WORKING PAPER

This review is associated with the Evidence-Based Forestry initiative, a collaboration between CIFOR and partner institutions supporting systematic reviews of evidence to enable better-informed decisions about forests and landscapes.

Fine root dynamics within land-use change from tropical forests to agriculture

A systematic review protocol

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Working Paper 200

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Photo by Kate Evans/CIFOR
Landscape near Rio Branco, Acre, Brazil.

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1 Background

Tropical forests contribute about one-third to global net primary production (NPP), making them one of the most productive ecosystems on earth (Field et al. 1998; Roy and Saugier 2001; Malhi et al. 2011). However, estimates of ecosystem carbon (C) fluxes are still uncertain, due to limited understanding of belowground C dynamics. Fine roots, which are short-lived, non-woody and small in diameter (< 2 mm), are the most important component of belowground C dynamics and can contribute up to 27% of the annual NPP in tropical forest (Malhi et al. 2011). As tropical forests are threatened by forest degradation and deforestation at an alarming rate (Achard et al. 2002, 2014), fine root dynamics, i.e. root production, mortality and decomposition and their roles in the carbon cycle are a critical area of research to improve the accuracy of greenhouse gas (GHG) emission estimates as a result of land-use change. GHG emissions from deforestation and forest degradation are estimated to be 11% of global GHG emissions (IPCC 2014), contributing significantly to global warming. The single most important proximate driver of deforestation in the tropical countries is the conversion to agriculture (Geist and Lambin 2002; Boucher et al. 2011; Hosonuma et al. 2012). Conversion to large-scale cattle ranches and soybean plantations is the dominant driver in Latin America (Boucher et al. 2011; Hosonuma et al. 2012) but land expansion for biofuel production is expected to further increase pressure on forests in this region (Lapola et al. 2010). In Southeast Asia, forest conversion is mostly driven by large-scale agricultural and timber plantations, such as oil palm, rubber, coconut and teak (Boucher et al. 2011). Unlike Southeast Asia and Latin America, deforestation in Africa is dominated by small-scale subsistence activities (DeFries et al. 2010; Fisher 2010).

Forest carbon conservation schemes, such as Reducing Emissions from Deforestation and forest Degradation plus enhancement of carbon stocks (REDD+), suggest that rewarding forest users through incentives could be an effective means to both protect and/or enhance forest stocks and reduce GHG emissions (Murdiyarso et al. 2010; Barr and Sayer 2012; Kissinger et al. 2012). Following this trend, current research on how land-use change affects the C cycle focuses on GHG measurements and the quantification of aboveground biomass C stocks. Fine root dynamics and their influence on the belowground C cycle are less frequently studied in forests or agriculture and similarly, studies on how land-use change affects fine root dynamics are critically lacking. Identifying the research gaps in how land-use change affects fine root dynamics in tropical forests could prioritize this topic in carbon cycle research and thus help to more accurately quantify GHG emissions from land-use change.

Despite their important role in global C cycling and accumulation, our knowledge of fine root dynamics is still limited (Hertel and Leuschner 2010; Finér et al. 2011). Pan-tropical estimates of fine root production range from 75 to 2193 g dry matter (DM)m^{-2} y^{-1} (Hertel and Leuschner 2010). Species composition, soil nutrient content, temperature and precipitation, among other factors, explain some of the variation in fine root dynamics between study sites (Hertel and Leuschner 2010). Recent reviews on fine root dynamics incorporate only a small number of studies and have limited overlap between cited articles (Figure 1, Table S1). To date, only the review by Hertel and Leuschner (Hertel and Leuschner 2010) focused specifically on the tropics, whereas the other reviews were conducted at a global scale (Nadelhoffer and Raich 1992; Vogt et al. 1995; Gill and Jackson 2000; Finér et al. 2011). The scoping study of this systematic review identified more than double the amount of potentially relevant studies on fine root dynamics in tropical and subtropical forests compared to the amount of studies included in past reviews (Figure 1).

