CONSERVATION AND SUSTAINABLE MANAGEMENT OF BELOWGROUND BIODIVERSITY IN INDONESIA IN THE CONTEXT OF THE GLOBAL CSM-BGBD PROJECT

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Introduction

Poverty, associated with increasing pressure on the land in the humid tropics, is a major driver of global change, leading to accelerated habitat modification and fragmentation of remaining pristine areas. Although it is not apparent to the naked eye, soil is one of the most complex habitats on earth and contains one of the most diverse assemblages of living organisms. As part of a move to make up for the neglect of this aspect of biodiversity in much of the current discussion and policy frameworks for biodiversity, the CSM-BGBD project has been initiated to assess impacts of land use change on belowground biodiversity. The project aims to clarify the function of soil biota along gradients of agricultural intensification around global biosphere forest reserves in Brazil, Côte d'Ivoire, India, Indonesia, Kenya, Mexico, Uganda. Our work will include i) making a comprehensive inventory of soil biota and ii) developing a strong theoretical framework linking the documented belowground biodiversity to demonstrated soil functions. In this overview of the how the global project connects to the specific efforts in Indonesia, we will consider (on the basis of the various international workshops and consultations):

- The conceptual framework,
- The global sampling design,
- An operational definition of 'intensification' at plot and landscape scale,
- The sampling scheme for Indonesia,
- From data on soil biota to 'sustainable management' of belowground biodiversity,
- Organizational matters.

The Conceptual Framework

Few people will doubt that the biodiversity value of any piece of land will decrease with increasing intensity of agricultural management, aimed at harvesting crops that may or may not be part of the original flora of the area, but have undergone 'domestication' that makes them less compatible with other parts of the local ecosystem (which become labeled as 'pest and diseases'). The shape of the 'trade-off' curve between biodiversity value and land use intensity is, however, less certain. Yet, this shape has major implications on how societies can best achieve a balance between biodiversity conservation and production of food, feed and fiber.

Three hypotheses indicated in Figure 1 are:

Hypothesis 1: '*The most valuable components of the local flora and fauna are likely to be sensitive to and incompatible with agricultural use, and will thus tend to disappear (or be eradicated) in early phases of land use intensification; once this part of the biodiversity is lost further intensification will be of little consequence for on-site loss of biodiversity, but may actually help in as far as higher yields per unit area decrease 'land hunger' for further agricultural expansion*'

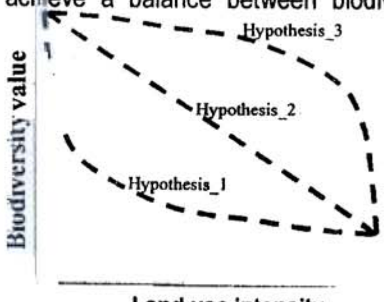


Figure 1. Three hypotheses on the way 'biodiversity value' will tend to decrease with increasing 'land use intensity'; for further discussion see text.

Hypothesis 2: *'Loss of biodiversity value is approximately proportional to the increase in land use intensity'*

Hypothesis 3: *'by appropriate management of above- and below-ground biota, optimal conservation of biodiversity for national and global benefits can be achieved in mosaics of land-uses at differing intensities of management and furthermore result in simultaneous gains in sustainable agricultural production'*

The CSM-BGBD project wants to test this third, 'optimistic' hypothesis. Yet, empirical evidence is thin on the ground, so outcomes closer to hypothesis 2 or even 1 would not be unexpected. Evidence for plant species richness obtained during the surveys of the Alternatives to Slash and Burn (ASB) project in Jambi (Figure 2) indicate an outcome that may be close to hypothesis 2, although in more limited parts of the range both the convex curve of hypothesis 1 and the concave curve of hypothesis 3 can be recognized (if one wants…).

