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REVIEW ARTICLE

An essay on the Boserupian model with particular emphasis on labour input and productivity in upland rice swiddens in Southeast Asia

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ABSTRACT This study examined several aspects of Ester Boserup's model (1965), which has been highly influential in human ecological discussions on the dynamics of agricultural systems. The starting point of her model is that population pressure is the engine for changes in agricultural systems. For the cultivation stages prior to annual cropping, the result of the mathematical formulation devised in the present study is expressed by a simple equation whose independent variable is the population density in the territory of a community and dependent variable is the duration of fallow period of the fields in the territory. This equation can be graphically depicted as an equilateral hyperbola, although a few other factors may somewhat modify this basic pattern. This suggests that the fallow periods of the agricultural system of a community should be drastically shortened in the early phase of its population growth. At the next step, using a reasonably selected collection of available quantitative data originally obtained from upland rice swiddens in Southeast Asia, the assertion of the model that the labour productivity of a cultivation system with a longer fallow period is superior to that of a cultivation system with a shorter fallow period is tested. On the whole, the results do not confirm this assertion, most likely because such a test is strongly affected by local factors than by the common factor of the fallow period. Still, when the whole data of labour productivity are divided into those of the eight and the nine cases in the equatorial and the monsoonal zones, respectively, the results do roughly show the expected trend that labour productivity decreases with a shortened fallow period. Furthermore, if the two outliers of the nine values of the latter zone are excluded, this trend becomes highly noticeable and statistically significant.

Key words: Boserupian model, mathematical formulation, labour input, upland rice swidden, Southeast Asia

INTRODUCTION

Almost half a century has elapsed since the publication of the influential yet relatively compact book 'The Conditions of Agricultural Growth: the Economics of Agrarian Change under Population Pressure' by Ester Boserup (1965). Nevertheless, till date, it remains so intellectually stimulating that many human ecologists (e.g. Nielsen et al. 2006), including myself, still enjoy the discussion on issues surrounding the model proposed by her. Although she herself emphasized that it was quite antagonistic to the classical Malthusian model, a number of scholars took a different perspective and considered the two models to be complementary to each other (Nakano 1983, Lee 1986). At present, the relationship between these models is considered to be that of the chicken and the egg (Cohen 1998).

The basic logic of Boserup's model is simple as follows:

(1) Population pressure intensifies the use of land (Carlstein 1982) for agricultural production and gradually reduces fallow periods to less than a year, ultimately leading to a system of cropping twice or even several times a year.

(2) As the system of land use is intensified, labour input into a given area in the cropping cycle increases, while the yields of crops tend to decline. Consequently, the labour productivity on a farm will necessarily be reduced.

To prevent reduction in crop yields owing to very frequent use of land, labour-intensive technology, even without any institutional pressure, has been adopted by agriculturalists. Notably, Boserup's model deals mainly with agricultural landscapes in the pre-industrial era, although she certainly examines, to some degree, the circumstances in which the application of modern technology to agricultural production is likely to result in increased labour productivity, even on farms where systems of land use have been highly intensified. The application of her model seems to be better suited to the dynamics of agricultural systems over the very long term (Bayliss-Smith 1974, Cassen 1976, Nakano 1983). This is despite a series of studies represented by Tiffen et al. (1994) and Tiffen and Mortimore (1994) that illustrate a case in which population pressure was the key factor inducing indigenous agriculturalists to promote technological development, over a relatively short period of a few decades, for the prevention of soil erosion in a region of Kenya.

As suggested by Kaldor (1965) in the foreword of Boserup's book (1965), the majority of scholars who are partiacularly interested in her model think that it is based on the optimistic tradition derived from the French illuminists, given that agricultural development is accomplished by the stimulation of technological innovation, which is induced by population growth itself (Dyson 1996, Cohen 1998). In contrast, others (e.g. Cohen 1989), including myself, consider the model to be a very pessimistic approach because of its emphasis on the abovementioned premise (2), which assumes an inevitable decline in labour productivity that requires agriculturalists to sacrifice their leisure time for periods of prolonged drudgery.

Boserup's classification of land use systems begins with shifting cultivation, i.e. long and short fallow systems, with the former being further divided into forest fallow and bush fallow cultivation and the latter implying grass fallow cultivation with fallow periods of one year or a few years. Incidentally, her perspective of forest fallow cultivation is mainly formed on the basis of cases in which secondary (or regrowth) forests are cleared after having undergone fallow periods for 'at least some twenty to twenty-five years' (Boserup 1965, p. 15). If premise (2) is true, forest fallow cultivation should have the highest labour productivity of all of the agricultural systems, while the labour productivity of bush fallow cultivation, with shorter periods of fallow than forest fallow cultivation, should be lower in comparison. However, she herself seems to admit that this may not be applicable in some cases such as the cultivation of swiddens by the clearing of 'old-growth forest' (van den Top 2003), which often needs 'a far more arduous task than the clearing of secondary forest' (Boserup 1965, p. 31). Unfortunately, quantitative data in the book that may support this inference are insufficient.

Notably, agricultural labour productivity can be divided into two factors: the yield in a definite area (land productivity) and the labour input used in the cultivation of this area. In the present study, the values of labour productivity in upland rice swiddens in Southeast Asia, the majority of which still appear to be cultivated with production methods similar to those in the pre-industrial era, were examined with respect to the duration of fallow periods using an available collection of quantitative data including those in unpublished doctoral theses and official study reports. Nielsen et al. (2006) have already examined this topic. Although they also reviewed such data from eight sources, the primary data for their detailed analyses, which include testing the effect of fallow periods on labour productivity, are their own original data obtained in Sarawak. The focus of the present study is on labour input rather than on yield. The relationship between yield and fallow periods of upland rice in Southeast Asia has already been quantitatively discussed in several other studies (Cramb 1984, Mertz 2002, Bruun et al. 2006, Mertz et al. 2008).

Before the abovementioned discussion begins, the section that follows proposes a mathematical expression to capture the process of the shortening of fallow periods with population growth. This process is considered to be the starting point of the Boserupian model, as described in premise (1) above.