Much of the research on fine root dynamics is impeded by methodological difficulties and the labor-intensiveness of their operations (Majdi 1996; Vogt et al. 1998). Direct methods to estimate fine root production include sequential coring (SC), various ingrowth methods (IG) and minirhizotron (MR) approaches, which all suffer from over or underestimation, depending on site-specific conditions (Vogt et al. 1998; Majdi et al. 2005; Hendricks et al. 2006; Strand et al. 2008; Milchunas 2009). Several authors explain that possible underestimation using the SC method is probably due to the

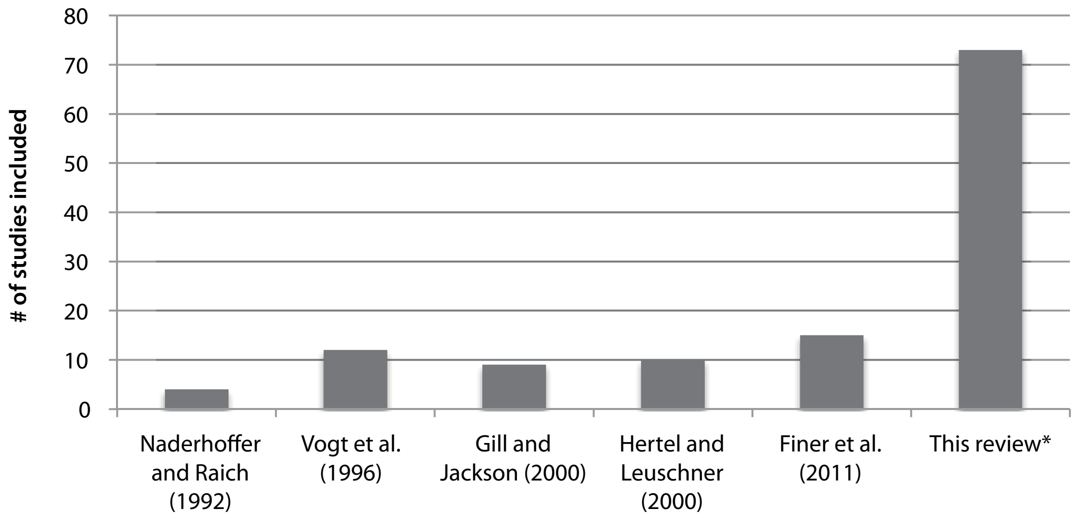

Figure 1. Number of studies on fine root dynamics in tropical forests included in current reviews.

Note: The number given for this review is based on a preliminary assessment of relevant studies.

Source: Nadelhoffer and Raich (1992); Vogt et al. (1995); Gill and Jackson (2000); Hertel and Leuschner (2010); Finér et al. (2011)

simultaneous occurrence of production and mortality (McClaugherty et al. 1982; Aber et al. 1985; Gower et al. 1992; Publicover and Vogt 1993) and low estimates of root decomposition rates that may occur when using litter bags that expose fresh, fine roots (e.g. Fahey et al. 1999; Lauenroth 2000; Hertel and Leuschner 2002). However, the SC method could also lead to overestimation of root production when fine root biomass is large (Singh et al. 1984; Kurz and Kimmins 1987; Nadelhoffer and Raich 1992; Hendricks et al. 1993), causing large, random errors of biomass estimates and a high spatial heterogeneity of root biomass linked to weak seasonality; repeated sampling may lead to biomass and necromass differences that are nonsignificant and are confounded by large, random errors (Sala et al. 1988; Lauenroth 2000; Nadelhoffer 2000). Sequential coring combined with the compartmental flow calculation is particularly sensitive to overestimation if high spatial heterogeneity of root biomass is linked to weak seasonality (Sala et al. 1988). Similarly, IG methods assume that disturbances of roots and the surrounding soil do not alter fine root dynamics (Lauenroth 2000), whereas soil disturbance is inevitable, growth stimulation of adventitious roots is likely and low root biomass may lead to reduced root competition, which could lead to overestimation (Vogt et al. 1998; Fahey et al. 1999; Lauenroth 2000; Hertel and Leuschner 2002). Conversely, IG methods are prone to underestimation, because decomposition is not accounted for, especially when the sampling period is long (Steele et al. 1997; Lauenroth 2000; Hertel and Leuschner 2002). The MR method may yield more reliable estimates of fine root production of forests than all of the other available techniques (Hendricks et al. 2006; Moser et al. 2011), particularly in climates with low seasonality. However, this method is also subject to bias due to disturbance of the rhizosphere during minirhizotron tube installation. Nonetheless, it is assumed and generally agreed that among the direct methods to measure fine root dynamics, the MR approach yields the most reliable root production rates (Hendricks et al. 2006; Moser et al. 2011).

