their own experience, they can promote the emulation of the experience. The methodology works because the peasants can verify the results with their own senses, and because the experience in the plot stimulates creativity and imagination (Rosset and Val, 2018) . Once they return to their plots, they put the knowledge they have learned into practice on a small scale, testing whether the promoter's practice also works in their own contexts. The method is appealing because peasants do not make an exact copy of what they learned in the exchange; instead, the objective is for each family to find solutions tailored to their own reality (Machín et al. 2010). The principle is that the same recipe cannot be applied to different circumstances; it is best to spark creativity so that everyone innovates and finds the optimum according to their own ecological conditions and resources at hand. One of the characteristics of CaC is its ability to work gradually, slowly but persistently, introducing agroecological practices one by one, starting with the simplest and working up to the most complex. Without being overwhelmed with too many practices, the family gradually converts its plot to agroecology, and through their example they stimulate other families to live agroecologically (Giraldo, unpublished).

The purpose is for the organization itself to take stock of these dispersed, fragmented riches—one piece of knowledge here, another there—and to engage them in dialogue through exchanges and encounters. Thus, isolated knowledge is brought into contact with other isolated knowledge, methodically reconstructing a system of knowledge (Giraldo, unpublished). This methodology differs substantially from the technical extensionism by means of which the Green Revolution spread throughout the world. By technical extensionism we refer to the methodology of technical assistance provided through public and private programs and projects, which for decades was implemented so that the peasantry would adopt the technological packages of the Green Revolution. This model consists in the hiring of several technicians by a public program, an international organization, or an Non Governmental Organization (NGO) to "extend" technical knowledge, so that modern technologies are "transferred" to their clients or beneficiaries, through visits to their plots. CaC is different, because it is no longer the technician who is the protagonist of the process, telling the peasants what to do. It is the peasant organization that is the protagonist: it builds a network of peasants who share their own practices among each other, while the role of the technician changes to that of an organic facilitator in the design and execution of the whole process (Giraldo, unpublished).

Despite the great achievements of this methodology to spread agroecological practices among the peasantry, the same model of technical extensionism used by the Green Revolution to disseminate agroecological practices continues to be used. We believe that much confusion remains. Within the global movement there are already several strategies that differ substantially from the classical agricultural extension approaches—among which CaC stands out—and which, as many cases have shown, are capable of transforming territories and even entire nations, as in the case of Cuba (Giraldo and Rosset, 2021). It is therefore necessary to understand more systematically why CaC is more effective, less costly, and much more dynamic than classical extensionism for territorializing agroecology.

In this article we propose a model in which we qualitatively simulate CaC using the ANAP experience in Cuba. The goal is to show how this methodology differs from technical extensionism and to understand the capacity of this form of work to have such a wide scope with much fewer resources. We use the example of Cuba's ANAP not only because it is the most successful case in the world, but also because its peasant network structure allows us to understand the social substratum on which agroecology can expand.

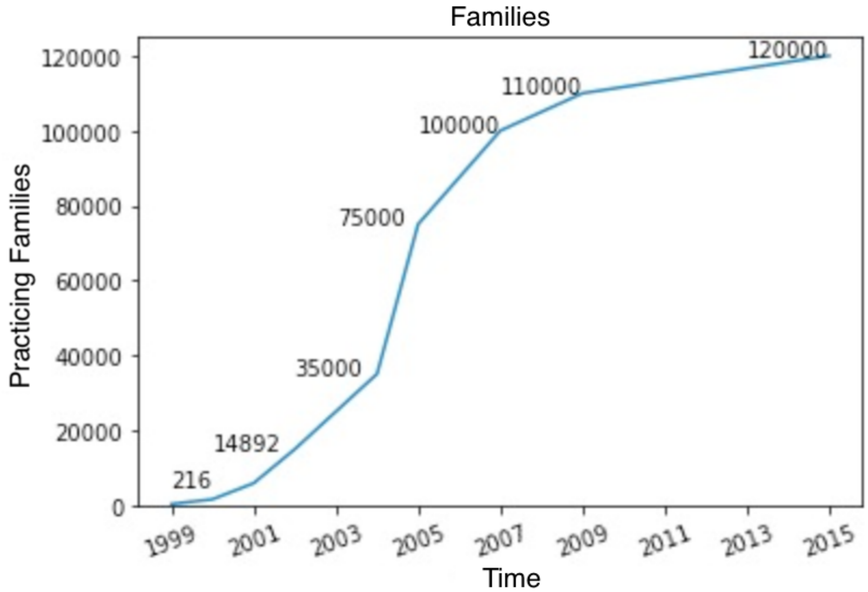
Modeling *Campesino a Campesino* at the ANAP

The ANAP is made up of a network of cooperatives spread throughout the length and breadth of the Cuban territory. In total there are 4,331 cooperatives that bring together 331,874 members. The cooperatives are Credit and Service Cooperatives (CCS) and Agricultural Production Cooperatives (CPA). The ANAP is thus a conglomerate of cooperatives, both CCS and CPA, geographically distributed throughout the island. Each of these cooperatives is made up of a network of 80 to 120 peasant families. Based on this structure, in our model we studied the diffusion of agroecology by simulating each of the methodologies in a network of networks. The implementation of the model was done in the Python programming language.

It is important to note that the model is heuristic in nature. Therefore, is not intended to make predictions or look for optimal diffusion parameters. We mention this because there is a very popular theory in the diffusion of innovations proposed by Rogers (2003), which describes innovation adoption curves in terms of different sectors of the population (innovators, imitators, early majority, etc.) and analyzes the differences in the mindset of each group. This theory gave rise to the Bass model (1969), which has been one of the most widely used models in marketing to predict the sales performance of different products. This model is based on two parameters: the coefficient of innovation (p) and the coefficient of imitation (q), used to propose a mathematical model describing Rogers' adoption curve. Our approach differs from these models, as we rely on preexisting organizational structures and intentional methodological processes. For these reasons, we ran a simulation using individual agents organized in the structure mentioned in the previous paragraph. On the other hand, while Bass' model analyzes the optimization of parameters at the population level to make predictions, and Rogers' theory proposes a categorization of social behaviors to develop market strategies, in our model we seek to compare the methodological processes of CaC and technical extensionism to analyze the elements that characterize their diffusion and interpret the advantages that one strategy can have over the other.

The bibliography on agroecology in Cuba has already emphasized the exponential adoption of agroecological practices by Cuban families through MCAC (see Figure 1). In this model we seek to analyze the impact on the speed of dissemination by the different actors of the CaC methodology (promoters, facilitators) and the pre-existing structure of the ANAP that allows exchanges between different cooperatives through the role of "coordinators" introduced by MCAC in Cuba. We also made a qualitative comparison of the potential difference in scope, time and personnel needed in the case of disseminating agroecological practices using technical extensionism.

Graph 1
Growth in the number of peasant families between 1999 and 2015 in the MCAC



Source: Machín et al (2001) updated with ANAP figures (Roque, 2020)

Below we describe the elements that we simulated in our model of agents.

The ANAP and Cooperatives

Implementation of the Structure

To simulate the structure of the network of cooperatives we defined a 2-dimensional mesh-like array where each entry is a dictionary with each cooperative's attributes and variables. One of these attributes represents the network of peasant families; for this we used the networkx library that allows us to define the structure of a small world where the nodes represent the peasant families that have a plot of land. In the same network we defined the other attributes for each family, which are mentioned in the following subsections.

Practice adoption processes

We modelled practice adoption with 2 elements:

1. The probability of adoption related to each family's decision.
2. The learning processes, which in turn are of two types:
    a. Self-taught: It occurs individually when peasants experiment on their own in their plots.
    b. Intentional pedagogical processes: It occurs through horizontal knowledge exchange or through vertical technical assistance.

It is worth stressing that the self-taught process is always active in an underlying way. Even if there is an ongoing pedagogical process, families always continue to experiment and emulate practices on their own.

The probability of adoption

The decisions that families make regarding their agricultural practices are complex because they depend on knowledge and experience, and on external factors such as the market, neighbors, agricultural policies, etc. In another paper (Bernal et al, 2022) we proposed a model through which we studied some of these factors. However, in the model presented in this paper we focused on diffusion, so that the complexity of the decision to change agricultural practices was simplified by a stochastic process associated with different factors, including the influence of neighbors, the presence and intensity of a problem in the plot, and trust in the person who shared the practice. There are also other variables that relate to self-learning ability, such as creativity. The implementation of this probability changes according to the learning process, so it will be described within each process.

