4.5

Measuring Intensity of Land Use in Tropical Forest-Agriculture Mosaics with the I_{LUI} Index

Meine van Noordwijk and Suseno Budidarsono

INTRODUCTION

Changing land use patterns can be broadly categorized into two: first, wholesale land clearing to make way for new plantation crops, for instance, which can be directly observed by remote sensing, and second, the more gradual transformations through the intensification or extension of existing types of land use, which does not register immediate changes in the remote sensing signature of a landscape. Here we address the question of how to measure the second, more subtle, change in land use. Currently, for instance, a gradual reduction in tree density within a section of closed forest, which could have major implications on properties such as terrestrial carbon stocks, can take place without being reflected in the remote sensing data (Lusiana et al. 2005). The difficulties of obtaining operational definitions of "forest" in the context of the Kyoto Protocol are essentially derived from the conflict between a discrete definition and a continuum of realities on the ground. We may equally find important variations in biodiversity within types of land cover, especially where agro-ecosystems gradually lose their complexity due to intensified cultivation of one or more crops (Matson et al. 1997; Vandermeer et al. 1998; Swift et al. 2004).

To test any hypotheses that relate consequences for environmental services to "intensification" of agriculture, however, we need to be clear on how to measure "intensity" as a property of land use systems. The relationship between rural population density and the intensity of land use has been studied for several decades (Boserup 1965; Ruthenberg 1980) but there is no consensus of how "intensity" can be measured. There is a tendency to use the yield (output) obtained per unit of land as an indicator of intensity, but economists prefer a "total factor efficiency" that relates the outputs to the sum of inputs of labour, land and capital. Taking the output as a basis leads to circular arguments in the discussion of intensification and production. A definition that is essentially based on the activities or inputs of the farmer is to be preferred.

INTENSIFICATION INDEX

Conceptually, the definition of land use intensity used by Giller et al. (1997) has found some followers, but it needs to be further operationalized. In the context of a global project on below-ground biodiversity, we introduced an "Intensification index (I_{LUI})" that covers the full range—from forests with very extensive "shifting cultivation" systems to intensive horticulture. As part of this intensification trajectory, the number of plant species using the land decreases, while the chemical, physical as well as biological properties of the rooting medium of the species targetted for harvesting come under complete technical control. The index responds 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 harvesting). The resulting index is dimensionless, so it requires appropriate "scaling factors" for all the elements of the equation. The starting point for the index was the ratio that Ruthenberg (1980) introduced for the description of shifting cultivation and fallow systems.

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 $T_c / (T_c + T_f)$, where T_c is the length of time (or the fraction of area) cropped, and T_f 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. This same "harvest index" 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). Combining these elements, we get the following equation:

Figure 4.5.1 Measuring intensity of land use

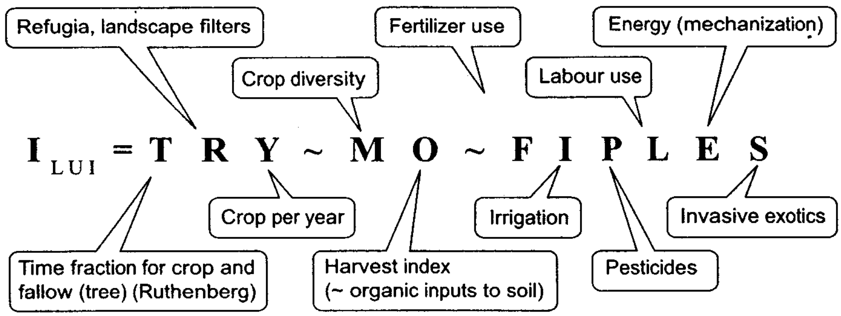
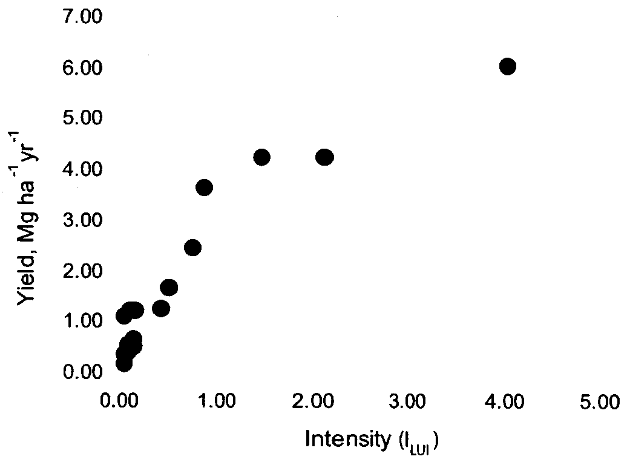


Table 4.5.1 Examples of values of the land-use intensity I_{LUI} index for a range of production systems