This systematic review aims to understand the effect of land-use change from primary forests to degraded forest to agriculture on fine root dynamics across the tropical regions of the world. The review will identify, appraise and synthesize current knowledge in the field; it aims to discuss the current methods used in fine root dynamics, their potential biases and quantify the magnitude of differences in fine root production, mortality and decomposition estimations between forests and agriculture.

1.1 Objective of the review

Reviews on fine root dynamics in tropical forest have been frequently conducted (Nadelhoffer and Raich 1992; Vogt et al. 1995; Gill and Jackson 2000; Hertel and Leuschner 2010; Finér et al. 2011) but to date, they have not addressed the important issue of how forest degradation and land-use change to agriculture impacts on fine root dynamics in the landscape. This review will focus on the broader dynamics of fine roots in ecosystems at different stages of change from forests to agriculture in the tropics. The aim of this synthesis is to give a broader view of the impacts that land-use change can have on the C cycle. Subsequently, this systematic review will analyze the differences in root production rates between the most commonly used direct methods in order to assess and quantify the potential methodological bias between each, and improve future estimates on the effects of land-use change on fine root dynamics.

1.2 Primary question

How does land-use change from primary forest to degraded forest to agriculture affect fine root dynamics? (See Table 1).

In particular, we will address the following sub-questions:

A. What is the effect of forest degradation on fine root dynamics?

Different stages of degradation (e.g. low, medium and high disturbance) may be defined by reduction of basal area of a particular stand compared to an undisturbed reference forest, but will depend on the data available (to be determined after the data extraction is completed and analyzed accordingly).

B. What is the effect of conversion from primary forest to the most prominent types of agriculture within each tropical region on fine root dynamics?

The most prominent drivers by region are (Geist and Lambin 2002; Boucher et al. 2011; Hosonuma et al. 2012):

- Southeast Asia: Oil palm plantations, rubber plantations, coconut plantations and timber plantations
- Latin America: Soybean and cattle ranching
- Africa: Shifting cultivation.

1.3 Secondary question

What is the methodological variability in estimating root production in tropical forests?

Estimated production rates will be grouped by different methods, regions and land-use types. The variability between methods will be assessed by comparing the different means estimated by more than one method from similar sites with each other (i.e. MR vs. IG, MR vs. SC and IG vs. SC).

Table 1. Study population, exposures, comparators and outcomes (PECO) relevant to the systematic review question.

Population	Exposures	Comparators	Outcomes
Fine root dynamics in tropical and subtropical forests	Land-use change causing forest degradation or deforestation and conversion to agriculture	Fine root dynamics in degraded forest or agriculture	Change in fine root dynamics, i.e. root production, mortality, decomposition and turnover rates

2 Methods

2.1 Search strategy

The literature searches will be conducted in English. However, if only the title and the abstract are in English and the full text is in another language, it will be translated. No restriction of publication year will be applied.

2.2 Search terms

A scoping study was conducted in January 2015 using Web of Knowledge (WoK), CAB Abstracts and Scopus to identify a comprehensive search strategy (Table 2). This resulted in 6376, 8346 and 8926 hits for the abovementioned databases, respectively. The search iteration was compared against a test library, which contained all references from Hertel and Leuschner (Hertel and Leuschner 2010) and Finér et al. (Finér et al. 2011) (Table S2). In the final iteration of the search, 18 of 20 studies were included and one study (Castellanos et al. 1991) that did not include fine root dynamic estimates, was missing.

The search terms within each category of 'Subject/Population', 'Outcomes', 'Geographical focus' and 'Exposures' will be combined with the Boolean operator 'AND'. The use of Boolean operators and truncations will be modified according to the requirements of the bibliographic databases and recorded in an appendix of the full review.

Table 2. Final categories of search terms, phrases and strings.