Self-taught adoption

Self-taught adoption occurs through the experimentation that peasant families carry out on their plots. When they are successful and find a practice that solves a specific problem, they adopt that practice throughout their plot. Each family has different levels of experimentation and the search for alternatives is also influenced by what neighboring families are doing, which in turn depends on the presence of a problem on their plot and the intensity of the problem. Understanding this pedagogical process is important. Peasant agroecological knowledge emerged thanks to experiments based on the trial/error/learning formula. However, self-taught adoption is quite slow as a method of dissemination compared to intentional processes.

Implementing self-taught adoption

We simulated self-taught adoption using a stochastic process. To do so, we started the simulation by considering the individuality of self-taught adoption by assigning the "creativity" variable to each family using a folded normal distribution. This variable is used during the exercise to calculate the probability of that family changing practice in a self-taught manner ($p_{self-taught}$). This probability is calculated at each time step for each family in the following way:

$$(1)\ p_{self-taught} = .5 * (1 + problem) * creativity + Influence_{self} * fraction_{neighbors}$$

The $problem$ variable indicates whether the family has a problem that the agroecological practice solves. On the other hand, the $Influence_{self}$ parameter indicates the level of influence of the neighbors on the decision to change. Influence is taken as an average of the presence of the practice in the total number of neighbors. Thus, the term representing the influence of the neighbors on the probability of adoption is obtained by multiplying the $Influence_{self}$ parameter by the fraction of neighbors with the practice. To determine whether a family participating in an exchange will change its practice, we take a number generated from a uniform distribution. If that number is less than the probability, the family changes and becomes a practitioner. We do this in each cycle for each family.

Adoption by intentional pedagogical processes

We compared two strategies: technical extensionism and the CaC methodology. As mentioned, the first consists of hiring technicians who visit peasant families to provide assistance and teach agroecological practices. In the second, instead of hiring "specialist" technicians from outside the network, some peasants from the same network play the role of disseminating the agroecological knowledge of the peasant families. The methodology works through exchanges between peasants and a promoter who already has solutions because they have tested them on their farm.

To understand the modeling, it is necessary to understand all the players in the MCAC.

1) Peasant families (cooperativists). This is the group of people who learn agroecological practices and experiment on a small scale to test whether the promoter's practice works on their plot.
2) Promoters. They are those who successfully carry out an agroecological practice that solves a specific problem. They receive visits from cooperativists who have the same problem. They share their experience with other peasants in workshops organized on their own plots of land.
3) Facilitators in the cooperative. These are the members of the technical team in charge of organizing exchanges between promoters and cooperativists.
4) Coordinators in the municipality. They are in charge of carrying out exchanges between cooperatives, usually over longer distances. They carry out the engineering to plan exchanges more efficiently.

An important method used by facilitators and coordinators to improve the organization of exchanges, as well as to monitor the MCAC process, is the inventory of agroecological practices. It corresponds to a matrix (see Graph 2) in which the practices carried out by each cooperative member are identified. Thus, exchanges are more effectively directed to where they are most needed and with the most appropriate contents (Machín et al., 2001). This method in the MCAC is known as Banes because it was in the municipality of Banes, Holguín province, where this way of working was first created and tested with the purpose of better organizing the exchanges.

Graph 2
Example of an inventory matrix of agroecological practices by cooperative (Banes method)

	Polycultures	Organic fertilizers	Ecological pest management	Green fertilizers	Mulch	Crop rotation	Animal integration	Agroforestry
Family 1	x			x	x			
Family 2		x		x		x		
Family 3				x				x
Family 4		x						
Family 5		x				x		
Family 6	x	x		x		x		x
Family 7			x		x			

Implementation of CaC figures and technical extensionists

Peasant families are represented as agents in the cooperatives' nodes. Promoters are a fraction of these families, so the $p_{promoter}$ parameter was defined to represent that fraction. Families with the potential to be promoters during the exercises were determined using this parameter. At the beginning of the simulation, a number was generated for each family based on a uniform distribution, and those families with a number lower than $p_{promoter}$ were the ones that could become promoters. In the case of the ANAP, which has several cooperatives, the $p_{promoter}$ parameter will be different in each one. In some cooperatives it may even be so small that there is no promoter family within it. These assigned $p_{promoter}$ parameters have a normal distribution. All families start without the agroecological practice (except for an $N_{starting}$ number used to describe the initial promoters), so that the characteristic of acting as a promoter only manifests itself once the family adopts the practice.

To simulate the organization of workshops by the facilitators in each cycle of the simulation, the number of promoter families available in each cooperative is reviewed. In case they are found, we proceed to set up a workshop for each promoter without exceeding a parameter that represents the maximum number of workshops ($Max_{workshops}$) that can be organized in a cycle within a cooperative. When organizing a workshop, families from the cooperative that do not have the practice are chosen. The number of families selected will be less than the limit of participants per workshop ($Max_{participants}$). In the simulations we did at the ANAP level we included extra space in each workshop so that some families from neighboring cooperatives could participate.

To simulate the Banes method, a value was assigned with a $p_{problem}$ probability to the $problem$ variable for each family. Thus, some families have in their plot a problem that the agroecological practice solves, while others do not. Later in the exercise, the choice of the family is made on the basis of an arrangement sorted by the presence of the problem in the plot, so that the families with the presence of the problem are chosen first.

The role of the coordinators, which is to promote exchanges between families from different cooperatives, was implemented after the cooperatives held their own workshops in each cycle. The model was designed in such a way that it checks each cooperative for families without a given practice and looks for available workshops in neighboring cooperatives (using Moore's neighborhood, 9 neighbors). The neighboring cooperative with the largest number of free spaces within its workshops is chosen and that number of families is assigned to attend the workshop. If the Banes method is being used, the choice is made based on the ordered arrangement mentioned in the previous paragraph.

Finally, to simulate the technicians, we defined a parameter ($N_{technicians}$) representing the number of technicians hired. Each one is assigned a cooperative where they will spread the practice. Each of them will have a maximum number of exchanges ($Max_{technicianExchanges}$) per cycle.

In both pedagogical processes—technical extensionism and CaC—there is an exchange of knowledge, and a $p_{pedagogical}$ probability is used to determine whether the family will adopt the new practice. This probability is calculated as follows:

$$(2)\ p_{pedagogical} = problem + trust + Influence_{pedagogical} * fraction_{neighbors}$$

The $problem$ variable indicates how the probability of a family adopting the practice increases if their plot has the problem. The $trust$ parameter indicates the increase in the probability of adoption given the trust that families have in the source of the knowledge, i.e., the external technician, the network or the promoter family. In general, trust in the promoter family is greater; however, for the sake of simplicity and to focus on differences in the methodologies, we do not make this distinction. Finally, the third term affecting the probability of adoption represents the influence exerted by neighbors.

This influence depends on two elements:

1. The first is the $Influence_{pedagogical}$ parameter, which indicates how great the influence of neighbors is on the family's decision to adopt a new practice.
2. The second element is the fraction of neighbors ($fraction_{neighbors}$) who have already adopted the practice. This element takes into account the overall effect of all neighboring families.

In the simulation, a number is generated from a uniform distribution to determine if a family adopts the practice. If that number is less than the $p_{pedagogical}$ probability calculated for that family, then their practice will change. The calculation of this probability is done for each family that participates in the exchanges of each cycle, either in CaC workshops or with the technicians.

It is also important to note that the variable representing the presence of the problem in the plot is only considered in comparison with the Banes method, so that the probabilities are as follows in all other simulations:

$$p_{pedagogical} = trust + Influence * fraction_{neighbors}$$

$$p_{self-taught} = creatividad + Influence_{self} * fraction_{neighbors}$$

Results

The results come from simulations of the diffusion dynamic using the described model. Taking into account that the simulations include stochastic processes, the results we present are the average of several repetitions with the same initial conditions. We have two objectives in presenting the results obtained:

1) To compare the performance for the different dissemination processes (self-taught, extensionist and CaC)
2) To point out the parameters that limit the scope or speed of diffusion in each pedagogical process and in the various figures of CaC

At first we focused on simulated experiments in a single cooperative to analyze what happens inside it and, in particular, to understand what advantages the figure of the "facilitator" brings to the CaC process. Then we conducted experiments to study the changes in the diffusion behavior in the mesh of cooperatives, emphasizing the figure of the "coordinator," who is able to take advantage of a pre-existing structure. Before we begin, we would like to recall that the basis of CaC are the "promoters." Without them the other figures are meaningless. For this reason, if the fraction of the population that can become promoters changes, all the results change. We assumed that this fraction is 10%, a data obtained in the MACaC data (Machin, et al,). Other variables that we set throughout our experiments include: $trust = .1$, $Max_{technicianExchange} = 10$, $Max_{participants} = 10\ internal\ and\ 10\ external.$, $creativity_{average} = .001$ e $Influence_{self} = .002$.