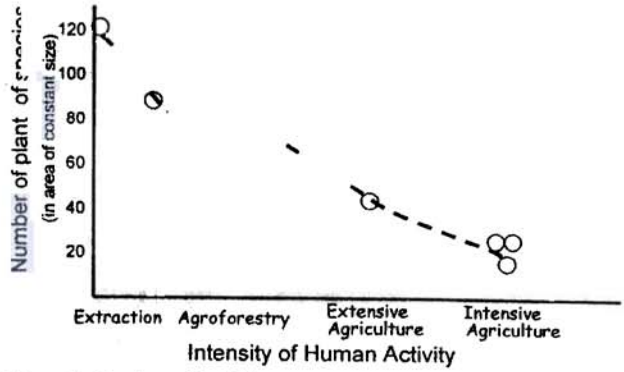
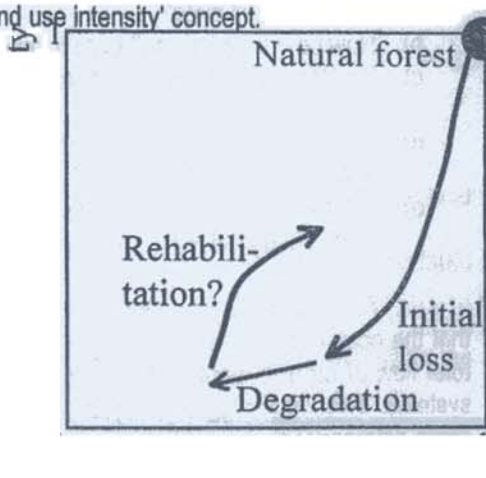


Figure 2. Plant species richness across a land use intensity gradient in Jambi (Murdiyarso *et al.*, 2002; Van Schaik and Van Noordwijk, 2002).

If we compare such data with the hypotheses, however, we can see a number of important challenges to empirical work, referring to the X and the Y-axes of the graph:

a) The hypotheses (and Figure 1) speak of biodiversity 'value', while the survey data are primarily expressed in numbers of species observed; there are many steps to be taken between the primary observations by soil biologists and the 'value' that different stakeholders in society assign to it,
b) The concept of 'agricultural intensification' is used loosely in a ranking of different agricultural systems, but the shape of the curves (convex or concave) can change according to the way 'land use intensity' is defined quantitatively.

In the CSM-BGBD project, we aim to address both of these challenges, by going beyond the 'survey' stage into an exploration of the functional value of soil biota for farmers and external stakeholders, and by using an operational version of the 'land use intensity' concept.



The data in Figure 2 refer to plant species rich-ness in plots of standard size. Plants live both above and belowground, so plant species rich-ness can be a first indicator of both parts of the ecosystem. However, aboveground parts of plants provide both the structure and primary production of food sources for all other parts of the ecosystem, and may thus be used as first indicator. Belowground, however, plant roots are only one of the contributing elements to the structure of the ecosystem, and provide only part of the energy basis for the food web. It is likely that changes in above- and belowground biodiversity can at least be partially uncoupled (Figure 3). Again, there is little consistent data on this topic, so the data collection of the CSM-BGBD project may become a benchmark in the discussion on the topic (Bignell *et al.*, in press; Gillison *et al.*, in press). If the relation is as depicted in Figure 3, we may tentatively conclude that hypothesis 3 holds for BGBD even in situations where aboveground biodiversity changes according to hypothesis 2.

The starting point for the BGBD project will thus be to establish, at the plot and landscape level, the connections between aboveground and belowground biodiversities and between either of these and land use intensity.