Category	Search terms
1. Subject/Population	*root
2. Outcomes	dynamic* OR production OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation
3. Geographical focus	*tropic* OR humid OR equatorial OR rain OR lowland OR montane OR angola* OR benin* OR botswa* OR "Burkina Faso*" OR burundi* OR cameroon* OR "Cap Verde*" OR "Central African Republic*" OR chad* OR comor* OR congo* OR "The Democratic Republic of Congo*" OR "DRC" OR "Côte d'Ivoire*" OR "Ivory Coast" OR djibouti* OR "Equatorial Guinea*" OR eritrea* OR ethiopia* OR gabon* OR gambia* OR ghana* OR guinea* OR "Guinea Bissau*" OR kenya* OR liberia* OR madagasca* OR malawi* OR mali* OR mauritania* OR mauriti* OR mayott* OR mozambi* OR namibia* OR niger* OR nigeria* OR réunion* OR rwanda* OR "Saint Helen*" OR ascension* OR "Tristan da Cunha*" OR "Sao Tomé*" OR principe* OR senegal* OR seychell* OR "Sierra Leon*" OR somalia* OR sudan* OR tanzania* OR togo* OR uganda* OR zambia* OR zimbab* OR bangladesh* OR bhutan* OR "British Indian Ocean Territory*" OR brunei* OR cambodia* OR india* OR indonesia* OR lao* OR malaysia* OR maldiv* OR myanmar* OR burm* OR nepal* OR philippin* OR singapor* OR "Sri Lanka*" OR thai* OR "Timor-Leste*" OR "Viet Nam*" OR vietnam* OR beliz* OR "Costa Rica*" OR salvador* OR guatemala* OR honduras* OR mexic* OR nicaragua* OR panam* OR anguilla* OR "Antigua Barbuda*" OR arub* OR baham* OR barbad* OR bermud* OR "Cayman Islands*" OR cuba* OR curaçao* OR dominica* OR "Dominican Republic*" OR grenad* OR guadelou* OR haiti* OR jamaica* OR martinique* OR montserrat* OR "Puerto Ric*" OR bolivia* OR brazil* OR colombia* OR ecuador* OR "French Guia*" OR guyana* OR paraguay* OR peru* OR surinam* OR venezuela* OR "American Samoa*" OR australia* OR "Christmas Island*" OR "Cocos Island*" OR "Cook Island*" OR fiji* OR "French Polynesia*" OR guam* OR kiribati* OR "Marshall Island*" OR "Micronesia*" OR nauru* OR caledonia* OR niue* OR "Norfolk Island*" OR "Mariana Island*" OR palau* OR "Papua New Guinea*" OR png* OR pitcairn* OR samoa* OR "Solomon Island*" OR tokelau* OR tonga* OR tuvalu* OR vanuatu* OR "Wallis and Futuna*"
4. Exposures	*forest* OR tree* OR *plantation OR agricult* OR ecosystem OR soy* OR *palm* OR coconut OR eucalyptus OR acacia* OR "slash and burn" OR *fallow* OR pasture OR grass*

2.3 Databases

This review will search the following databases:

- ISI Web of Knowledge
- Scopus (including secondary documents)
- Science Direct
- CAB Abstracts
- Wiley Online Library
- JSTOR.

All retrieved records including the abstract will be exported to EndNote, cleaned for duplicates and screened according to the inclusion/exclusion criteria explained below.

2.4 Internet searches

The following Internet search engines will be used with a modified search string.

- Google
- Google Scholar
- Scirus.

The first 300+ hits for each search will be recorded and examined for relevant data.

2.5 Specialist searches

No additional searches will be conducted apart from those listed under 'Internet searches' as it is anticipated that gray literature on fine root dynamics will be limited. Experts in the field of fine root dynamics in tropical forests and agriculture will be contacted and invited to suggest the inclusion of any additional studies to ensure comprehensiveness of the evidence base. All relevant (peer-reviewed or unpublished) literature will be screened for possible inclusion. Furthermore, the bibliographies of included articles will be searched for other relevant studies that were not retrieved using the agreed search strategy.