Comparison of diffusion processes at the cooperative level

It is important to note that the CaC process at the level of a cooperative does not require the figure of a coordinator. Therefore, the advantages and limitations can be linked to the facilitators (remembering that the fraction of promoters is fixed for all simulations).

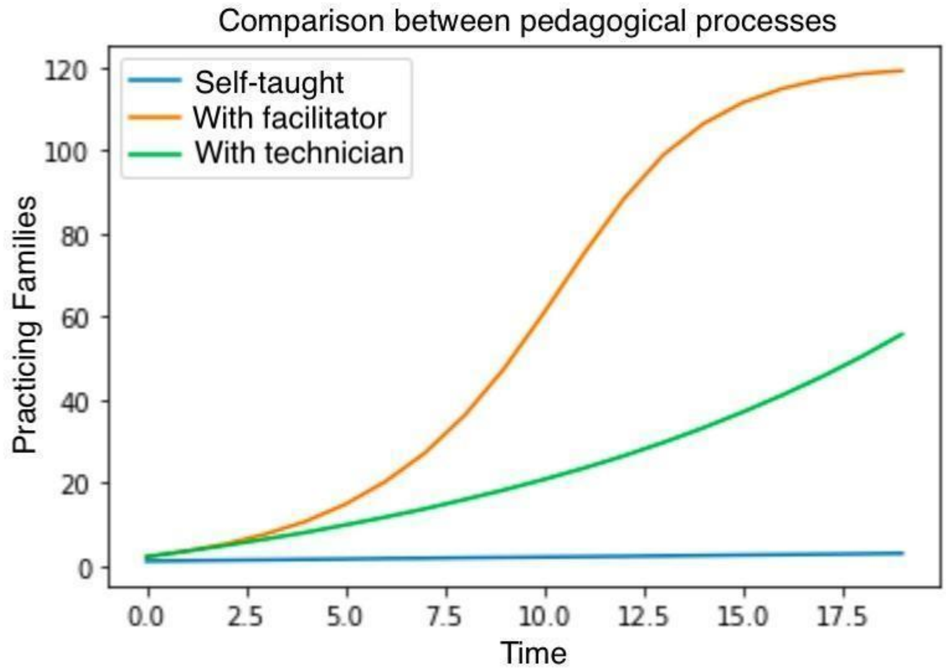


Fig. 1 *Simulation results with a cooperative of 120 families.* With the following parameters: $trust = .1$, $Influence_{pedagogical} = 1.$, $N_{technicians} = 1$, $Max_{technicianExchange} = 10$, $Max_{workshops} = 3$, $Max_{participants} = 10.$, $creativity_{average} = .001$ e $Influence_{self} = .002$. We see that the blue line, which represents self-taught adoption, remains at 0. Meanwhile, the curves of the pedagogical processes show a logistic behavior. We also distinguish that, in a short time, the CaC curve breaks away from the technical curve and permeates the entire network.

This simulation was done with a cooperative of 120 families. Figure 1 shows that the self-taught curve remains at 0. This occurs because the simulation time is only 10 periods, and the probability of adoption is estimated as 1 in 1000. With this population and time, not a single adoption occurs, which does not mean that no spontaneous adoptions have occurred in the individual simulations. On the other hand, the curves that represent the pedagogical processes show a logistic growth. To understand where this growth comes from, it is useful to look at the results in Fig 2.

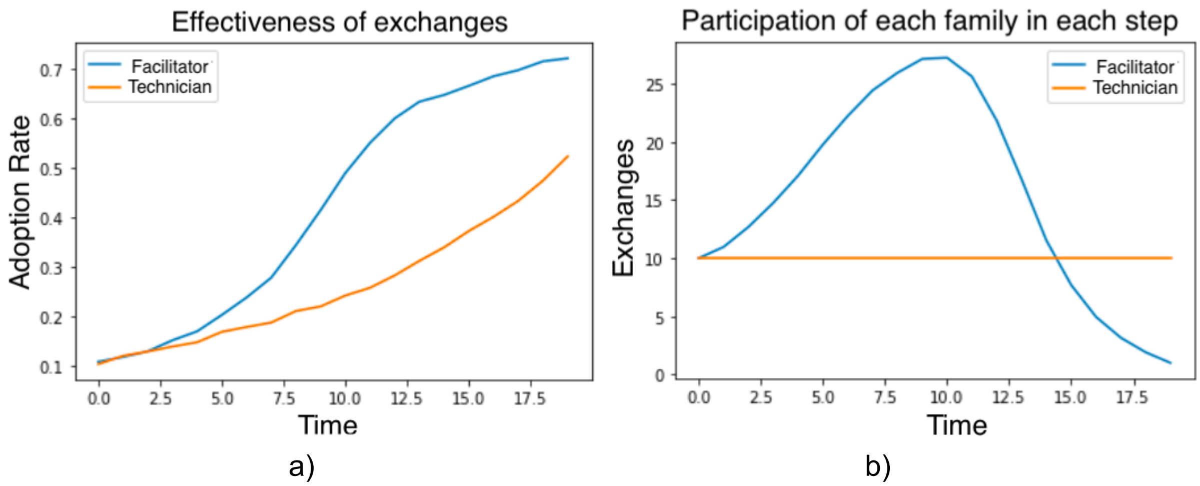


Fig. 2. *Effectiveness and number of exchanges for a cooperative.* In a) we see how the adoption rate grows, that is, the effectiveness of the exchanges. Both curves are increasing and tend to one, i.e. every exchange is an adoption. However, we can observe that the adoption rate in the process with facilitators grows more rapidly. On the other hand, b) is the graph of the knowledge exchanges that occur between the peasant families and the disseminating agents (promoters or technicians). The technicians' line is included as a reference for comparison with the curve of the CaC process. The CaC exchanges start to decrease after time 10 because the dissemination is already reaching the whole network, so there are no new families that can participate in the exchanges.

Figure 2, a) shows the fraction of families that participated in a knowledge exchange and adopted a particular agroecological practice. We see that both curves increase over time. On the one hand, this increase is due to the influence of neighbors, similar to what happens in the Bass (1969) model. However, since the influence of the neighbors is equal in both simulations, to understand why the CaC rate grows faster, we need to take into account another element: the number of exchanges. This is a variable that helps us understand the advantage of CaC compared to technical extensionism. In b) we see that while in extensionism this variable remains constant, in CaC it grows logistically. This means that we have two interacting acceleration elements in the case of CaC diffusion. This result motivated another simulation (Fig. 3), in which we tried to understand the interaction between the influence and the increase in the number of workshops.