THE REDUCTION OF FALLOW PERIODS WITH POPULATION GROWTH: AN ATTEMPT AT DEVISING A MATHEMATICAL FORMULATION

Using the logic of premise (1) on the population growth and fallow periods noted in the preceding section, let us consider the simplest case in which the territory of a community is fixed with no out-migration and all the agriculturalists cyclically shift their swiddens or farms every year before annual cropping begins. Such a system of agricultural land use is often observed in the Southeast Asian communities that use upland rice swiddens for the inhabitants' daily subsistence (e.g. Nakano 1980). First, key factors by the following variables are described:

T = the total area of the territory of the community;
P = the total population of the community;
A = the total area in the territory actually available for agricultural production at a given time;
x = the total number of agriculturalists in the territory;
a = the average swidden or farm area annually cultivated by an agriculturalist; and
t_f = fallow period in years, which must be $\geqq 0$.

Because $(t_f + 1)$ is equal to the fallow period plus one year of cultivation in the abovementioned case, the total area in the territory actually available for agricultural production can be mathematically determined as follows:

$$A = ax\,(t_f + 1) \tag{1}$$

Equation (1) can be transformed as follows:

$$t_f = \frac{A}{ax} - 1 \tag{2}$$

The following additional factors should be then considered

for examination of Boserup's model:
$P/T = d$, where d is the population density in the territory;
$A/T = g$, where g may be denominated the geographic factor; and
$x/P = c$, where c may be referred to as a demographic factor.
If these three factors, a, c and g, are constant, equation (2) leads to the following equation:

$$t_f = \frac{g}{acd} - 1 \quad (3)$$

When the condition of $t_f \geqq 0$ is added, equation (3) can be graphically expressed as the thick line in Fig. 1 with the tentative values $g = 0.3$, $a = 0.5$ hectare · person^{-1} · year^{-1} and $c = 0.5$. In many situations, e.g. when every agriculturalist in the community has only one crop season over a number of fixed months annually, t_f values cannot be continuous, but rather, must be integer values. The thin lines in Fig. 1 are more appropriate in such cases. This figure suggests that the transition between the stages of forest fallow and bush fallow within the definition used by Boserup (1965) will occur at an early phase of population growth and that the fallow periods should be drastically shortened as population grows. It also shows that the short fallow system within her definition corresponds to a much wider range of population density (d) than either the forest or bush fallow system. Her empirical studies (Boserup 1981, Chapters 2 & 3) support the results of this analysis.

In reality, however, the assumption that all the three factors a, c and g are constant is highly unlikely because of their dependence on various factors. If one assumes that all the three factors are primarily related to population density, which would fit her theoretical direction (Boserup 1965, Chapter 8), the following equation can be obtained:

$$t_f = \frac{g(d)}{a(d) \cdot c(d) \cdot d} - 1 \quad (4)$$

In a pre-industrial society, the geographic factor g increases as d increases, inasmuch as marginal lands that remain unused for agricultural production are put into use. On the other hand, it is almost inconceivable that the average farm area a managed by an agriculturalist would

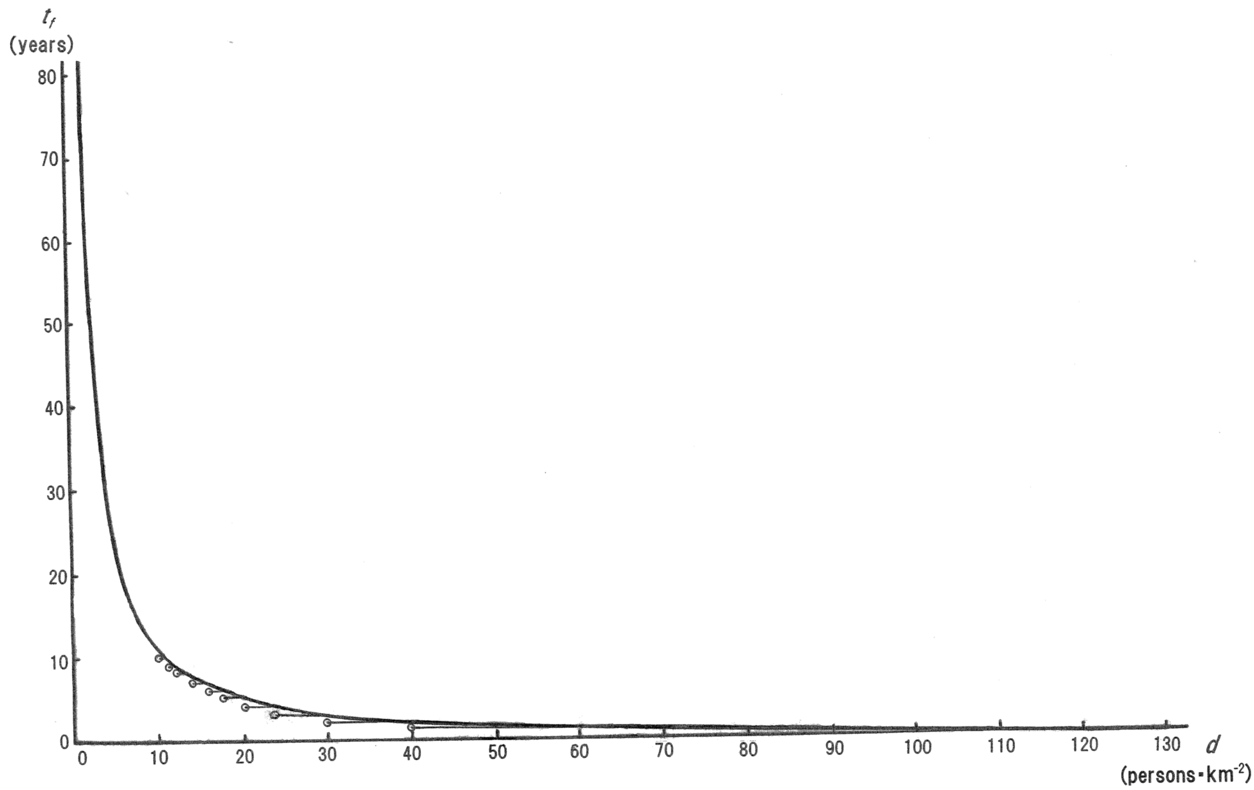

Fig. 1. The theoretical relationship between the fallow period (t_f) and population density (d) in the simplest case in which, until the transition to the annual cropping phase begins for the whole community, a cropping field is actually used for a duration of less than or equal to one year before the following fallow period. The curve shown by the thick line is computed under the tentative assumptions that (1) the ratio of area actually available for agricultural production to the total area of fixed territory of a community is always 0.3; (2) the ratio of the number of agriculturalists in the community to its total population is always 0.5 and (3) the average field area annually cultivated by an agriculturalist is always 0.5 hectare · person^{-1} · year^{-1}. The thin lines indicate the similar relationship for the case in which the cropping season for an agriculturalist is limited to a number of fixed months annually. The thin lines at small values of d cannot be technically depicted merely because of their proximity to the thick line.