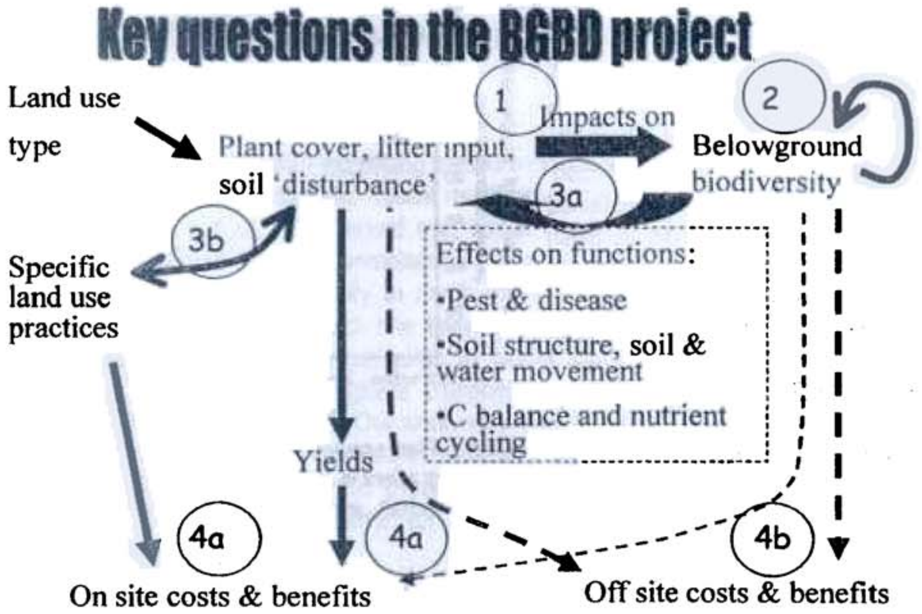


Figure 4. Diagram of the four main questions for the CSM-BGBD project.

As summarized in Fig 4, we will analyze the relationship between land use practices and belowground biodiversity in a number of steps or questions:

a) How do land use change and specific management practices within broad land-use categories impact on soil biota?
b) How do the various soil biota function in belowground food webs in different ecosystems?
c) 3a. What are the key functional roles of soil biota in agro ecosystems? And, which groups play these roles?
d) 3b. How can farmers, as managers of agro-ecosystems, work through (or with), rather than against soil biota?
e) 4. How do the presence of specific soil biota, and the diversity of the belowground ecosystem as such, contribute to the overall cost – benefit balance at the farm, landscape and global levels?

A first analysis of the food web structure for the data collected during the ASB surveys, suggests that the occurrence of the 'top predator' group among the soil invertebrate fauna is closely linked to the total flow of organic inputs (from litter fall, root turnover and remnants of previous vegetation) in these systems. This may suggest a 'hypothesis 2' type relationship, but data for Jambi and Lampung show some differences that need to be further explored.

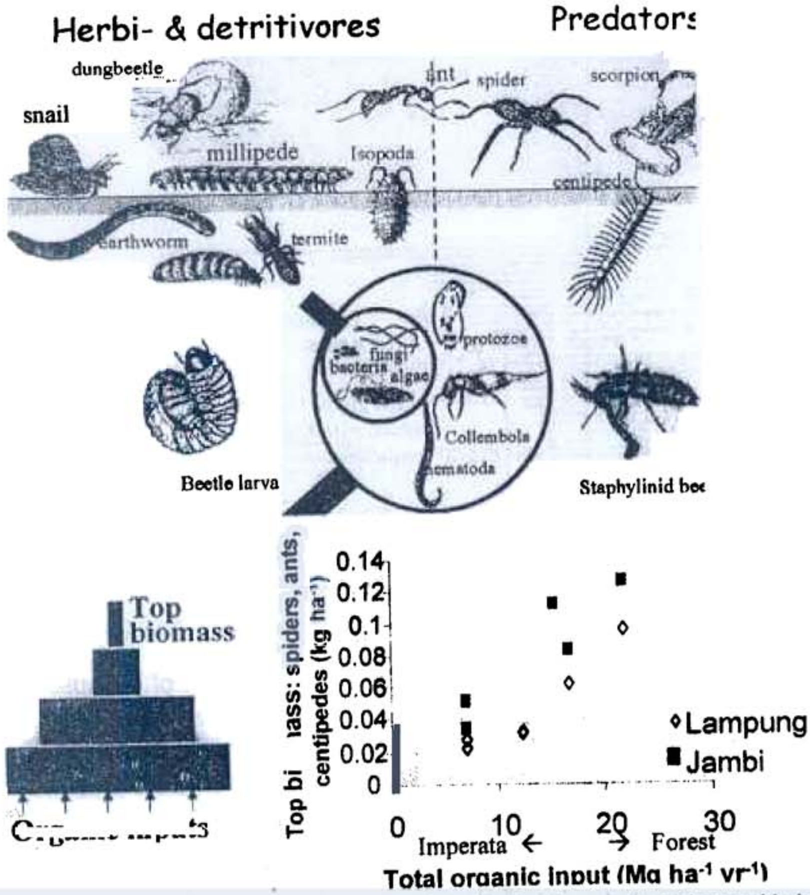


Figure 5. Key groups of soil biota that can be ranked into a food web or ecological pyramid; data for the ASB surveys suggest a general relationship between total organic inputs and the biomass of spiders *plus* centipedes *plus* ants based on (Hairiah *et al*., 2001; Susilo *et al*., *in press*).