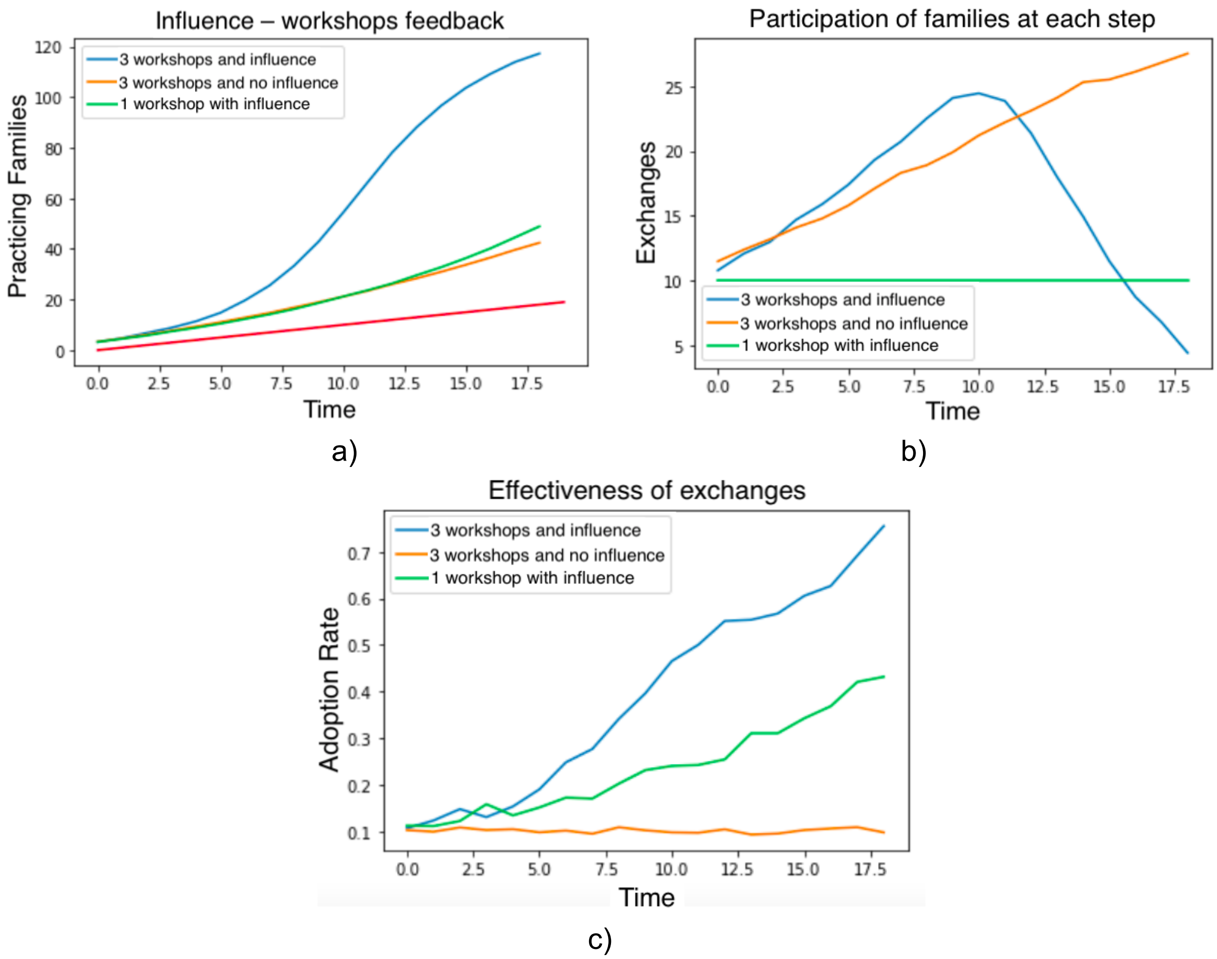


Fig. 3. *Results when separating the effects that increase the number of adoptions: increase in exchanges (due to workshops) and increase in adoption rate (due to influence).* In a) the red line at the bottom corresponds to a linear growth representing technical extensionism without the effect of influence. The two closest curves come from the independent effects: orange is the case when only the influence is considered (restricted to 1 workshop), and green is the case when only the increase in workshops is considered (without the effect of the influence). The fastest diffusion is the one with the combined effects; it corresponds to the CaC curve of the previous simulation. On the other hand, in b) we observe the number of exchanges for each restriction mentioned (note that the curve corresponding to the simulation restricted to 1 workshop is constant) and in c) we see the adoption rates (now the constant rate corresponds to the case where there is no influence of neighbors). We emphasize that in b) the blue curve reaches a maximum at 10 and from there it decreases because the diffusion is already reaching the whole network, so there are no new families that can participate in the exchanges.

The second experiment consisted of decoupling the effects that increase adoption in order to understand how they enhance each other. To do so, we did the following:

1) In one simulation we limited the number of workshops so that exchanges did not increase, as we see in the green line in Fig. 3, b).

2) In another simulation we removed the influence of neighbors, obtaining a constant adoption rate, as we see in the orange line in Fig. 3, c).

The result of this experiment is in Fig 3, a). The influence of neighbors and the increase in exchanges independently have similar logistic behavior. However, we see that when coupled they cause a diffusion that exceeds the sum of the diffusions separately. This occurs because there is positive feedback, i.e., the increase in exchanges produces more adoptions, so the influence increases. The same happens the other way around: as the adoption rate increases, it is easier for the promoters to adopt the practice and therefore the exchanges increase.

Other observations from the second experiment that we would like to highlight are as follows:

a) When we limited the variable of the maximum number of workshops to 1 per period, we noticed that the potential of the CaC process is lost and, in fact, this limitation makes its behavior equal to that of technical extensionism.
b) Recalling that the number of participants per workshop is fixed, we observed that if the number of workshops allows participants per period to increase to a certain percentage of the population (25% in our experiment), then adoption will continue with a logistic behavior, even when families are not influenced by what their neighbors do.
c) Extensionist diffusion without influence has a linear behavior (in red in Figure 3, a). This adds a second limitation to the extensionist pedagogical process. In general we see that technical extensionism is very similar to what was described by Bass (1961), where the logistic behavior of the adoption curve depends on the influence parameter.

We summarize the findings of the experiments with 1 cooperative as follows.

Technical extensionism has two limitations: the number of exchanges is constant and without the influence of neighbors on families, the behavior becomes linear. On the other hand, we found that the benefits brought by facilitators can be associated with the number of workshops that can be organized. Indeed, the increase in exchanges, resulting from an increase in workshops, contributes to the logistical behavior of the adoption curve. This happens even though there is no influence from the neighbors. But, when this influence is present, there is a positive feedback effect that results in an acceleration greater than the sum of the independent effects. The only variable that causes the CaC effect to be lost is the maximum number of workshops per period.

We will now turn to the results at the level of the mesh of cooperatives, which corresponds to a regional, municipal or even ANAP-wide level. It will be important to remember the restrictive variables mentioned in the synthesis.

Comparison at the regional level

In this section we explore the effect that coordinators have on the diffusion process. In the simulations at the regional level we found that diffusion takes place at two levels:

1) At the level of each cooperative (as studied in the previous section)
2) At the mesh level, through the cooperatives

Throughout the experiments we will be referring to dissemination at both levels. We begin with the comparison between the pedagogical processes of technical extensionism, CaC without coordinators and CaC with coordinators.

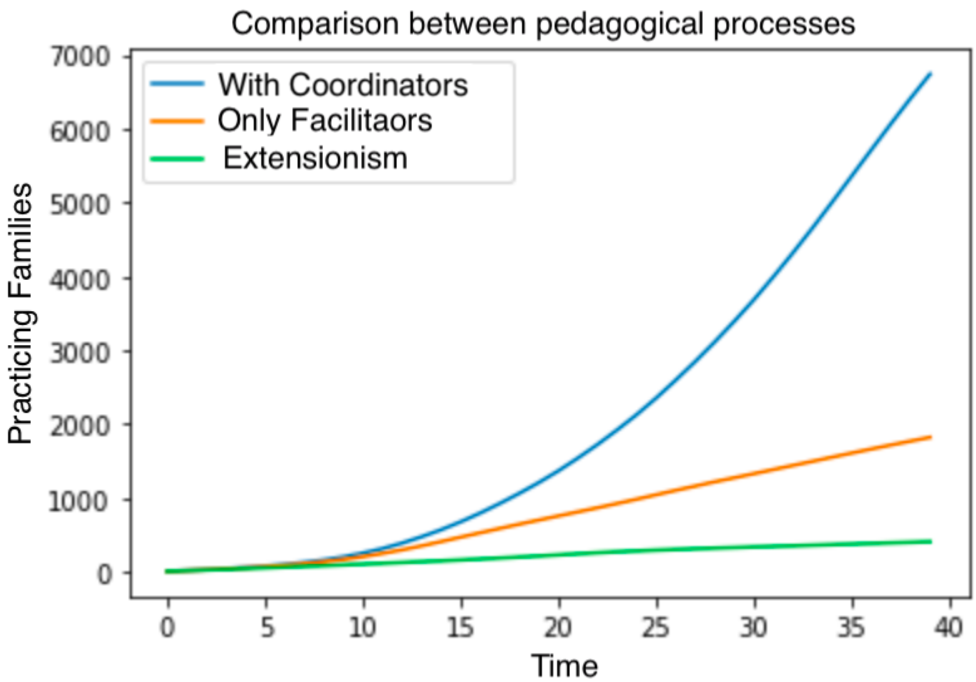
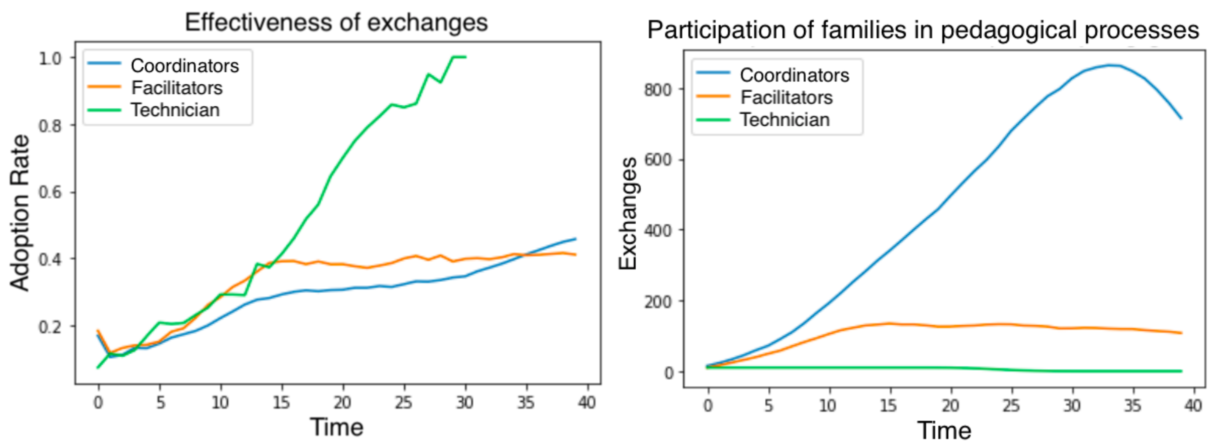


Fig. 4. Simulation results on a mesh of 10 X 10 cooperatives, each comprising 80 to 120 families (X=100), for a total of 10,000 families. The following parameters were estimated: $trust = .1$, $Influence_{pedagogical} = 1.$, $N_{technicians} = 4$, $Max_{technicianExchanges} = 10$, $Max_{workshops} = 3$ (per cooperative), $Max_{participants} = 20.$ (10 spaces were added to the workshop so that neighboring cooperatives can join in), $creativity_{average} = .001$ and $Influence_{self} = .002$. The graph shows that in technical extensionism, adoption is limited due to the fact that the pedagogical process is reduced to the families of the cooperative visited by the technician. In the case of CaC with facilitators we see that the speed of diffusion seems to have linearized, and only in the case of coordinators we see that the logistical behavior persists.