increase as the population grows within the fixed territory of a community. In addition, according to Boserup's view (1965, p. 71), the value of factor c is expected to decrease when d increases. Hence, population growth—an increasing value for d—will shift the value of $\frac{g(d)}{a(d) \cdot c(d)}$ upward on the whole. Consequently, the thick line in Fig. 1 will shift somewhat to the right, as d increases. This result theoretically implies that population growth itself somewhat violates the principal trend that it shortens fallow periods. This implication is compatible with her affirmation that agriculturalists reluctantly shorten their fallow period when they are required to do so (Boserup 1965, p. 53).

The detailed computation of equation (4) should be left to computer simulations, and is out of the scope of Boserup's work (1965). Further examination of the various and complicated methods of swiddening do not seem to change fundamentally the relationship expressed in equation (4). For example, if the agriculturalists shift their swiddens after m years of cultivation at identical parcels of land, then

$$t_f = m \left\{ \frac{g(d)}{a(d) \cdot c(d) \cdot d} - 1 \right\} \quad (5)$$

Consequently, in this case too, the population density at which the agriculturalists enter the stage of annual cropping is the same value as that calculated in equation (4) because according to the theory discussed above, the density is expected to be the value at the stage when $\frac{g(d)}{a(d) \cdot c(d) \cdot d} - 1 = 0$.

Thus, the relationship between the duration of the fallow period and population density can be regarded as one of the core themes of the Boserupian model(1).

MATERIALS AND METHODS

Available studies containing quantitative data describing labour inputs in new (first-year) swiddens of upland rice in Southeast Asia were identified and the data were collected. Data describing the swiddens of swamp rice (e.g. *padi paya* on Borneo Island) were excluded.

An overview of upland rice swiddens in Southeast Asia

The successive production of upland rice in swiddens over two or more cropping cycles does not appear to be frequent in Southeast Asia(2). According to a very large number of studies, an alarming yield decline in the second and subsequent successive cropping cycles is considered to be mainly due to the markedly lowered soil fertility in swiddens. In addition to this most frequently mentioned factor of the decline in soil fertility after one cropping cycle and the other obviously critical factor that amongst all important crops, upland rice belongs to a group that is highly sensitive to the presence of weeds (van Heemst 1985, de Rouw et al. 2002), more attention should be paid to the scientific evidence that upland rice is severely influenced by the hazard of continuous cropping(3) (Hirano 1977, George et al. 2002), which is rarely the case for wet paddy fields. Traditionally, many swiddens for upland rice production in Southeast Asia are fallowed after only one cropping cycle.

The reasons why quite a few data are excluded from the collection for the dataset

The data collected were limited to those that appeared to be obtained by actual observations of the paper or book authors themselves and/or their assistants over one cropping cycle. Cases in which the observations began at the half way point of a cycle and ended at the half way point of the next cycle (Durrenberger 1978) were allowed to be included. Using this criterion, studies by Padoch (1982 & 1985), Roder et al. (1997) (who exclusively obtained information through interviews), Douangdara et al. (1991) and Inoue (1989) (a very interesting study that will be mentioned later) should be excluded from the construction of the dataset to be examined in the present study. Of these five studies, the latter two are the reports of the surveys for rapid rural appraisal. My own research principle is in accordance with A. Terry Rambo's suggestion (2007) that the results of such surveys should be taken lightly, although, ironically, he is also one of the co-authors of the former of the two reports, namely Douangdara et al. (1991). The following comment by de Rouw et al. (2003, pp. 20−21) is particularly noteworthy: 'Comparison of farmers' estimates and our direct observations showed that farmers accurately estimate the work spent on clearing, sowing and harvesting, but tend to overestimate the work lost in weeding. This could also have been the case in the data of Roder et al (1997).' Thus, it may be concluded that the quantitative data obtained from agriculturalists' memories, including many based on surveys administered by questionnaire, are often not entirely reliable. Incidentally, data obtained by Saito et al. (2006) on labour input from detailed records of nine swiddeners are used as part of analysis in the present study, although their study lacks the yield value of upland rice.

For excluding cases in which any cultivation techniques using the products of modern industry are applied, data are excluded for sites where one or more of those products such as herbicides, chemical fertilizers and chain saws are used. For example, the data of Chin (1985) should not be included under this criterion, although Nielsen et al. (2006) included them in their list for the review of labour productivity in upland rice swiddens in Southeast Asia. The first-year swidden where he evaluated the labour input for weeding was sprayed with a composition of herbicides, although it may have been excessively diluted. Similarly, quantitative information of Cramb (1984 or 1989) and Gerrits (1994), both of which appear in the abovementioned list of Nielsen et al. (2006), is excluded here on account of the applications of small quantities of fertilizers and herbicides to the upland rice by a majority of swiddeners as well as the occasional use of chain saws. Furthermore, the original data obtained by Nielsen et al. (2006), who conducted a field survey of two long-house communities where chemical fertilizers, herbicides and chain saws are widely used, are excluded from consideration here. In fact, according to them, the influence of these modern techniques at their survey site is found to exert statistically significant effects on a few aspects of swiddening, including the time used for weeding.

The data from Durrenberger (1979), which Hunt (2000) used as a material for the evaluation of labour productivity in upland rice swiddens in Southeast Asia, should be omitted from the dataset for the present study because his research only shows the value of total labour input for the production of upland rice without breaking down the input into each of the core operations, whose concept is to be explicated later in this section, in the swiddening of upland rice. For a similar reason, Yengoyan's quantitative data (1964), which are too brief to be precisely examined, are also excluded from our dataset, although a very interesting suggestion of that author based on his data will be discussed later.