The Global Sampling Design

The research design for the global survey of belowground biodiversity in relation to intensification of land use is based on a number of layers:

- Countries representing the full spectrum of population densities and land use intensities within the (sub) humid tropics,
- Benchmarks within those countries that add to the spectrum at country level,
- Windows or landscapes that are selected to represent the full spectrum of land use intensities within the benchmark,
- Points representing the full spectrum of land use intensities within the window.

While the seven countries that participate in the CSM-BGBD project cannot fully represent the full spectrum of situations within the three tropical continents, they do represent the full spectrum of national-scale population densities in what are recognized as global 'hot spots' of biodiversity.

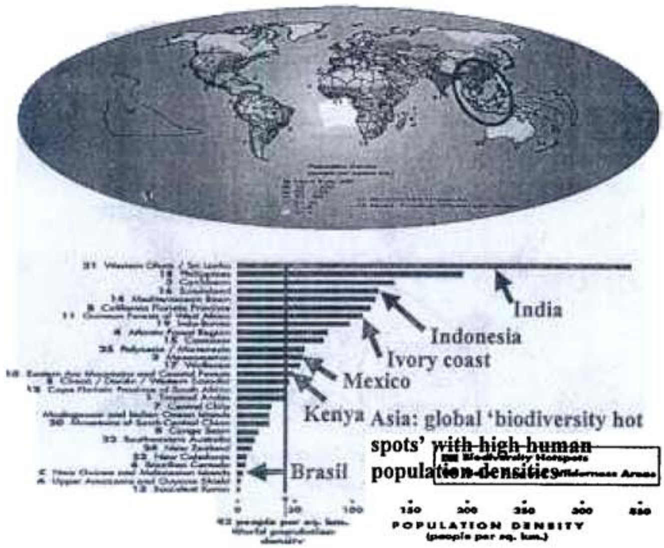


Figure 6. Global hot spots of biodiversity and the national-scale human population densities (quoted in Williams *et al.*, 2001).

In each of these 7 countries we expect to sample in four types of land use (forest, tree-crop production systems, annual-food crop systems and pasture), with a range of intensities in the three first groups, making 7 land use types in each country. Of course, the specific practices and crops in these systems will differ between countries and benchmarks, but if we want to test hypotheses at the level of 'land use intensity' we should not shy away from including jungle rubber and multistrata coffee into the 'extensive tree crop' class, and 'monoculture plantation rubber and sun coffee in the intensive class.

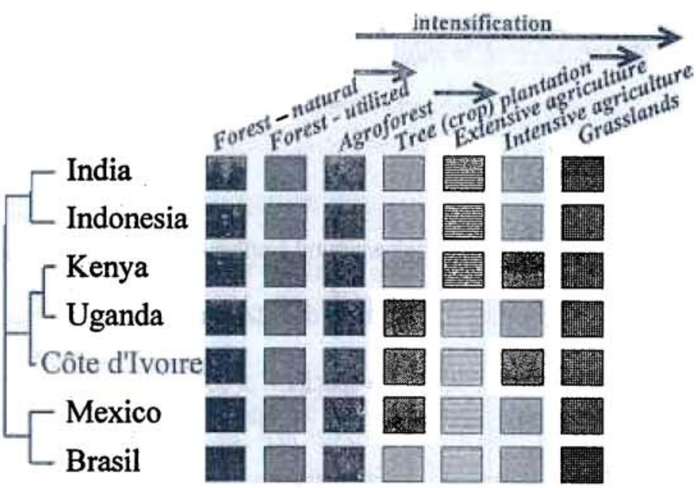


Figure 7. Global sample design, aiming for representative of 7 land use classes in each of 7 countries, to test both hypotheses on 'within land use class' intensification, and those that compare across the full spectrum.