Because families must have a follow-up after the adoption of practices, the disseminators of the practices must remain in the cooperatives where they disseminated the practice. This is not a problem in CaC, since the promoters of each cooperative are the disseminators, and the task of the facilitators is done by someone from the cooperative or volunteers related to the movement, but in general there has not been a delay due to lack of facilitators. However, this is a problem for technical extensionism, as shown in Fig. 4. Dissemination only occurs in the cooperatives where technicians have been assigned, so that to reach the entire network, one technician must be assigned to each cooperative.

In the case of the CaC curve without coordinators in Fig. 4, we note that, unlike technical extensionism, there is growth that appears to be linear. In both cases some adoptions are still present, due to the self-taught learning process. The reason we see growth in the CaC process is that the promoters may also be the ones doing the self-taught adoption of the practice. When this occurs in a cooperative where there were no practitioners, then the facilitator of that cooperative will be in charge of organizing the workshops and disseminating the practice internally (as in the experiments with one cooperative). Likewise, in Fig. 4 we can see how the logistical character that we had observed in the diffusion in a cooperative is manifested in the CaC process with coordinators.

The adoption rate and the number of exchanges are shown below.



a) b)

Fig. 5 *Results of adoption rate and number of exchanges at the regional level with 1 initial disseminator*. In a) we can see that adoptions in technical extensionism stop around time 25, because their scope is limited to a single cooperative. The CaC curves (orange and blue) reach an equilibrium, because a diffusion along the mesh is occurring. Later at time 30 the curve with coordinators starts to increase, which implies that the diffusion is already reaching the limits of the mesh. In b) we confirm this because the CaC curve reached the maximum of exchanges around time 30.

In Fig. 5 we see that the growth of the CaC diffusion without coordinators is linear, at least, from time 15 onwards, since the rates of adoption and exchange reached an equilibrium. This occurs because the self-taught adoptions occur at different times, so that while some are in their last stages where the rate is close to 1 and the exchanges are decreasing, other cooperatives that start adopting show the opposite behavior. The orange curves in Fig 5. represent the average of these behaviors, which results in an equilibrium in both variables consistent with the linear diffusion of CaC without coordinators shown in orange in Fig 4. This same equilibrium is seen in the adoption rate of the CaC curve with coordinators in Figure 5, a). In fact, this curve is below the others while the diffusion is the fastest, which indicates that the diffusion is accelerating along the mesh. In Fig 5, b) we see that the exchanges in the case with coordinators increase rapidly, which should be reflected in an increase in the adoption rate, but this does not happen. So the only reason it reaches equilibrium is because of the increase in new cooperatives that have low adoption rates. Thus, we know that diffusion accelerated across the cooperatives.

In Figure 5 b), as in the case at the cooperative level, the maximum number of workshops per cooperative is 3 per period. However, in this simulation there are 100 cooperatives, therefore, the number of workshops that can be given at the same time goes up to 300 and the maximum number of participants up to 6000. This is an advantage of the CaC methodology that stems from the granular growth of the rural population, so that when the rural population increases, it does so by forming small groups that facilitate their self-organization. Therefore the task of the facilitators does not increase, but rather they multiply along with the number of cooperatives. If to this granularity we add a structure—that is, if there is something or someone (a coordinator) that connects the cooperatives at the regional level—then they can benefit from each other with the processes that are occurring within. Thus, we see in Figure 5 b) that the logistical increase in exchanges that we observed within a cooperative in the previous experiments was scaled up to the regional level as a result of the movement of families made by the coordinator.

Returning to what we observed in the case of technical extensionism for this simulation, we know that the number of technicians required to spread the practice to an entire area is equal to the number of cooperatives within that area. So if we increase the diameter of the area where agroecology is to be disseminated, the number of technicians will grow quadratically. Even so, the diffusion time remains constant since there is precisely 1 technician per cooperative. In the CaC case, the figures automatically increase with the network; however, we do not know how the time it takes to reach the entire network changes. To understand this we did 2 experiments: we compared the "army of technicians" that should be hired through the extensionism methodology, and the CaC methodology, and we monitored how the diffusion time changes as the area of the region increases.

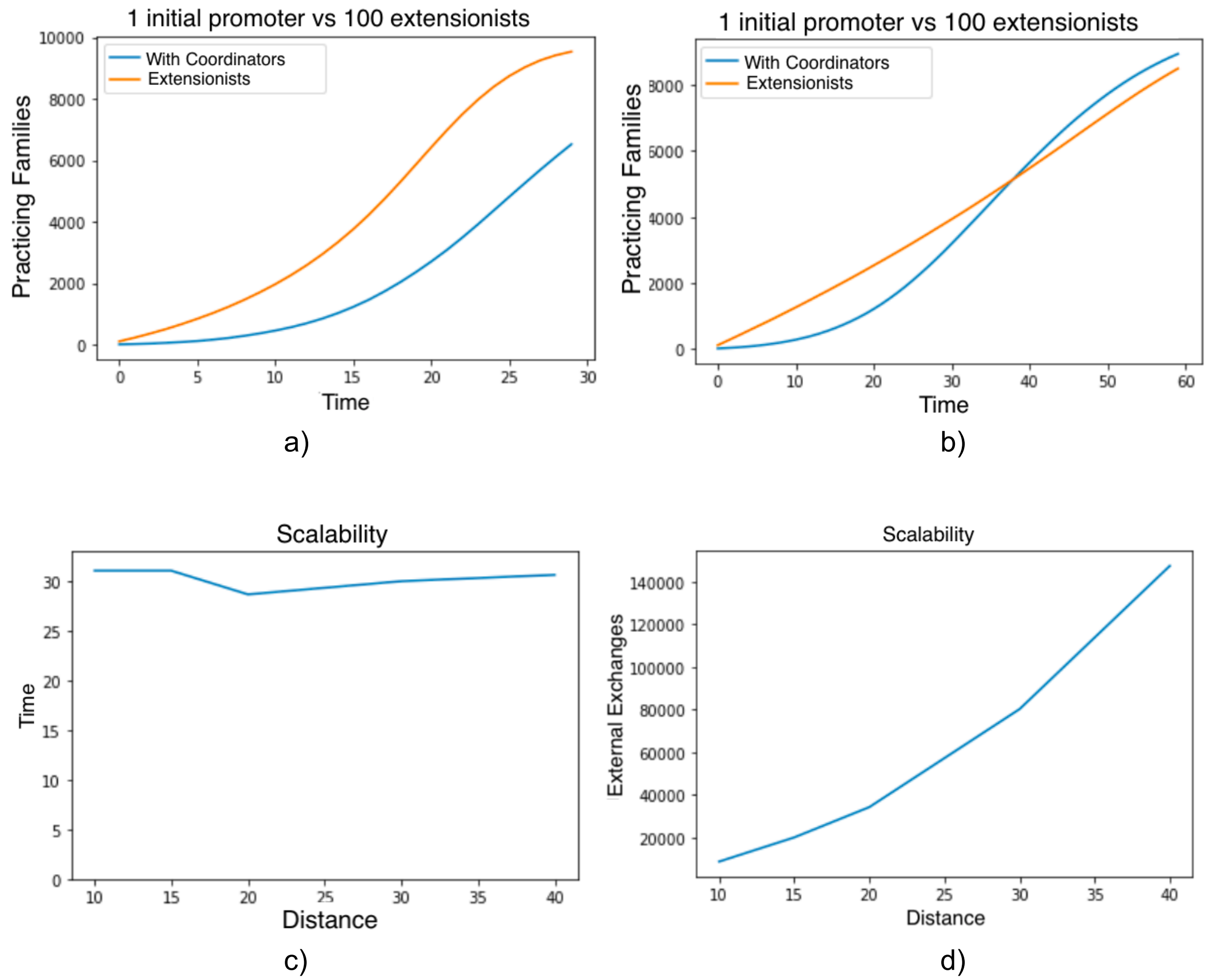


Fig 6. *Comparison of time and cost required for each pedagogical process.* In a) we see the result of comparing diffusion by 100 extensionists against 1 initial promoter with the same parameters as the previous simulation. In b) we decrease the level of influence that neighbors have on the decision to adopt the practice. As we saw at the level of 1 cooperative, the effect on extensionism is more severe and this causes the slight advantage between the methods to be reversed. In c) we plotted the number of periods (or time) that were required on average for the practice to spread by changing the length (distance) of the mesh. We see that the graph is practically constant despite the fact that cooperatives grow quadratically with distance. Finally, in d) we see how the number of external exchanges grows; these require transportation. It is the most relevant expense in the case of CaC. In this case, the increase in external exchanges is quadratic with distance. This means that the difference by cooperative between the costs incurred in CaC and those of technical extensionism is obtained by comparing the cost of 9 short trips vs. the salary of a technician with per diem for 30 periods (~8 years).