The methods of measurements and expression of the data on labour inputs

Ideally, as emphasized in my previous study (Nakano 2012), data on labour inputs should be obtained using the study method of secretly measuring time and motion to express the values in terms of person·hours·hectare^{-1}. In actuality, however, with the swiddens of upland rice in Southeast Asia, data fulfilling this strict condition cannot be found, with the exception of those presented in my previous study (Nakano 1980). Accordingly, similar to Hunt (2000), who tested the applicability of the Boserupian model with regard to the difference in labour productivity of rice cultivation between swiddens and wet paddy fields in Southeast Asia, we were tentatively obliged to conduct a study by means of values expressed in terms of person·days·hectare^{-1}. Although the present study owes a great deal to the untiring efforts of a considerable number of ethnographers and cultural anthropologists, many of them—quite regrettably unlike researchers who follow a scientific approach—often pay little or no attention to the description of the methods by which such quantitative data were obtained. Incidentally, in the present study as well as in my previous study (Nakano 1980), the conversion rate of six hours·day^{-1} for the computation of working days was tentatively applied to the data of a few studies where the values of labour input are expressed in terms of person·hours·hectare^{-1}. With regard to Hinton (1975), of course, the results of his own precise measurements of the working hours·day^{-1} of the respective core operations, whose meaning will be explicated shortly, should be used. His data support the applicability of the preceding value (six working hours·day^{-1}) when the conversions from person·hours·hectare^{-1} to person·days·hectare^{-1} are made in similar cases in the other studies examined here.

Attention to 'core operations' and the climatic factor

As stated in my previous study (Nakano 2012), the concept of the 'core operations' of swiddening cannot be ignored in the evaluation of labour inputs for comparing, by means of a standardised procedure for analysis, the values in multiple cases with one another. These operations consist of clearing the original vegetation, burning cleared debris and preparing the ground for planting, planting the crop (in the case of this study, only upland rice), weeding and lastly harvesting, which includes paddy threshing and winnowing. When discussing the values of the labour input into swiddens across Southeast Asia, we should first direct our attention to the data of only these core operations to omit circumstances that are overly regional. Then, if warranted, other operations that are more specific to individual regions, such as fencing, protecting and guarding can be considered. With regard to harvesting, which includes threshing and winnowing, the case of ear plucking with or without a 'finger knife' can be problematic, given that threshing and winnowing are often performed at a later stage in the settlement yard or within the house i.e. outside the respective swiddens (e.g. Brewer 1979). Because of such cases, the determination of the value of labour input for harvesting is complicated and the resulting values are often difficult to compare accurately when the total values of labour input across Southeast Asia are discussed. Owing to the lack of better options, in such cases, we tentatively use the values given by the respective studies with the understanding that we somewhat underestimate labour input for harvesting.

Tentatively, given that climate is considered to affect the cultivation methods used and consequently the labour inputs, the sites in which the respective data were obtained are divided into two series, with zones (A) and (B) being equatorial and monsoonal, respectively.

RESULTS AND DISCUSSION

The ordering of the data collected and reasonably selected

Based on the principles stated in the preceding section, the information available in the related literature necessary for the examination of item (2)—the effect of the intensity of land use on labour input and productivity—has been collected and summarized in Table 1. For both series A and B in this table, the case numbers are arranged in a roughly decreasing order according to the fallow periods of vegetation before swiddening. The table first lists cases of vegetation with the longest fallow period (old-growth forest, which is usually referred to as 'primary' and occasionally as 'virgin' forest), and proceeds to cases with shorter fallow periods.

In the books by Freeman (1970), Conklin (1957) and Schlegel (1979), data on labour inputs on operations for swiddening in parcels with old-growth and old or younger regrowth forests can be found. However, none of these authors indicate the values of yields of upland rice for the swiddens from respective types of vegetation; they rather provide only the average values for all the swiddens where they conducted their field surveys. Consequently, I must note an identical yield value in the two rows (A-1 and A-4; A-3 and A-6 as well as B-1 and B-4) of each type of original vegetation for the data collected from these sources. Use of these average values has undoubtedly lowered the accuracy of those estimates of labour productivity.

For Brewer's data (1979) in row B-9, the value of labour input for burning and preparing the ground for planting appears to be markedly higher than the corresponding ones for other data sources in that column. This difference is due to the reason that swiddeners in the region where the author conducted field surveys usually perform the labour-intensive operation of 'scraping the weeds off the soil with a medium-sized spade' (Brewer 1979, p. 97) in the interval between reburning the unburnt remnants of vegetation and planting the seeds of upland rice. This operation may be termed as weeding. If so, the allocation of labour input for burning and preparing the ground for planting will be reduced to 38 person·days ·hectare^{-1} (the value relative to the total labour input is 11%), whereas the value of labour input for weeding will increase to 169 person·days·hectare^{-1} and that of column a. + d. will also increase to 220 person·days·hectare^{-1} (the relative value is 62%). Incidentally, the value of labour input appearing in the column for reaping (or ear plucking), threshing and winnowing in row B-9 in Table 1 is much higher than the value actually measured by Brewer (1979). This deliberate change is based on his own reasonable estimation of labour input for this operation in a normal year. According to him, drought in the years (1975–76) when he actually measured the values of labour inputs reduced the actual crop yield to approximately one-third of the amount of harvest usually expected by the swiddeners.

For Conelly's data (1992) in row B-10, if the yield value in the previous year, which was solely based on swiddeners' reports, is taken into account, the mean value of the two years' yields is 700 kg·hectare^{-1} and, accordingly, the corresponding value of labour productivity for the two years is 5.2 kg·person^{-1}·day^{-1} under the inconceivable condition that the value of the labour input for the harvest operation in the previous year was identical to the input for the year when the author actually obtained the data and when a drought lasting for three weeks struck just before the harvest. The range of labour productivity values in Conelly's case estimated by Nielsen et al. (2006) seems to be based on the yields in the respective two years. In addition, their value of working hours·day^{-1} for the conversion from person·hours·hectare^{-1} to person·days ·hectare^{-1} is likely to be considerably higher than the value used for the estimation in Table 1. Thus, the difference between their estimate and my estimate of labour productivity in Conelly's case is probably due to the different values of the factors used in the calculation. Incidentally, in his original data of labour inputs, the value for guarding deliberately excluded from the total of labour inputs in Table 1 is effectively negligible.