System	I_{LUI}	Total yield Mg ha^{-1} yr^{-1}	T_c yr	T_f yr
ShCult - no inputs, no harvest from fallow	0.03	0.13	2	30
ShCult - no inputs, some harvest from fallow	0.03	0.31	2	30
ShCult - no inputs, fallow products harvested	0.03	1.06	2	30
LongFallow - no inputs, no harvest from fallow	0.07	0.33	2	10
LongFallow - no inputs, some harvest from fallow	0.07	0.50	2	10
LongFallow - no inputs, fallow products harvested	0.08	1.17	2	10
Short Fallow - no inputs, no harvest from fallow	0.11	0.46	2	5
Short Fallow - no inputs, some harvest from fallow	0.12	0.60	2	5
Short Fallow - no inputs, fallow products harvested	0.14	1.17	2	5
Permanent cropping - no inputs	0.40	1.20	4	0
Permanent cropping - low fertilizer rate	0.48	1.60	4	0
Permanent cropping - idem, higher harvest index	0.73	2.40	4	0
Permanent cropping - idem, higher fertilizer rate	0.85	3.60	4	0
Permanent cropping - idem, pesticide use	1.47	4.20	4	0
Permanent cropping - idem, fully mechanized	2.09	4.20	4	0
Permanent cropping - idem, double cropping + irrigation	4.00	6.00	4	0

Figure 4.5.2 Relationship between total harvested yield of a grain crop equivalent to upland rice and the "intensity" index I_{LUI} for a number of cropping systems



In this equation variations in the amount of biomass harvested in "no input" systems can lead to the intensity indices of 0–1, while the use of fertilizer will double the result for nutrient application rates up to "balanced nutrient budget" level and more for higher rates, and the use of pesticides, fossil energy and irrigation can lead to higher values. The index is "open ended" on the right hand side, and values above 10 are possible.

To utilize this index for a particular cropping system, we will thus need to collect data on the typical duration of crop and fallow, the amounts of biomass harvested from both phases of the cycle, the amounts of fertilizer (N + P + K expressed as nutrient application rates) and irrigation water. The total use of fossil energy may be derived from fuel use for tractors and the like. Pesticides should be recorded as amounts of active ingredient, and we will need to get some expert advice on half-life times and the index of overall biological impact of the active ingredient.

APPLICATION OF INDEX

We applied the method to the forest + coffee garden + horticulture + rice fields landscape mosaic of Sumberjaya (Lampung, Indonesia), as part of a broader farming system characterization.

To apply the index, protocols and questionnaires were developed for the following parameters:

t = length of cropping or fallow period in a typical rotation [year] (interview the farmer for plot history)

B = (final) total biomass of a crop or fallow vegetation [Mg ha^{-1}] (destructive biomass sample, use of allometrics for woody perennials)

Bh = (cumulatively) harvested part of the biomass of a crop or fallow vegetation [Mg ha^{-1}] (interview the farmer for plot history)

Nfertilized = 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}] (interview the farmer for plot history)

nc = typical nutrient (N + P + K) concentration [kg Mg^{-1}] (for crops there are databases that we can use, occasionally we may need to sample ourselves)

Wirrigated = amount of water provided by irrigation during one cropping year [mm] (interview the farmer for plot history)

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

Table 4.5.2 Descriptive statistics of $I_{(LUI)}$ of plot sample by land use category (N=47)

Land use category	n	Area (Ha)	Min	Max	AVG	Median	Sd
Forest-Natural	1	0.20	0	0	0	0	-
Forest-Utilized	1	0.20	0.40	0.40	0.40	0.40	-
Agroforest	4	8.28	0.72	2.58	1.47	1.30	0.90
Tree (crop) plantation: coffee gardens	17	16.36	0.27	16.79	4.77	3.94	4.52
Extensive food crop systems	6	6.03	0.37	12.86	2.98	0.88	4.90
Intensive food crop systems: horticulture	11	4.52	0.14	21.14	9.03	4.78	7.64
Grassland/ shrub	7	11.27	0.11	0.18	0.15	0.15	0.02
Total	47	46.86	-	21.14	4.37	2.51	5.67

Source: Budidarsono et al. (2005)

dimensionless) (database to construct lookup table for local climate and C_3 versus C_4)

Eutilized = sum of fossil energy used for all soil tillage and mechanized harvest operations [MJ ha^{-1}] (interview the farmer for plot history)

e = typical energy content of crop biomass [MJ Mg^{-1}] (database for lookuptable based on harvested product)

Pused = total amount of active ingredient of pesticides used [kg ha^{-1}] (interview the farmer for plot history)

T1/2 = half-life time of the active ingredient [year] (database)

p = a biological impact rating of the various active ingredients [kg year ha^{-1}] ("expert" rankings)

Table 4.5.2 shows that the I_{LUI} of 47 plot sample varied between 0.11 (shrubs/grassland) and 21.14 (intensive agriculture). The lower the index the less intensive the land use is. Shrubs/grassland is the least intensive land use category, while a considerable range is identified within the coffee gardens.

We thus have a basis for testing hypotheses on the tradeoff between environmental and agronomic functions.

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