In the first "army of technicians" experiment we see that if families are easily influenced in their decisions, as shown in Fig. 6, a), then technical extensionism will perform slightly better than CaC. We also noticed that the time it will take for diffusion will be the same as in the case of a cooperative, because in essence this is what is happening (1 technician per cooperative).

However, when the importance of the influence decreases as in Fig. 6 b) we see that now the CaC curve reaches and exceeds the diffusion of technical extensionism.

We did the second experiment to analyze how the CaC case behaves when we introduce the distance variable. The result is shown in Fig. 6, c) where we can see that there is no significant change. The time remains practically constant even though the number of cooperatives increases quadratically with distance. This result is very important, since it implies that the diffusion time of the CaC process to a whole region is scale-free (in the model), i.e. no matter how much we increase the number of cooperatives in the network, the CaC process has the necessary components (or figures) for the diffusion to occur in the same time as when there were fewer cooperatives. Finally, in the second experiment we also monitored the number of external exchanges that take place. In Fig. 6, d) it is possible to see that the exchanges grow quadratically with distance, as does the number of technicians. Thus, to compare the cost we can divide the number of trips by the number of cooperatives. The number of trips can be approximated by dividing the number of exchanges by 10, which is the minimum free space that exists in the workshops for neighboring cooperative families to attend. This approximation makes it easy to see that the average number of trips per cooperative is around 9. Thus the difference in cost would be between 9 short-distance trips versus the salary of one technician (including transportation and per diem expenses) during the 30 periods of diffusion (around 8 years), so that the magnitude of the savings in the CaC process is evident.

The last experiment we did for this paper was the comparison of the use of the Banes method, in which the organization of the exchanges is refined, so that families that present a problem that agroecological practice can solve are chosen first. In practical terms, the families most likely to adopt the practice are chosen first. Here is the result.

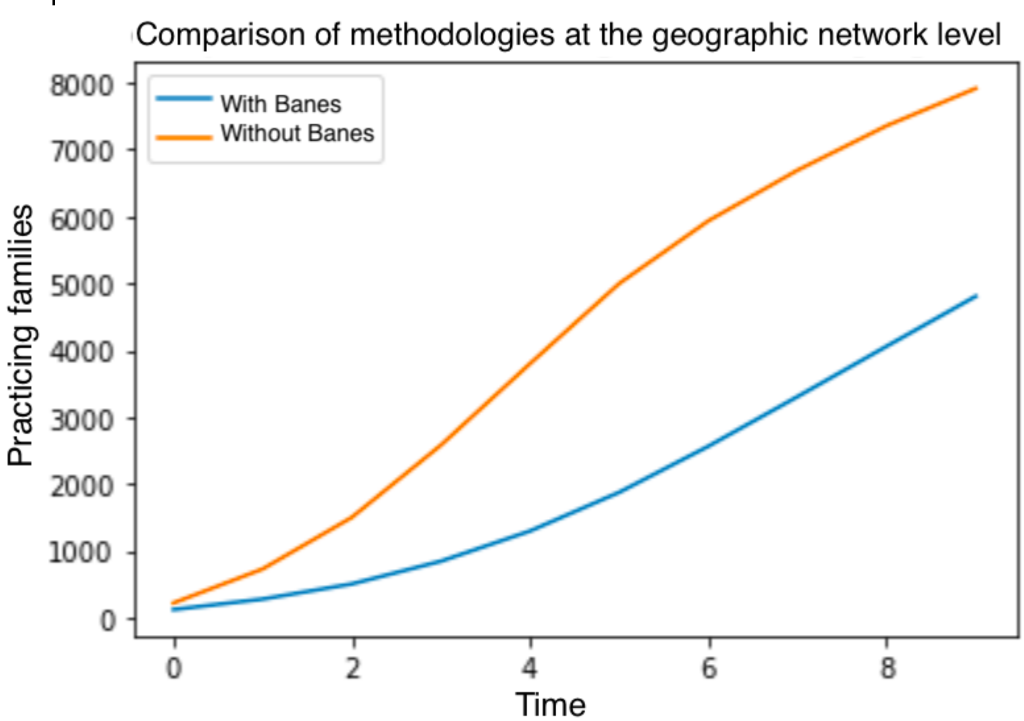
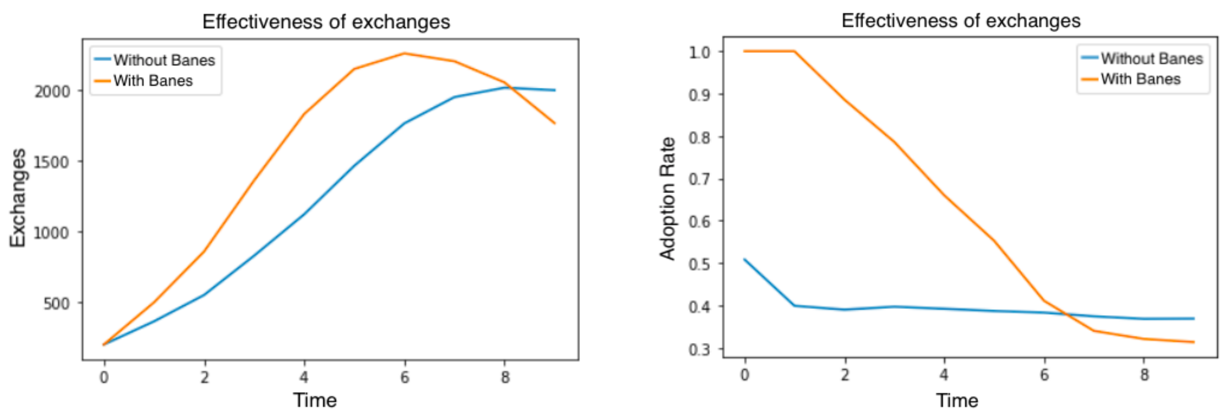


Fig. 7. *Results of the Banes comparison*. We first observed that both curves are faster when looking at the time scale. This occurs because the introduction of the problem variable in the experiments increases on average the probability of adoption for the families (even though only some of them have the problem). We also see that the curve with Banes is much faster (it takes half the time to reach half the population).

What we can observe in Fig. 7 is that the diffusion time is shorter. This happened because we increased the problem variable. In addition, the Banes curve is much faster, but after reaching the middle of the population, the growth changes. To better understand what happens we can again look at the graphs of exchanges and adoption rate.



a) b)

Fig. 8 *Exchanges and adoption rate in the Banes method experiment*. We see in a) that the exchanges increased for both curves, but there is not much difference, except that Banes' curve is ahead. The difference is in b), the adoption rate. During most of the simulation, the Banes rate is above and starts at 1, i.e., full effectiveness of exchanges. However, the rate falls throughout the exercise unlike in the other experiments.

In Fig. 8 b) we observe that the Banes experiment starts with a probability of 1, i.e., all exchanges are effective. However, in contrast to what we observed in the previous experiments, now the probability decreases. This is due to two factors. On the one hand, the Banes method first selects the families that will adopt with the highest probability, so eventually these families will decrease and only the families with the lowest probability of adoption will remain. In the previous experiments, the influence caused the probability to increase over time, but here we chose to show an example with a small influence, which is why the influence does not manage to lift the curve. The increase is not visible in the curve without the Banes method either. In fact, there is a slight decrease, which is a consequence of the fact that the families with the lowest probability of adoption will be the ones that remain. This occurs because each time a family with the problem on its plot participates, it adopts the practice, which does not occur when a family without the problem participates.