With regard to the data originally obtained by Conklin (1957), the estimates of labour productivity noted in Table 1 of this manuscript are much higher than the corresponding

Table 1. A collection of the quantitatively comparable data describing the labour inputs and yields of rice production in conventional and dry first-year swiddens in Southeast Asia

Case no. & vegetation before clearing [The swidden type defined in Boserup (1965)]	Survey region	Labour input into core operations of swiddening (person・days・hectare^{-1} & the percentage of the total labour)							Paddy yield (kg・hectare^{-1})	Labour productivity (kg・person^{-1}・day^{-1})	Data source
		a. Slashing & felling	b. Burning & preparing the ground for planting	c. Planting	d. Weeding	e. Reaping, threshing & winnowing	Total* (a.−e.)	a. + d.			
	A. Equatorial										
A-1. Old-growth forest [Forest fallow]	Westerly Mindanao Island	75 28%	47 18%	55 21%	16 6%	73 27%	266 100%	91 34%	2,600	9.8	Schlegel (1979)
A-2. Old-growth forest [Forest fallow]	Northern West Kalimantan	20 31%	1 2%	13 20%	0 0%	30 47%	64 100%	20 31%	340	5.3	Dove (1985a)
A-3. Old-growth forest [Forest fallow]	Central Sarawak	47 30%	9 6%	22 14%	35 23%	42 27%	155 100%	82 53%	770	5.0	Freeman (1970)
A-4. Old-regrowth forest [Forest fallow]	Westerly Mindanao Island	68 25%	41 15%	55 20%	37 14%	73 27%	274 101%	105 38%	2,600	9.5	Schlegel (1979)
A-5. Mainly older regrowth forests [Bush fallow]	Northern West Kalimantan	13 10%	4 3%	15 12%	49 38%	49 38%	130 101%	62 48%	500	3.8	Dove (1985a)
A-6. Five to twenty years' fallow forests [Bush fallow]	Central Sarawak	25 18%	9 6%	22 16%	43 30%	42 30%	141 100%	68 48%	770	5.5	Freeman (1970)
A-7. Mainly five to nine years' fallow forests [Bush fallow]	Eastern Sarawak	44 42%	1 1%	15 14%	13 12%	33 31%	106 100%	57 54%	470	4.4	Strickland (1986)
A-8a. Though not noted, perhaps young regrowth forest [Bush fallow]	Western Sarawak	39 > 34%		10 > 9%	< 43** Roughly 37%	24 > 21%	<115 101%	<82 Roughly 71%	360	> 3.1	Geddes (1954)
A-8b. Same as above [Bush fallow]	Western Sarawak	55 > 22%		26 > 10%	< 102** Roughly 40%	70 > 28%	<253 100%	<157 Roughly 62%	1,640	> 6.5	Ditto
	B. Monsoonal										
B-1. Old-growth forest [Forest fallow]	Mindoro Island	68 30%	31 13%	26 11%	50 22%	55 24%	230 100%	118 51%	2,320	10.1	Conklin (1957)
B-2. Mainly old-growth forests [Forest fallow]	Northern Thailand	24 15%	12 7%	44 27%	31 19%	50 31%	161 99%	55 34%	1,290	8.0	Walker (1970)
B-3. More than ten years' fallow forests [Bush fallow]	Northern Thailand	12 17%		9 13%	18 26%	30 43%	69 99%	30 43%	1,730	25.1	Miles (1974)
B-4. Mainly young woody-regrowth forests [Bush fallow]	Mindoro Island	42 16%	24 9%	23 9%	124 46%	55 19%	268 100%	166 62%	2,320	8.7	Conklin (1957)
B-5. Though not noted, perhaps mainly young regrowth forests [Bush fallow]	Northern Thailand	45 21%		41 19%	63 30%	63 30%	212 100%	108 51%	1,390	6.6	Durrenberger (1978)
B-6. Two to fifteen years' fallow forests & bushes [Bush fallow]	Northerly Laos	39 14%	16 6%	14 5%	145 52%	64 23%	278 100%	184 66%	Not available		Saito et al. (2006)
B-7. Mainly very young regrowth forests [Bush fallow]	Northern Thailand	51 15%	30 9%	46 14%	153 46%	50 15%	330 99%	204 62%	1,500	4.5	Hinton (1975)
B-8. Five or six years' fallow forest [Bush fallow]	Northern Thailand	9 5%	7 4%	8 5%	92 53%	59 34%	175 101%	102 58%	1,160	6.6	Nakano (1980 & 2012)
B-9. Somewhat above three years' fallow bushes [Bush fallow]	Sumbawa Island	51 < 14%	91 < 25%	49 < 14%	116 < 32%	> 50***&**** Roughly 14%	>357 99%	167 <47%	Inconvertible to the metric system		Brewer (1979)
B-10. Two to four years' fallow bushes [Bush fallow]	Palawan Island	23 17%	2 1%	24 18%	63 47%	23 17%	135 100%	86 64%	556	4.1	Conelly (1992)
B-11. One to three years' fallow bushes [Bush fallow]	Northerly Laos	41 20%	27 13%	43 20%	74 35%	25 12%	210 100%	115 55%	1,900	9.0	de Rouw et al. (2003)

* Each value in this column is calculated as the sum of the noted values in the respective columns to the left in the row.
** Includes labour for fencing.
*** Quantitative labour data are available for neither threshing nor winnowing.
**** Value estimated by the author of the data source.

value in Table I of the manuscript of Nielsen et al. (2006). The main reason for this difference is probably that this study focuses only on the core operations. According to Conklin's original data (1957), in contrast to Conelly's case mentioned above, quantities of required labour are substantial for the operations excluded from the core operations, namely fencing, protecting and guarding. Therefore, in Conklin's cases (B-1 and B-4) in Table 1, if the values of labour inputs for the three abovementioned operations are also taken into account, both estimates of labour productivity will be much lower than those in this table, as shown in Table I of the manuscript of Nielsen et al. (2006).