The basic research design, and the levels of data that need to be represented in the global database, is summarized in Figure 8.

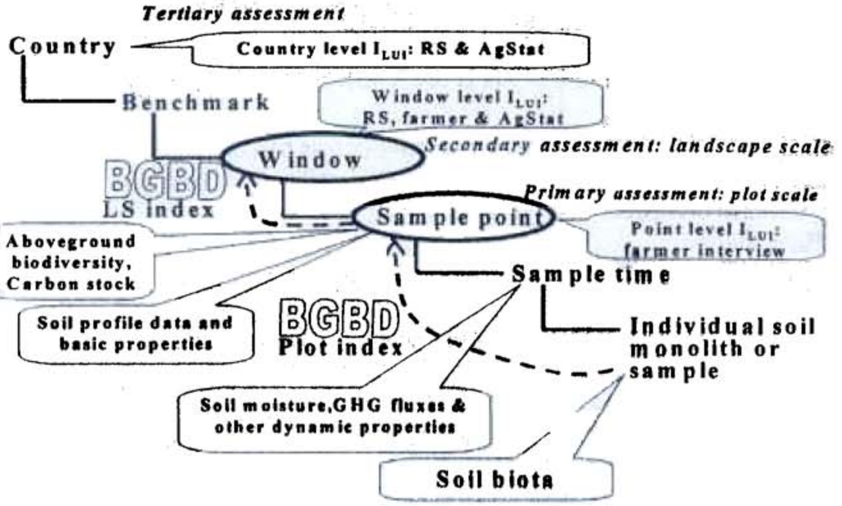


Figure 8. Overall research design, with a focus on data analysis at the 'sample point' and 'landscape' level, where underlying data on soil biota are compiled into a BGBD-index that can be compared with a land use intensity index.

An Operational Definition Of 'Intensification' At Plot And Landscape Scale

The central CSM-BGBD hypothesis refers to 'intensification' of agriculture. Other 'Integrated Natural Resource Management' research is equally interested in the balance between productive and environmental functions in agriculturally used landscapes. To test such hypotheses we need to be clear on how to measure 'intensity' of land use systems. While in most case studies the term intensification is used in a relative sense, referring to specific practices, a more generic concept is usually implied

In agricultural economics, the term 'intensity' is used for 'total production factor input' per unit of land, with monetary equivalents for factors such as labour, fertilizer, pesticides, growth regulators and agricultural machinery. From the perspective of the use of a limited amount of financial resources, 'intensification' is juxtaposed to 'extensification' (as acquiring additional land competes with the capital needs for obtaining inputs), but at the scale of a larger scale strategy both may be needed to meet the expected future demand. Ideally, economic valuation of the various inputs used should take into account the environmental costs associated with them, but currently such costs often remain external to the price-forming mechanisms and considerations. For discussions of 'integrated natural resource management' consequences of intensification we may thus need other 'currencies' to estimate the combined and interactive effect of various measures to increase agricultural production.

A first attempt at a generic land use intensity index was formulated by Giller *et al.* (1997), combining the Ruthenberg (1980) cropping index, with terms for the use of fertilizer, pesticides, irrigation and mechanization. The index, however, needs to be further operationalized, and may have to include other dimensions of intensification. Our '***intensification***' concept has to cover the full range from very extensive 'shifting cultivation' systems to intensive horticulture, where the chemical, physical as well as biological properties of the rooting medium are under complete technical control. It has to respond to increases in the fraction of time land is used for crop production, the fraction of total biomass harvested, the amounts of fertilizer, irrigation and pesticides used, as well as the amount of fossil energy used in soil tillage and mechanized farm operations (including harvest). The resulting index should preferably be dimensionless, so we have to choose appropriate 'scaling factors' for all the elements of the equation.

A first step in developing the index is to recognize five parts of an agriculturally used landscape:.