The Banes method with the parameters we used gives a great advantage. In fact, by repeating the exercise of comparing the "army of technicians" with a promoter, now even with the high influence, the CaC curve gave a result very close to the technician, and the costs decreased to just under 4 trips per cooperative. However, we have to consider 2 parameters that regulate the benefits that the method can bring: 1) the fraction of families with a problem (if all have it or nobody has it, it would not bring any benefit); 2) the magnitude of the problem (if the difference in the probability of adoption increases between a family with the problem and one without the problem, it will be observed that the curves will separate more and the diffusion time with the Banes method will be lower); 3) influence also has an effect, albeit to a lesser extent. This is because it will make the efficiency rates stick together.

Discussion

The proposed model aims to encourage reflection and dialogue on the differences and limitations of pedagogical processes for disseminating agroecology. The model is a kind of laboratory that allows us to experiment and propose scenarios to select the most effective methodology to make agroecology a mass phenomenon. It also allows us to understand how different variables of the diffusion process interact, such as the influence and number of exchanges or the influence and the Banes methodology. We can discern under which conditions an aspect or element of the methodology can bring the greatest advantages. These learnings could assist in the planning of strategies.

In the results, we found two variables that helped us analyze the experiments: number of exchanges and adoption rate. In the analysis, we found 3 important limitations for technical extensionism:

1. Exchanges are constant
2. Without influence, diffusion occurs in a linear fashion
3. A minimum of one technician is needed for each cooperative in the mesh

We also mentioned that the process of the technicians is consistent with the Bass model, because it has in essence 2 elements that affect the probability of adoption: an external one (influence by neighbors) and an intrinsic one (the trust that the families have in the technician). However, using the Bass model it would not be possible to explain the CaC process, since despite eliminating the influence component, logistic growth persists.

The key to this difference lies in the figure of the facilitator: their ability to organize workshops as the promoters appear. This occurs gradually over the course of the exercise, which leads to an increase in the number of exchanges per period and therefore in the number of adoptions. When the effect of influence is added to this process, there is positive feedback that results in diffusion that far exceeds any of the individual behaviors, as well as those of technical extensionism. Moving on to the study of dissemination at the regional level, we observe that the self-organization of the rural population in small communities is advantageous for the CaC methodology because it allows the number of facilitators to grow with the population, autonomously and without the need for external resources. At the same time the burden on each facilitator does not increase (in the model, it is not necessary to increase the maximum number of workshops per cooperative; the opposite would happen if the number of families per cooperative increased, i.e., we would need to increase the burden on the facilitator).

Although this advantage means that the diffusion of CaC at the regional level surpasses technical extensionism, when it is done without coordinators, the growth of adoptions is linear. This is equivalent to the situation faced by CaC in some countries, such as Mexico, where it was able to develop in some communities but not at the regional level. We saw that in the model, this situation could be explained by the fact that the simulation did not take advantage of the strength acquired in the cooperatives where the dissemination process had already begun. This changes when the figure of the coordinator appears, since their role makes it possible to connect the cooperatives so that they can benefit from each other. In the case of Cuba, the ANAP already had a broad structure of cooperatives, so the presence of a coordinator to link the potential of each cooperative was essential to accelerate the process. The task may seem simple: find cooperatives with families that do not follow the practice and take them to workshops in a neighboring cooperative where agroecological practices are used to solve a production problem. Nevertheless, such a simple method is enough to accelerate dissemination once the potential accumulated in the cooperatives where the CaC process has already begun is tapped. The role of the coordinator is to scale the increase of exchanges, thus generating logistical behavior at the regional level. In our model we did not implement a mechanism of influence between cooperatives, so this benefit will be left to be explored at a later time.

We also did the exercise of comparing an "army of technicians" that could reach the entire network against the CaC process, starting with 1 promoter. We found that they have similar behavior, although the technical process is more dependent on the level of influence exerted by the neighbors on the families. In addition, we saw in that section that the CaC diffusion time is scale-free, i.e., even if the regional mesh grows, the diffusion time is the same without modifying the initial parameters. This does not happen in technical extensionism, since the number of technicians hired would have to increase in proportion to the number of cooperatives in the network. Regarding the resources used, we saw that the two pedagogical processes grow linearly with the number of cooperatives (quadratically with the radius of the area where they are located). However, there is a significant difference since the expense per cooperative in the case of extensionism is 3 months of salary, transportation and sustenance for the technician versus 9 trips to neighboring cooperatives in the case of CaC.

Another aspect we explored was the Banes method. We found that starting with an adoption rate advantage can provide a significant benefit over the case where the method is not used. We looked at 3 parameters that determine how significant the difference is: 1) the fraction of families with the problem, 2) the change in the probability of adoption due to the presence of the problem (which could be related to the intensity of the impact), and 3) the influence—to a lesser extent. At the same time, we noticed an increase in the average probability, simply due to the introduction of the problem variable, which results in a shorter diffusion time for both cases. We also saw that the adoption rate in the case of the Banes method starts to decrease over time, which leads us to believe that this strategy could be accompanied by other ways of choosing families so that the adoption rate does not decrease. For example, if we think about influence, given that this variable affects the entire population, a greater effect could be achieved by giving preference to families that have a high (or low?) portion of practicing neighbors; this case can also be explored on another occasion.

Among the limitations that we found in the model and that could be addressed in future experiments on the subject, we would like to emphasize four others. The first is that we did not include an abandonment rate. This is important to explore the effort that would be required for follow up. In our model, both technicians and facilitators remained in the cooperatives organizing workshops; however, since there was no abandonment rate, we did not analyze this aspect. The second limitation is that we did not take into account the time between the adoption by the promoter families and the beginning of the workshops. The effect of introducing this variable may be delaying the process by some years. Whether this effect is important could be explored in a later model. The third has to do with using a formal method to calculate the distance between the adoption curves of different experiments. Finally, our experiments on the mesh with coordinators only included the Moore neighborhood (the 8 nearest neighbors). It would be interesting to test other types of larger neighborhoods and see how the diffusion accelerates, taking into account that it would entail higher transportation costs.

Conclusion

We made a model of a network of networks, inspired in the ANAP, to simulate the dissemination of agroecological practices with the purpose of comparing two pedagogical processes: technical extensionism and the *Campesino a Campesino* (CaC; peasant to peasant) methodology. We saw how 3 limitations are manifested in the case of technical extensionism, which make it inefficient to disseminate agroecology, especially when compared to the benefits of the CaC methodology. We reached this conclusion after analyzing the change in two variables: the number of exchanges and the adoption rate.

In the CaC process we saw that the definitive variable is the maximum number of workshops that a cooperative can organize in each period. This characteristic enables the exchanges per period to increase in the exercise and a logistic adoption curve is acquired even when there is no influence. However, when influence is present, there is positive feedback that far exceeds the results of the individual effects and of technical extensionism.

We also recognized the importance of a pre-existing structure in the network of cooperatives such as the ANAP. When we studied diffusion at the regional level we saw that it occurs at two levels: internally within the cooperatives and externally over the mesh. If there is no structure connecting the cooperatives, they will not be able to benefit from each other and diffusion in the CaC case will be linear. This changes when considering the coordinators, who use the pre-existing structure to move families between cooperatives, thus scaling to the mesh level the benefit of the increase in exchanges provided by the facilitators. This way, the logistical growth is observed at the mesh level. We further found that this benefit in terms of diffusion time is scale-free (in terms of the grid size). As for the cost, we saw that although it increases with size, the difference with respect to the expense involved in technical extensionism is substantially lower.

We believe that this type of models can be interesting tools for exploring and proposing experiments. The purpose is to promote dialogue and discussion on relevant topics such as the methodology for disseminating agroecological practices. In these laboratories we can test strategies in different situations to analyze the advantages and modifications that could improve the response of a social process.

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Nothing to declare

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Capítulo 4: Conclusión

Presentamos nuestra conclusión a partir de dar respuesta a la pregunta de investigación:

¿Qué modelos se pueden proponer para estudiar los procesos de la masificación de la agroecología y qué aportaciones se obtienen de ellos?