2.6 Study inclusion criteria

The screening of articles for relevance will be conducted in three different stages using the inclusion/exclusion criteria described below. Once all articles are retrieved, they will first be screened by title only. The second stage will screen the selected articles by abstract, and the third stage will screen by full text. A randomly selected subset of 100 articles will be used at the first and second stage of screening to test consistency between two reviewers, using a kappa test of agreement (Pullin and Knight 2003). A score of 0.6 or greater will be used as sufficient reviewer agreement. Disagreements will be discussed and the inclusion/exclusion criteria will be adapted accordingly, with any changes noted for the full review.

Studies will be included in the review if they fulfil the following criteria:

Relevant study subject: primary studies (e.g. cohort studies, case-control studies and cross-sectional studies) that measure one or more component of fine root dynamics, i.e. root production, mortality and decomposition, in primary forest and/or degraded tropical forest and/or agricultural systems. Study sites must be located in the tropics/subtropics (± 23.4°S and ± 30°N, respectively).

Relevant study method/design: studies used relevant, transparent and repeatable quantitative methodology, i.e. the SC and/or IG and/or MR method.

Relevant study comparators: degraded forests and/or agricultural systems. An ideal study would compare primary forest with degraded forest and an agricultural system, but those types of studies are rare. Consequently, we will accept studies that have a reference site close enough to the primary forest site so that the ecological conditions remain similar.

Relevant study outcomes: estimates of fine root dynamics, i.e. root production and/or root mortality and/or root decomposition rates.

Exclusion criteria: pot or greenhouse studies; studies only on seedlings; epiphytes or mycorrhizae/fungi; studies that only include root biomass; or studies using only models and simulations.

2.7 Potential effect modifiers

Effect modifiers, which might influence the outcome of relevant studies, included:

- methods (e.g. SC, IG, MR)
- type of tropical forest (lowland, pre-montane, montane)
- soil nutrient content (e.g. N, P, K)
- climatic variables (e.g. precipitation, air and soil temperature, length of dry season).

The above is a preliminary list, which may expand or reduce during the course of the review process. Potential modifiers and their effect on measurable outcomes will be discussed and documented during the review process.

2.8 Critical appraisal

After completion of full text screening, the remaining studies will be assessed for robustness of their study design. The appraisal will be based on sampling period, number of replicates and sampling depth. Each study will be placed into one of three categories: below acceptable quality, acceptable quality and high quality (Table 3). Two researchers will first critically appraise a subset of 20% of the included studies and calculate a kappa score. Upon agreement, one researcher will carry out the complete assessment.

Where studies have missing or abbreviated data sets, the reviewers will request the additional data from the authors. Any studies that are rejected during the critical appraisal process will be listed in an appendix to the review, and the reasons for their exclusion will be included.

2.9 Data extraction strategy

Metadata will be recorded in a spreadsheet with the following predefined categories:

- title
- lead author
- name of publication
- date of publication
- location of the study (latitude, longitude, elevation)
- agro-ecological and climatic zone classification
- climatic variables (precipitation, air temperature, length of dry and wet seasons)
- soil variables (soil temperature, soil moisture, bulk density, pH, nutrient content)
- land-use type (forest and crop type)
- stand variables (aboveground biomass, belowground biomass, stem density, basal area, etc.)
- method used (SC, IG, MR, etc.)
- sample size, sample depth, sample means and standard deviations/errors.

Authors of incomplete records will be contacted or other studies from the same study area will be used, to retrieve missing information. We anticipate that not all information will be accessible, hence subsamples with complete records of the different effect modifiers in the data set will be analyzed accordingly.

2.10 Data synthesis and presentation

This review will use a quantitative synthesis to describe how land-use change from tropical forest, degraded forest and/or agriculture affects fine root dynamics. A meta-analysis will be conducted on the subgroups, i.e. root production, root mortality and root decomposition, to show the effects of land-use change on the different components of fine root dynamics. We expect that the effects of land-use change from forest to shifting cultivation on fine root dynamics in Africa will be impossible to assess because of the data limitation on the different types of shifting cultivation practices used, which are very region specific.

The meta analysis will use R software (R Core Team 2014). Different weighted effect sizes will be computed to test for differences in fine root

Table 3. Categories of the critical appraisal.