$R_{rot} + R_{per} = 1$ (1a)

where

R_{rot} = fraction of the area used for rotational systems,

R_{per} = fraction of the area used for permanent systems, with no 'open field' stage

$R_{rot} = R_{crop} + R_{fallow}$ (1b)

R_{crop} = fraction of the total area used for annual or tree crops as part of a rotational system,

R_{fallow} = fraction of the total area left as fallow part of a rotational system, with some potential use for grazing and production of firewood and NTFP's,

$R_{per} = R_{pas} + R_{for} + R_{ref}$ (1c)

R_{pas} = fraction of the area used for permanent pasture or grazing land

R_{for} = fraction of the total area used for permanent 'forest' or 'tree based' systems (with internal regeneration but no 'open field' phases) (please note that classical plantation forestry belongs to the 'rotational' category, while selective logging or agroforests with forms of 'sisipan' rejuvenation belong here),

R_{ref} = fraction of the total area left for 'refugia and filters' (landscape elements that consist largely of 'border' and for which 'area' is not a straightforward concept).

Intensification can be based on a reduction of the R_{per} and R_{fallow} fractions of the land use, as well as an increase of intensity within the R_{crop} or R_{pas} fractions. We here assume that the 'refugia and filter' fractions have no or negligible direct production functions (otherwise this land is supposed to belong to one of the two other fractions).

In the shifting cultivation -> long fallow -> short fallow -> permanent cropping range, we can make use of Ruthenberg's ***cropping index*** or index of land use intensity. In a 'steady state' form we can equate the time fractions to area fractions. The Ruthenberg index then reads $T_{crop} / (T_{crop} + T_{fallow})$, where T_{crop} is the length of time (or the fraction of area) cropped, and T_{fallow} is the length of time (or the fraction of area) under a fallow of zero use intensity. Where the fallow vegetation is also used for harvestable products (e.g. through grazing or production of firewood), we may want to include it in our intensity concept on the basis of the 'harvest index', the fraction of total biomass harvested (either as consumable product, as crop residues used for fodder, or removed through the use of fire). This same '***off take index***' (a term broader than the '***harvest index***' as used in agronomic studies) may well be used in the 'cropping phase' to distinguish between situations where only grain (or tuber) is harvested and those where all crop residues are removed from the field as fodder. For the cropping phase we include ***fertilization*** (relative to nutrient removal at crop harvest), ***irrigation*** (relative to total water use by the crop), soil tillage and mechanization (based on the ***fossil energy used*** per ha relative to the energy content of the crop harvested) and the use of ***pesticides*** (based on 'active ingredients' and their half-life time). These intensity factors can apply both to an 'annual crop dominated' and a 'tree dominated' of fallow stage of a cyclical production system.

Combining these elements, we get the following equation for a 'land use intensity' index (I_{LUI}):

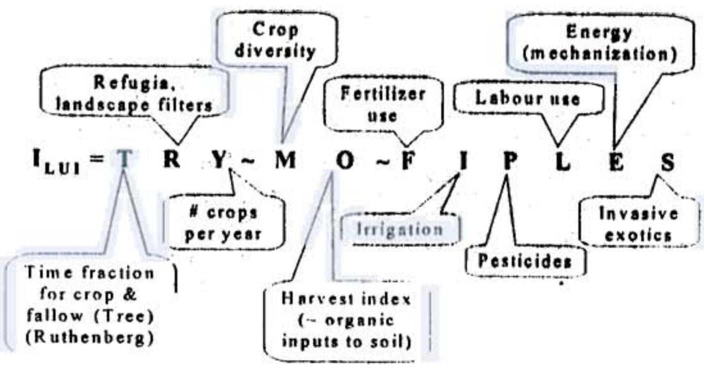


Table 1. Parameters of the index of land use intensity, and their representation at landscape scale