With regard to paddy yields, the values of Freeman (1955a or 1955b or 1970)[(4)] and Geddes (1954) are considerably different between Table 1 of the present study and Table III of the manuscript of Hunt (2000). These differences may be partly due to the conversion factor between values in *gantang* or imperial gallons (approximately 4.55 litres), which is one-eighth of an imperial bushel, and the values of paddy weight in kilograms. In the present study, on the basis of the FAO table, the conversion factor of one U. S. bushel (approximately 35 litres) of paddy rice to 20.4 kg was used. Thus, one litre of it weighs 0.57 kg, and one imperial gallon (or *gantang*) weighs 2.6 kg. My own actual measurements in a swidden area of northern Thailand, where the *tang* (20 litres) is usually used for measuring, support this conversion rate. With respect to the case of Freeman (1970), however, the difference in yield values between the study of Hunt (2000) and the present study cannot be fully explained by conversion factors. He adopted a value of 0.62 kg/litre as the conversion factor, as noted in Kunstadter et al. (1978). In fact, the variation in this factor is considerable. With regard to the data of Durrenberger (1978), he himself notes that one *tang* of paddy rice weighs 10 kg. In other words, for a given quantity of paddy rice, the ratio of the figure in kilograms to that in litres is calculated at 0.50. Special attention should be given to the value of labour productivity calculated from the original data of Freeman (1955b) by Nielsen et al. (2006). The value noted in the text of their manuscript is 4−11 $\mathrm{kg{\cdot}person^{-1}{\cdot}day^{-1}}$; however, the value in their Table I is 11−16 $\mathrm{kg{\cdot}person^{-1}{\cdot}day^{-1}}$. Obviously, the latter value is incorrect.

Applicability of the Boserupian model to the ordered dataset

Table 1, as a whole, hardly fits the narrative of the aspect of Boserup's model presented in premise (2) in the Introduction, which asserts a relationship between the intensity of land use and labour input and productivity. In particular, when series A and B are viewed together, supporters of the Boserupian model who examine this table would be like children, having lost their way, wandering deep into an equatorial old-growth forest. Similarly, from data obtained by their own field surveys, Nielsen et al. (2006) state that they 'are unable to confirm or reject the Boserup thesis' (p. 213).

Labour input — into the chaos —

The data of total labour inputs of both series A and B in Table 1 imply, as concluded by Nielsen et al. (2006), that 'We are…unable to verify or reject the thesis that more labour is required when fallow periods are shortened' (p. 215).

With regard to both series A and B of this table, however, attention should be paid to the percentage values of the respective core operations because they reveal the allotment changes of labour inputs in accordance with the reduction of fallow periods. For example, the following trend, with only a few exceptions, may be observed: as the case numbers increase, the rank order of values of weeding for the respective cases in the five core operations does not decrease. In other words, this trend quantitatively confirms the comment stressed by most actual swiddeners and the observation stated by Boserup (1965, p. 30) that weeding becomes more difficult with the shortening of fallow periods. In addition, this table shows that in the cases of forest fallow in the sense defined by Boserup (1965, p. 15), the amount of labour input for the operation of slashing and felling is higher than that for the operation of weeding, with the exception B-2. However, in the cases of bush fallow as she defines it (Boserup 1965, p. 15), the quantitative relationship between these two operations is the opposite of that of forest fallow, with only one exception (A-7). Such a reversal is very often emphasized by research experts on shifting cultivation and was suggested by Boserup (1965, pp. 29−30).

With regard to the column of the labour inputs describing slashing and felling and weeding (namely the column of a. + d. in Table 1), some interesting points emerge. In both series A and B, the simple averages of the percentage values of this column in forest fallow cases are lower than those in bush fallow cases. In addition, the simple averages and standard deviations of the values in forest fallow cases and bush fallow cases in both series are similar. In particular, the average values in series A for slashing and felling and for weeding are 39.0% ± 9.8 (n =

4) and 56.6% ± 9.9 (n = 5), respectively. In series B, the average values for this column are 42.5% ± 12.0 (n = 2) and 56.4% ± 8.0 (n = 9), respectively. Accordingly, when both series are united, the average value of the column of a. + d. for bush fallow cases (56.5% ± 8.3; n = 14) is significantly higher (at the 1% level; one-tailed test) than that for forest fallow cases (40.2% ± 9.5; n = 6). This result is probably due to the markedly greater burden of weeding in swiddens made from shorter-fallowed vegetation. Incidentally, partly owing to the small number of the cases shown in Table 1, the often-told story [(also mentioned by Boserup (1965, p. 31)] that slashing and felling in old-growth (so-called primary) forests requires more labour input than that in old-regrowth forests with a fallow period for more than twenty years cannot be confirmed using the data in this table.

Land productivity — in the middle of the chaos —

With regard to the yields of upland rice in relation to the length of fallow periods, no trend is clearly recognizable in Table 1. In charting data over fallow periods ranging from 0 to 25 years, Cramb (1984) has depicted an almost flat line for yields in swiddens in two neighbouring districts of Sarawak. Mertz et al. (2008), analyzing data from their own field studies in a total of eight communities in Sarawak and North and West Kalimantan on Borneo Island, have reached a conclusion similar to that from Table 1, although the frequent application of inorganic fertilizers and herbicides in limited amounts even in the swidden areas of Sarawak has more or less affected the results of their studies. Incidentally, their Fig. 2 suggests that overly long fallow periods reduce the yields of upland rice. Deegan (1980) who obtained yield data in two Lun Bawang villages in Lawas District, Sarawak, for one farming year 1975–76 has also asserted that a quadratic regression of yield on the actual fallow period is likely to be a good fit and that the curve should move slightly downward after approximately fifteen years' fallow at one village. This village 'exhibits a modest but significant correlation between yield and actual fallow' (Deegan 1980, p. 761), whereas the other village 'shows little difference between its actual and optimum fallow periods and no correlation between yield and actual fallow period" (p. 761). In addition, in Table 1 of this manuscript, the phenomenon that the yield value of upland rice in swiddens mainly from older regrowth forests is higher than that from old-growth forests is exemplified by the pair of cases A-2 and 5 based on the original data in Dove (1985a).