Category	Sampling period	Number of Replicates	Sampling depth*
Below acceptable quality	No measurements in wet and dry season OR ≤ 6 months	< 4	< 50 % of fine root biomass OR < 14 cm
Acceptable quality	≤ 10 months	≤ 10	< 95 % of fine root biomass OR < 91 cm
High quality	> 10 months	> 10	≥ 95 % of fine root biomass OR ≥ 91 cm

* If fine root biomass was not measured in a study, a sampling depth of 14 cm and 91 cm was taken, which corresponds to the depth for 50% and 95% of the fine root biomass in tropical forest (Schenk and Jackson 2002)

production, fine root mortality and fine root decomposition between land uses, including tests for heterogeneity and temporal changes of the effect sizes. A test for publication bias will be conducted and if a bias is present, adjustments will be made using the trim and fill method (Duval and Tweedie 2000). Finally, a sensitivity analysis will be carried out to test for robustness of study design using the environmental risk of bias tool (Bilotta et al. 2014).

Results from each method (i.e. SC, IG, MR) will be synthesized separately and the results from studies using a particular method will be compared to assess the differences between methods across regions and/or land-use types. The overall synthesis will show how the different land-use change trajectories affect fine root dynamics and how the differences in methods assessing fine root dynamics may influence these estimates.

This could be a first step in improving our current knowledge on the contribution of fine roots to the terrestrial C cycle within the land-use trajectory from forest to agriculture in the tropics. Furthermore, this review could help to more accurately quantify GHG emissions from this particular land-use change, which is required in the context of forest carbon conservation schemes such as REDD+.

2.11 Competing interests

The authors declare that they have no competing interests.

2.12 Authors' contributions

SP conceived the study. SP and JC coordinated the study. SP, JC and LD designed and drafted the manuscript. CJ provided valuable feedback and input to the manuscript. All authors read and approved the manuscript.

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Supplement

Table S1. References cited in the current reviews on tropical fine root dynamics [1–5].

Reference	Naderhoffer and Raich (1992)	Vogt et al. (1996)	Gill and Jackson (2000)	Hertel and Leuschner (2010)	Finer et al. (2011)	Overlap	Region	Country
Cuevas and Medina, 1989	1	1	1	1	1	5	South America	Venezuela
Singh and Singh, 1981	1	0	1	0	1	3	South Asia	India
Jordan and Escalante, 1980	1	0	1	1	0	3	South America	Venezuela
Kummerow et al., 1990	0	1	1	0	1	3	Central America	Mexico
Srivastava et al., 1986	0	1	0	0	1	2	South Asia	India
Visalakshi, 1994	0	1	0	0	1	2	South Asia	India
Arunachalam et al., 1996	0	0	1	0	1	2	South Asia	India
Cuevas et al., 1991	0	0	1	0	1	2	Caribbean	Puerto Rico
Sundarapandian and Swamy, 1996	0	0	0	1	1	2	South Asia	India
Ostertag, 2001	0	0	0	1	1	2	Pacific Islands	Hawaii
Sánchez-Gallén and Alvarez-Sánchez, 1996	0	0	0	1	1	2	Central America	Mexico
Röderstein et al., 2005	0	0	0	1	1	2	South America	Ecuador
Vitosek and Sanford, 1986	1	0	0	0	0	1	South America	Venezuela
Roy and Singh, 1995	0	1	0	0	0	1	South Asia	India
Priess and Foester, 1994	0	1	0	0	0	1	South America	Brazil
Huttel and Bernhard-Reversat, 1975	0	1	0	0	0	1	West Africa	Ivory Coast
Huttel, 1975	0	1	0	0	0	1	West Africa	Ivory Coast
Brown and Lugo, 1982	0	1	0	0	0	1	South America	Brazil
Cannell, 1982	0	1	0	0	0	1	West Africa	Ivory Coast
Klinge and Herrera, 1978	0	1	0	0	0	1	South America	Brazil
Sanford, 1989	0	1	0	0	0	1	South America	Venezuela
Sah, 1994	0	0	1	0	0	1	South Asia	India