Para la primera parte de esta pregunta y en conformidad con los objetivos de esta investigación, hicimos dos modelos. En el primero, logramos integrar la racionalidad campesina, la dinámica ecológica de la parcela y la intervención de agentes externos que influyen en las decisiones de las familias campesinas. Esto lo hicimos usando dos dinámicas ecológicas: la dinámica que ocurre al usar prácticas agroecológicas y la que ocurre al usar agroquímicos, estas dinámicas representan cómo cambia el estado ecológico de una parcela por el uso de las dos diferentes prácticas. Las familias campesinas establecen un balance entre la importancia que dan a la producción, ganancia y estado ecológico, con este evalúan qué práctica les conviene usar al cabo de cierto número de años, si deciden cambiar de práctica la dinámica ecológica cambiará también. Observamos que de este modo nuestro modelo es congruente con ejemplos de familias campesinas que a pesar de que puedan tener una ganancia mayor inmediata no deciden cambiar de prácticas. Así, exploramos el caso donde se activa un subsidio a agroquímicos, lo que causa una distorsión en los balances de los campesinos, de modo que ciertas familias que no hubieran escogido las prácticas agroquímicas terminan adoptándolas, ocasionándoles pérdidas económicas y ecológicas a largo plazo. Finalmente, apuntamos a que existe una fragilidad ante los subsidios de esas familias campesinas con perfiles más inclinados hacia la producción y la ganancia.

El segundo modelo que hicimos simula la difusión de prácticas dentro de una organización con una estructura pre-existente y usando métodos pedagógicos intencionales. Con este modelo logramos identificar un comportamiento emergente de la retroalimentación que se genera entre el componente de la influencia de los vecinos sobre la adopción de una práctica agroecológica por parte de una familia y el incremento de oportunidades para tener intercambios de saberes y adoptar la práctica, lo cual ocurre en los talleres que organizan los facilitadores en la metodología Campesino a Campesino. Además, vimos que la figura del coordinador es la que logra aprovechar la estructura pre-existente y escalar los beneficios de la metodología a un nivel regional, lo cual no ocurre sin alguien que se encargue de mover a las familias entre las cooperativas. También comparamos el extensionismo clásico y se hizo evidente que tenía un desempeño inferior por 3 motivos: no aumenta los intercambios por periodo a lo largo de la dinámica, la influencia de los vecinos determina el comportamiento logístico de la curva de adopción y por último, es necesario contratar un técnico por cada cooperativa o comunidad donde se quiera difundir. Los gastos en los que se incurriría para masificar la agroecología con extensionismo clásico en comparación con Campesino a Campesino son proporcionales a la diferencia en costos de un mes de salario, transporte y viáticos de un técnico extensionista contra 3 viajes en autobús para transportar familias campesinas de entre dos cooperativas cercanas. Por último, hicimos una simulación donde incluimos una implementación del método de Banes, en el cuál los coordinadores y facilitadores al organizar los talleres y mover a los campesinos eligen primero como participantes a aquellos que tienen mayor probabilidad de cambiar su práctica (ya que presentan un problema que se puede resolver por la práctica). En esta simulación vimos que se logra reducir considerablemente el tiempo para difundir la práctica.

Con esto logramos alcanzar los objetivos que nos planteamos para esta investigación y ahora que hemos sintetizado las conclusiones de nuestro trabajo queremos abordar de manera más amplia la segunda parte de la pregunta de investigación, esto es: ¿cuáles son las aportaciones al entendimiento de la masificación de la agroecología?

1. Con el primer modelo aportamos un argumento sistematizado de cómo un subsidio que aporta dinero a las familias campesinas termina haciéndolas más pobres. Esto significa que en primer lugar encontramos un conjunto de supuestos fundamentados en la investigación y los representamos en variables y reglas de interacción. Es importante reconocer que en esa representación matemática estamos proponiendo una forma de hacer lo que McCune et al. (2021) se refieren como: “superposición de dos marcos provenientes de distintas tradiciones: por un lado, las transiciones críticas en los sistemas complejos; por otro, los equilibrios dinámicos que conforman un principio organizativo en las economías campesinas locales que existen y resisten, dentro de y frente a la cultura del capital”. (McCune et al.,2021). Al integrarlo en un modelo matemático, podemos analizar las consecuencias de una forma sistematizada, es decir, explorando los cambios en la dinámica al cambiar los parámetros y condiciones iniciales en el modelo. Esta última parte también aplica para nuestro segundo modelo.
2. Un segundo beneficio que aplica para ambos modelos, es que son un punto de partida desde donde se puedan estudiar otros escenarios y usarse como laboratorios de experimentos pensados, realizando algunas modificaciones será posible incluir otros elementos que no hayamos considerado.
3. El tercer beneficio tiene que ver con nuestro segundo modelo, el cual, nos permitió identificar las características de las figuras que potencializan la masificación de la agroecología. Esto es, si bien sabíamos los roles de cada figura de CaC, en nuestro modelo, vemos que en particular la capacidad de armar talleres por parte del facilitador es lo que va alimentar la retroalimentación positiva entre dos variables (influencia de vecinos - talleres organizados) que resulta en una aceleración no lineal de la adopción de la práctica agroecológica.
4. Por último, queremos señalar que el segundo modelo aporta un argumento sistematizado sobre las ventajas de CaC sobre el extensionismo clásico y a su vez hace una aproximación de la diferencia de costos.

Pensamos que nuestro trabajo debió haberse completado con un modelo que uniera a los otros dos, para así poder estudiar la superposición de los tres marcos conceptuales que abordamos dentro de la masificación, esto es, la difusión de prácticas usando métodos pedagógicos intencionados sobre organizaciones campesinas considerando la racionalidad campesina y los efectos ecológicos de las prácticas agroecológicas. Un modelo así, aportaría beneficios a ambos modelos, ya que, en el primer modelo, no incluimos la influencia de las prácticas de los vecinos sobre las familias. De esa manera se podrían incluir los procesos cognitivos sociales que refiere Jager et al. (2000) en su modelo del comportamiento humano. Al mismo tiempo podría quitar una de las carencias del segundo modelo, esto es, que no consideramos una tasa de deserción de las prácticas, ya que, con el modelo de la racionalidad campesina, las familias podrían encontrar conveniente abandonar la práctica. Además, daría lugar a incluir la dinámica ecológica a un nivel de paisaje, que es un elemento que no consideramos en ninguno de nuestros modelos.

Otras limitaciones de nuestros modelos que quisiéramos resaltar son las siguiente:

1) Para el primer modelo el trabajo de la tradición chayanoviana nos hizo proponer un balance multidimensional para modelar la racionalidad campesina de modo que el punto de equilibrio no sea necesariamente el óptimo de ganancia o producción, sin embargo, no incluimos un mecanismo que haga dinámico este balance, el cuál existe porque la familia cambia a lo largo del tiempo.
2) Tampoco incluimos en nuestro modelo la posibilidad de que una familia opte por abandonar la agricultura para dedicarse a otras actividades. En nuestro modelo la única posibilidad era hacer transiciones entre los esquemas agroecológico y agroquímico. Lo ideal sería que se pueda hacer un uso parcial del tiempo para dedicarse al campo, ya que en ese esquema trabajan la mayoría de campesinos.
3) Una limitación que compete a ambos modelos es que sólo se habla de una práctica agroecológica. Generalmente son varias prácticas agroecológicas y la transición agroecológica se observa de manera paulatina a través de ir adoptar cada vez más de estas prácticas. Esto a su vez generaría más ecuaciones en la dinámica de la parcela que podrían generar propiedades emergentes. Al mismo tiempo, en cuanto a la difusión de las prácticas, los coordinadores tendrían una tarea más complicada que resolver, sin embargo, muy probablemente eso implicaría que la dinámica usando el método de Banes diera beneficios aún más grandes de los que se observaron en nuestro trabajo.
4) En nuestro segundo modelo una de las limitaciones más importantes es que no consideramos un tiempo entre la adopción de una práctica por una familia con potencial de ser promotora y el comienzo de estas a fungir como promotoras en el siguiente ciclo.
5) Una limitación computacional que encontramos en nuestro segundo modelo es en nuestra implementación de la adopción espontánea, esta consiste en generar un

número aleatorio para cada familia campesina en la red regional en cada paso del tiempo lo cuál toma mucho tiempo. Es importante notar que si quitamos esta componente del modelo, la metodología CaC generalmente se alenta, este punto también es importante estudiarlo con más detalle.

Pensamos que nuestra investigación abre la puerta a un nuevo campo de modelación de procesos de masificación agroecológica. Con estos modelos podremos explorar con un enfoque diferente las teorías y propuestas que se encuentran en la investigación presente de la masificación desde las ciencias sociales. La idea para estos modelos es buscar entender cómo interactúan los factores que se han encontrado en los procesos de masificación, de modo que se propongan conjuntos de variables y reglas de interacción que puedan capturar el comportamiento de estos procesos. De ese modo generar laboratorios donde se puedan poner a prueba estrategias ante distintos escenarios, y también generar herramientas que presenten los resultados de forma que pueda servirles a los tomadores de decisiones (campesinos, ONGs, políticos,etc). Estos modelos pueden aportar argumentos sistematizados para aportar al debate sobre las ventajas y desventajas de las propuestas para masificar la agroecología.

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