Aspects of land use intensification that may impact on belowground biodiversity	Factor in plot-level 'LU Intensity index'	'Macro' indicators
Increasing time-fraction of annual food crops, leading to increase of 'open time' and reduced organic input	T	Remote sensing, agricultural production statistics
Reduction in landscape fraction of filters and refugia	R	Remote sensing
Yearly number of crops and concomitant increase in weeding intensity – reducing litter input to the soil, and increasing 'open time' of the soil at early stages of any new crop	Y	--
Reducing diversity of annual crops	M_c	Market, agricultural production statistics
Replacing mixed woody fallow by planted tree monoculture	M_f	Remote sensing, agricultural production statistics
Increasing harvest fraction of aboveground biomass	O_h	Animal production statistics, type of fuel used
Increasing burn fraction of aboveground biomass	O_b	Smoke/haze production
Inorganic fertilizer N P Lime	F	Trade statistics for fertilizer
Inundation/irrigation (e.g. paddy rice)		Remote sensing, Agricultural statistics
Pesticide use Fungicides Insecticides Herbicides Other	P	Trade statistics for pesticides
Trampling and soil compaction by People Animals Tractors	L	
Soil tillage Manual Animal traction Tractors	E	Agricultural statistics
Introduction and spread of invasive exotics	S	--
Lack of understanding of role of soil biota	--	Knowledge-survey

A more specific equation can be:

$$
\mathrm{I}_{\mathrm{LUI}} = \left\langle \begin{array}{l}
\left(\frac{R_r t_c}{t_c + t_f}\right)(y_c)\left(1 + \frac{1}{M_c}\right)\left(\frac{B_{h,c} + B_{f,c}}{B_c}\right)\left(+ \frac{N_{fertilized,c}}{n_c B_c}\right) \\
\left(1 + \frac{W_{irrigated,c}}{10 B_c / w_c}\right)\left(1 + \sum_i \frac{P_{used,c,i} T_{1/2,i}}{p_i}\right)\frac{L_c}{100}\left(1 + \frac{E_{utilized,c}}{e_c B_c}\right) \\
+ \\
\left(\frac{R_r t_f}{t_c + t_f} + R_p\right)\left(1 + \frac{1}{M_f}\right)\left(\frac{B_{h,f} + B_{f,f}}{B_f}\right)\left(1 + \frac{N_{fertilized,f}}{n_f B_f}\right) \\
\left(1 + \frac{W_{irrigated,f}}{10 B_f / w_f}\right)\left(1 + \sum_i \frac{P_{used,f,i} T_{1/2,i}}{p_i}\right)\frac{L_f}{100}\left(1 + \frac{E_{utilized,f}}{e_f B_f}\right)
\end{array} \right\rangle (1 - R_{ref})^r S
$$

Where the subscripts c and f refer to a crop (annual crops) and fallow (or perennial crops) phase of the land use system, and

t_c and t_f = length of cropping or fallow period in a typical rotation [year],
y_c = yearly number of cropping seasons,
M_c and M_f = number of crops planted per cropping season in the same field or number of trees planted,
B_c and B_f = (final) total biomass of a crop or fallow vegetation [Mg ha^{-1}],
B_h = (cumulatively) harvested part of the biomass of a crop or fallow vegetation [Mg ha^{-1}],
B_f = biomass burnt [Mg ha^{-1}],
$N_{fertilized}$ = the amount of plant nutrients (N + P + K) added to the field as external fertilizer (in inorganic or organic form, the key is that it is derived from outside of the 'system' under consideration) [kg ha^{-1}],
n_c = typical nutrient (N + P + K) concentration [kg Mg^{-1}],
$W_{irrigated}$ = amount of water provided by irrigation during one cropping year [mm],
w = water use efficiency of the crop, or biomass production per unit of water transpired [kg / l] (the factor 10 is required to make the term dimensionless),
$E_{utilized}$ = sum of fossil energy used for all soil tillage and mechanized harvest operations [MJ ha^{-1}],
e = typical energy content of crop biomass [MJ Mg^{-1}],
P_{used} = total amount of active ingredient of pesticides used [kg ha^{-1}],
$T_{1/2}$ = half-life time of the active ingredient [year],
p = a biological impact rating of the various active ingredients [kg year ha^{-1}],
R_{ref} = landscape fraction left for refugia and filters [],
r = power of the refugia factor [],
S = multiplier for the (irreversible) spread of invasive exotics.