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Table S1. Continued

Reference	Naderhoffer and Raich (1992)	Vogt et al. (1996)	Gill and Jackson (2000)	Hertel and Leuschner (2010)	Finer et al. (2011)	Overlap	Region	Country
Lehman and Zach, 1998	0	0	1	0	0	1	East Africa	Kenya
Schroth and Zech, 1995	0	0	1	0	0	1	West Africa	Ivory Coast
Herbert and Fownes, 1999	0	0	0	1	0	1	Pacific Islands	Hawaii
Cavelier et al., 1999	0	0	0	1	0	1	Central America	Panama
Priess et al., 1999	0	0	0	1	0	1	South America	Venezuela
Moser, unpubl.	0	0	0	1	0	1	South America	Ecuador
Castellanos et al., 1991	0	0	0	0	1	1	Central America	Mexico
Chen et al., 2004	0	0	0	0	1	1	Australia	Australia
Soethe et al., 2007	0	0	0	0	1	1	South America	Ecuador
Valverde-Barrantes et al., 2007	0	0	0	0	1	1	Central America	Costa Rica
Total	4	12	9	10	15	32		

Note: The column "Overlap" indicates how often a particular article was cited in all reviews.

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Table S2. Table of search terms trialled against number of hits from Scopus. Searches were conducted in the format: "Subject" AND "Outcome" AND "Geographical focus" AND "Exposures" for each iteration. Number of hits recorded based on searches conducted on 4 February 2015. Missing refers to the references missing when matched with the test library papers; Numbers refer to the reference list below.

Iteration	Subject	Outcomes	Geographical focus	Exposures	Hits in Scopus	Missing
1	root	dynamic* OR production OR turnover OR mortality OR decomposition	*tropic* OR humid OR equatorial	forest* OR agricult* OR ecosystem	1093	1,2,3,5,10,14,17,18,19
2	*root	dynamic* OR production OR turnover OR mortality OR decomposition	*tropic* OR humid OR equatorial	forest* OR agricult* OR ecosystem	1100	1,2,3,5,10,14,17,18,19
3	*root	dynamic* OR product* OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation	*tropic* OR humid OR equatorial	forest* OR agricult* OR ecosystem	1955	1,2,3,5,10,14,17,18,19
4	*root	dynamic* OR product* OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation	*tropic* OR humid OR equatorial OR rain OR lowland OR montane	forest* OR agricult* OR ecosystem	2885	2,3,5,17,18,19

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Table S2. Continued

Iteration	Subject	Outcomes	Geographical focus	Exposures	Hits in Scopus	Missing
5	*root	dynamic* OR product* OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation	*tropic* OR humid OR equatorial OR rain OR lowland OR montane	*forest* OR tree* OR "humid forest*" OR "dry forest*" OR "tropical forest*" OR "*deciduous forest" OR agroforest* OR "agro-forest*" OR "primary *forest*" OR "secondary *forest*" OR "forest fragment*" OR "degrad* *forest*" OR planted forest* OR plantation OR agricult* OR ecosystem OR soy* OR "Glycine max" OR "oil palm" OR "Elaeis guineensis" OR rubber OR "Hevea brasiliensis" OR coconut OR "Cocos nucifera" OR timer OR eucalyptus* OR acacia* OR agroforest* OR "agro-forest*" OR "swidden system*" OR "swidden agricultur*" OR "swidden farm*" OR "shifting cultivation" OR "slash and burn" OR "forest* fallow*" OR "permanent fallow*" OR pasture OR "cattle ranch*" OR "grass*" OR ecosystem*	2119	2,3,5,17,18,19
6	*root	dynamic* OR product* OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation	*tropic* OR humid OR equatorial OR rain OR lowland OR montane	*forest* OR tree* OR *plantation OR agricult* OR ecosystem OR soy* OR *palm* OR coconut OR eucalyptus OR acacia* OR "slash and burn" OR *fallow* OR pasture OR grass* OR savanna	4093	3,5,17,19