The methodological problem of this type of research from the viewpoint of a scientist

Fundamentally, an analytical methodology in which conclusions are drawn from the collection and comparison of one-time data obtained from geographically diverse areas does not, strictly speaking, meet the standard of the scientific method of experiments under controlled conditions. The great number of factors specific to the individual geographical areas in an analysis prevents the investigated property from appearing clearly. Mertz et al. (2008) state the following: 'Getting a clearer understanding

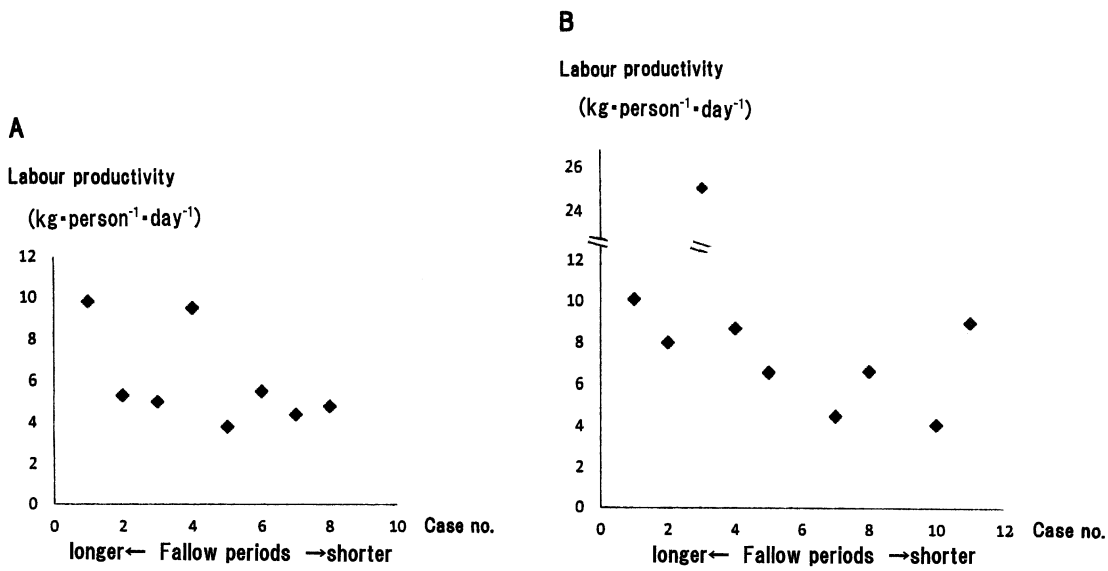

Fig. 2. Scatter diagrams of the values of labour productivity for the cases in the equatorial (A) and monsoonal (B) zones. Case nos. correspond to respective those in Table 1. For case 8 in A, the dotted value of labour productivity is a simple average of the values of cases A-8a and A-8b in Table 1.

of how fallow length influences crop yields will require field trials where all production parameters can be tightly controlled…' (p. 83). This comment can be applied to the question of how labour inputs are related to fallow periods. In other words, ideally, a scientist of human ecology who studies issues related to the Boserupian model should consider a research plan that follows the methods of experimental science as closely as possible.

Labour productivity — a clue to the way out of the chaos —

Still, fortunately, the earlier-mentioned children wandering into a deep tropical rainforest seem to have found a clue to the way to their house where their anxious parents and Mrs. Boserup are awaiting their return. Despite the many limitations stated above, there are some observations that can add clarity to this assessment of the Boserupian model. In Table 1, a trend that fits the model can be vaguely recognized in the column of labour productivity. When we focus on the relationship between the fallow period and labour productivity in both series A and B of this table, a rough trend can be observed: as the former lengthens, the latter increases (Fig. 2). Although such a relationship is statistically significant (in both series, individually) at only the 10% level (one-tailed test) according to Spearman's d^2 test, if two outlier cases in series B, namely case 3[(5)], which has an extraordinarily high value, and case 11 are excluded (Fig. 2B), the relationship in series B between the fallow period and labour productivity becomes significant at the 2.5% level (one-tailed test) and the value of Spearman's rank correlation coefficient is 0.86 ($n = 7$).

Incidentally, if Michael R. Dove's own tentative assumption (1985b) that, with regard to case A-5, a minimum of one-third of the total labour input was devoted to the production of non-rice cultigens is accepted, the value of labour productivity of case 5 will increase to at least 5.7 $kg \cdot person^{-1} \cdot day^{-1}$. Although this increase in the value of case 5 hardly changes the preceding conclusion of series A (statistically significant at the 10% level), if his assumption can be also similarly applied to case A-2, the trend in series A that labour productivity decreases with a shortened fallow period becomes significant at the 2.5% level (one-tailed test) and the value of Spearman's rank correlation coefficient is 0.79 ($n = 8$).

A few other studies supporting the Boserupian model

Inoue's study (1989) on 11 villages (nearly half of which were inhabited by the Kenyah) in East Kalimantan on Borneo Island should be mentioned here. Although these data were from field surveys for rapid rural appraisal, his results from the quantitative evaluation, covering most of those villages, of the labour productivity of upland rice in swiddens with respect to the fallow period are quite in line with the Boserupian model. Incidentally, the fact his field surveys had been conducted before he read Boserup's book (1965) with only a little knowledge of the model (Inoue 1990, personal communication) is noteworthy and highly interesting.

The ecologically remarkable part of Yengoyan's doctoral thesis (1964) should also be kept in mind, given that it describes a rather rare case and contains some interesting results on quantitative examination. His survey area was located in the southeastern part of Mindanao Island. In fields of shifting cultivation in the higher-elevation lands in this area, the year-round rainfall prevented agriculturalists from burning slashed and felled debris of old-growth or regrowth forests. Because this type of shifting cultivation does not involve burning the debris, I deliberately do not refer to it as swiddening (Nakano 2012), although Yengoyan (1964) has used this term. When the agriculturalists clear matured trees in old-growth forests, they use the method of 'domino-type reaction' (Yengoyan 1964, p. 88). Despite this efficient technique, the operation of felling trees in a definite area of an old-growth forest is particularly labour-intensive. Moreover, partly because they cannot burn the felled debris, high labour input is required for the manual clearing of debris. As a result of such procedures, 'from eight cases involving the cultivation of rice in primary forest growth, an average range of 3,500–3,800 hours per man per hectare was recorded. …These figures are significantly greater than the Hanunōō of Mindoro …' (Yengoyan 1964, p. 110) investigated by Conklin (1957). Nonetheless, according to Yengoyan, the shifting cultivators prefer old-growth forest to regrowth vegetation for their cultivation sites for the following reasons: (1) a cultivated field from the former is easier to clear and requires less labour to do so on account of the high probability of successfully conducting the abovementioned domino-type reaction if the vegetation of the old-growth forest is located on a steep or sloping terrain and (2) the fields from old-growth forests require less labour and time for weeding, and furthermore, such sites allegedly produce higher rice yields, although Yengoyan himself has suggested no significant yield difference. The abovementioned information partly seems to follow the Boserupian model, although she may have had no idea of the existence of a system of shifting cultivation without burning given that knowledge of such a system had not yet circulated widely even amongst experts in the ecology of shifting cultivation in the mid-1960s. From the foregoing item (2) stated by him and the remark of de Rouw et al. (2003), quoted in the Materials and Methods, regarding agriculturalists' overestimation of labour input for weeding, it should be noted that the operation of weeding is generally disliked very much by upland rice swiddeners.