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Table S2. Continued

Iteration	Subject	Outcomes	Geographical focus	Exposures	Hits in Scopus	Missing
7	*root	dynamic* OR product* OR turnover OR mortality OR decomposition OR elongation OR longevity OR growth OR variation	*tropic* OR humid OR equatorial OR rain OR lowland OR montane OR angola* OR benin* OR botswa* OR "Burkina Faso*" OR burundi* OR cameroon* OR "Cap Verde*" OR "Central African Republic*" OR chad* OR comor* OR congo* OR "The Democratic Republic of Congo*" OR "DRC" OR "Côte d'Ivoir*" OR "Ivory Coast" OR djibouti* OR "Equatorial Guinea*" OR eritrea* OR ethiopia* OR gabon* OR gambia* OR ghana* OR guinea* OR "Guinea Bissau*" OR kenya* OR liberia* OR madagasca* OR malawi* OR mali* OR mauritania* OR mauriti* OR mayott* OR mozambi* OR namibia* OR niger* OR nigeria* OR réunion* OR rwanda* OR "Saint Helen*" OR ascension* OR "Tristan da Cunha*" OR "Sao Tomé*" OR principe* OR senegal* OR seychell* OR "Sierra Leon*" OR somalia* OR sudan* OR tanzania* OR togo* OR uganda* OR zambia* OR zimbab* OR bangladesh* OR bhutan* OR "British Indian Ocean Territory*" OR brunei* OR cambodia* OR india* OR indonesia* OR lao* OR malaysia* OR maldiv* OR myanmar* OR burm* OR nepal* OR philippin* OR singapor* OR "Sri Lanka*" OR thai* OR "Timor-Leste*" OR "Viet Nam*" OR vietnam* OR beliz* OR "Costa Rica*" OR salvador* OR guatemala* OR honduras* OR mexic* OR nicaragua* OR panam* OR anguilla* OR "Antigua Barbuda*" OR arub* OR baham* OR barbad* OR bermud* OR "Cayman Islands*" OR cuba* OR curaçao* OR dominica* OR "Dominican Republic*" OR grenad* OR guadelou* OR haiti* OR jamaica* OR martinique* OR montserrat* OR "Puerto Ric*" OR bolivia* OR brazil* OR colombia* OR ecuador* OR "French Guia*" OR guyana* OR paraguay* OR peru* OR surinam* OR venezuela* OR "American Samoa*" OR australia* OR "Christmas Island*" OR "Cocos Island*" OR "Cook Island*" OR fiji* OR "French Polynesia*" OR guam* OR kiribati* OR "Marshall Island*" OR "Micronesia*" OR nauru* OR caledonia* OR niue* OR "Norfolk Island*" OR "Mariana Island*" OR palau* OR "Papua New Guinea*" OR png* OR pitcairn* OR samoa* OR "Solomon Island*" OR tokelau* OR tonga* OR tuvalu* OR vanuatu* OR "Wallis and Futuna*"	*forest* OR tree* OR *plantation OR agricult* OR ecosystem OR soy* OR *palm* OR coconut OR eucalyptus OR acacia* OR "slash and burn" OR *fallow* OR pasture OR grass* OR savanna	8713	none

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Conversion of tropical forests to agriculture contributes significantly to global warming, causing an estimated 12–18% of global greenhouse gas (GHG) emissions. However, estimates of ecosystem carbon fluxes are not accurate mainly because of the limited understanding of their belowground components. Root dynamics, i.e. root production, mortality and decomposition, are crucial elements of ecosystem functioning; an understanding of root dynamics is required to estimate the carbon cycle accurately.

This systematic review will assess the current evidence for how tropical and subtropical forest degradation and land-use changes to agriculture affects fine root dynamics. Several stages of forest degradation will be examined during the review process, including current agricultural conversion systems, such as oil palm plantations in Southeast Asia and soybean plantations and pastures in Latin America. The search strategy will follow a specific *a priori* review protocol. Searches will be conducted in English across six different scientific databases and Google Scholar will be used to ensure comprehensiveness of the evidence base. The retrieved articles will undergo a three-stage screening by title, abstract and full text using predefined inclusion/exclusion criteria. Screening consistency will be evaluated using kappa tests. From the final list of included studies, relevant information on fine root dynamics (i.e. rates and methods used), summary statistics (i.e. mean and variance), ecosystem (i.e. forest type or agricultural system), geographical location and climate and soil variables will be extracted and entered into a database. A meta-analysis will be conducted on subgroups such as root production, root mortality and root decomposition, to show how land-use change affects different components of fine root dynamics. The review will also synthesize the current methods used to assess fine root dynamics and discuss their methodological limitations and variances.

RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

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