Toward further development of the debate on the basis of scientific data between the pro- and the anti-Boserupian camps

Another inevitable problem in which Boserupian experts in the human ecology of shifting cultivation are keenly interested is the quantitative confirmation of the inevitable corollary to Boserup's assertion (1965, Chapter 5) that the labour productivity of upland rice swiddens is superior to that of wet paddy fields. This problem had already been examined prior to the publication of her study. Hagreis (1930/1931) quantitatively confirms, to some degree, the favourability of swidden cultivation in terms of labour productivity. Many similar conclusions are based on the quantitative data of the labour productivity of wet paddy fields in Java or the Tonkinese Delta (Gourou 1940) where various labour-intensive systems of irrigation are used. In contrast, the view that wet paddy fields tend to be more favourable than upland rice swiddens (Nakano 1980, Padoch 1985, Conelly 1992, Hunt 2000) is mostly based on observations and/or quantitative data obtained from wet paddy fields at the foot of hills, bottoms of narrow valleys, or other smaller basins where the labour-efficient system of gravity irrigation can be more easily utilized. In addition, considering the case reported by Toky and Ramakrishnan (1981 & 1982), this problem becomes further complicated, although the hilly area where they conducted their field surveys is in Northeast India, a region outside Southeast Asia and to the north of the Tropic of Cancer. The agriculturalists there invest more labour in wet paddy fields than in swiddens, mainly because the utilization of animal power for the preparation of fields is not common and the manual operation, which requires a large quantity of labour, is usually performed (Toky and Ramakrishnan 1981 & 1982). Consequently, the labour productivity of wet paddy fields is lower than that of swiddens (Toky and Ramakrishan 1982), which follows the Boserupian model. Thus, the values of labour productivity of wet paddy fields seem to depend greatly on the specific type of irrigation management and on the respective measures adopted for other purposes. Consequently, a very wide range of those values is likely because of the quantitatively large difference in the amount of labour input for the methods used in wet paddy fields. At any rate, deriving a quantitative solution to this debate seems to be an extremely difficult task given the numerous factors involved.

EPILOGUE

As mentioned earlier, the Boserupian model rests on a framework that is profoundly appealing to many scholars because it fosters the romantic notion that (1) human progress can be achieved by exercising one's potential ability for technological innovation to overcome difficulties (Wilkinson 1973, Simon 1992) or that (2) the ideal life can be found in an imaginary ancient time, where there exists 'primitive affluence' with no daily drudgery. However, it is extremely difficult to confirm scientifically the applicability of the model to real-world cases. Despite this and many other reasonable criticisms against it, for both reasons stated above, the Boserupian model, similar to the Malthusian model, will surely continue to survive in academic circles for a very long time.

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NOTES

(1) Although population density is considered to be closely related with the length of fallow periods, the fallowing of land is not always occasioned by a more sparse population itself. For example, according to Gliessman (1998, p. 128), 'In moisture-limited parts of the world

such as Great Plains of the United States and the southern wheat belt of Australia, farmers sometimes alternate between cropping one year and fallow the next to conserve soil moisture. …In fact, as long as sufficient rainfall for recharge is received during the fallow year, there is much less risk of crop failure if the crop season turns out to be drought year.' Gliessman (1998) discusses this system of fallow cropping in Chapter 9 of his text book, and shifting cultivation is explained in Chapter 10 with no reference to the agricultural system explained above. Thus, it is impossible to state that this example of fallow cropping perfectly fits the usual definitions of shifting cultivation. Certainly, a strict and precise definition of the system of shifting cultivation is extremely difficult.

(2) The following observation in Northeast India, which is geographically located outside Southeast Asia and to the north of the Tropic of Cancer, is noted in an article by Saikia (1982, p. 233): 'Usually a plot of *jhum* (the indigenous word meaning swidden—noted by the author of this manuscript) is cultivated for two consecutive years. In the first year a variety of crops are grown but in the second year paddy or millet is usually raised.'

(3) The hazard of continuous cropping means a noticeable yield decline of a crop because of its successive planting in the identical parcel of a field. However, a case in which the decline in the soil fertility is the main reason for poor yield is not referred to as such a hazard. For the purpose of preventing it, the method of crop rotation is popular.

(4) Derek J. Freeman's quantitative data on labour inputs and land productivity shown in all of the three publications, i.e. Freeman (1955a), Freeman (1955b) and Freeman (1970) appearing in the following Reference were based on the measurements during his field survey conducted in the early 1950s. Therefore, the corresponding values in these three sources are the same as one another.

(5) With regard to the data on labour inputs in Case B-3, a methodological problem must be described. According to Douglas J. Miles' doctoral thesis (1974), these data of labour inputs were estimated from the basic values obtained from measurements in test plots with pre-determined small areas. This method may appear to be similar to that of a time-motion study. The results of the two methods, however, very often become strikingly different from each other. In the latter case, the area dealt with by the study subjects is measured after one term of operation between resting times. In particular, when performed secretly, the process of measuring does not affect the manner of work at all and provides an opportunity to estimate exact values of for usual labour efficiency. In contrast, in a method using a test plot, the area for measurements is pre-determined, as mentioned above. In particular, when such an area is small, subjects tend to work harder than they do at their usual pace. Consequently, labour efficiency values tend to be overestimated. This concern was put forward by Anthony R. Walker (1973, personal communication), who had been a colleague of Douglas J. Miles and had actually attempted to measure labour efficiency after the method which Miles used, but was in vain for the reason stated above. Thus, for case B-3, both the underestimation of the values of labour inputs and the overestimation of labour productivity are problematic.

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