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Boserup versus Malthus revisited: Evolution of farming systems in northern Côte d'Ivoire

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Abstract

In the literature on the evolution of farming systems in Sub-Saharan Africa, the theses of Malthus and Boserup seem to offer contrasting views on rural development. The purpose of the present study is to revisit these theses and empirically examine them through a case study of northern Côte d'Ivoire. We surveyed a sample of farms in four villages in the Dikodougou region during three agricultural seasons. The villages mainly differ regarding their population density and historical genesis. Comparative analysis of the villages and farm types identifies population pressure as a key factor of the evolution of farming systems in this region. Our empirical analysis shows that Boserupian and Malthusian processes coexist, rather than contrast. Through mechanisation and intensification, Boserupian innovation has been largely able to compensate for the Malthusian repercussions of increasing population pressure. However, in a first stage demographic pressure engenders migration, i.e. Malthusian population control, rather than Boserupian mechanisms of induced innovation, which seem to be unleashed after a critical population density is attained.

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1. Introduction

In the literature on the evolution of farming systems in Sub-Saharan Africa, the theses of Malthus and Boserup seem to offer contrasting views on rural development. On the one hand, Malthus (1798) proposes that population, when it is not controlled, increases following a geometric ratio, while agricultural production growth follows an arithmetic ratio. The widening gap between demographic and agricultural growth rates engenders crises (famine, war and migration), leading to an endogenous "natural control" of population. On the other hand, Boserup (1965) contends that population pressure urges farmers to adopt more intensive cropping systems and, hence, to innovate. The purpose of the present study is to revisit the theses of Malthus and Boserup by examining them empirically through a case study of northern Côte d'Ivoire.

2. Data

During the period 1995–1998, the project IDESSA-K.U.Leuven (Institut des Savanes, Côte d'Ivoire – Katholieke Universiteit Leuven, Belgium) was active in Côte d'Ivoire, more specifically in the Dikodougou region, south of Korhogo. Four villages in a radius of 50 km from the regional capital town Dikodougou were purposefully selected to represent the demographic (population pressure and genesis of the villages) and economic (presence of a cash crop) diversity of farming: Tapéré at 8 km northwest, Ouattaradougou at 50 km southeast and Farakoro at 30 km southwest, Tiégana at 20 km northeast of Dikodougou (Table 1).

For each of the villages, a representative sample of farms was selected and surveyed during three agricultural seasons. For each farmer, field area, crop yields,

Table 1
Main characteristics of the surveyed villages

	Tapéré	Ouattaradougou	Farakoro	Tiégana
Distance and orientation from capital town Dikodougou	8 km northwest	50 km southeast	30 km southwest	20 km northeast
Genesis	Ancient (19th century)	Recent (60s)	Recent (60s)	Ancient (19th century)
Population density (inhabitants/km^2)	14	17	28	40
Share of native population	97%	8%	9%	91%
Share of immigrated population	3%	92%	91%	9%
Annual population growth	−2.5%	28.1%	9.5%	−1.3%

Source: Demont (1998) and Demont and Jouve (2000).

input use, capital costs, family structure and daily labour allocation were surveyed. Moreover, numerous surveys and informal interviews were carried out on historical, sociological and economic aspects of farming in the Dikodougou region. Hence, we had at our disposal an extensive database of data on four villages, surveyed during three agricultural seasons, i.e. 1995/1996–1997/1998. The survey contained 34 farms in the 1995/1996 season and was extended to 47 farms in the 1996/1997 and 1997/1998 seasons. As our sample size is relatively small, the data for each of the 3 years are used as independent observations. As a result, we dispose of a dataset of 125 observations, i.e. between 21 and 35 observations per village (Table 2). A complete description of the villages and the sampling method is reported by Demont (1998) and Stessens (2002).

These villages differ strongly with regard to factors such as population density and historical genesis (Table 1). The southern part of the Dikodougou region (Ouattaradougou and Farakoro) is located in the pioneer zone of forest land clearing. While this zone remained "underpopulated" up to the 1980s, since then it has been characterised by a high rate of demographic growth, due to progressive colonisation of uncultivated land by immigrants coming from northern Côte d'Ivoire. Especially in Ouattaradougou, where an annual growth rate of 28% is recorded, land

Table 2
Population density and farm economics

	Tapéré	Ouattaradougou	Farakoro	Tiégana
Population density (inhabitants/km^2)	14	17	28	40
Number of observations	21	34	35	35
Economic dimension of the farms				
Number of annual family work units	3.78	4.97	4.40	4.12
Number of annual non-family work units	0.03	0.30	0.26	0.03
Total number of annual work units (AWU)	3.81	5.27	4.66	4.16
Usable area per family work unit U (ha)	8.7	8.4	6.6	3.9
Cultivated area per family work unit S (ha)	1.1	1.6	1.5	1.1
Degree of intensification of the farms				
Cropping period C (years)	3	6	6	9
Fallow period F (years)	22	18	16	21
Land use intensity (%) $R = C/(C+F) = S/U$	12	24	27	31
External input costs of the farms				
Fertilisers (FCFA/ha)	316	2858	3646	4224
Herbicides (FCFA/ha)	0	227	482	444
Insecticides (FCFA/ha)	14	978	1752	1983
Total inputs (FCFA/ha)	330	4064	5880	6651
Total inputs on food crops (FCFA/ha)	55	393	1134	1109
Investment level of the farms				
Total fixed costs (FCFA/ha)	8727	14,070	13,070	18,823

Note: fixed conversion rate: 1 Euro = 656 FCFA.
Sources: Demont (1998), Demont and Jouve (2000) and Stessens (2002).

colonisation is very active, while in Farakoro the first signs of land saturation become perceptible. Hence, being founded in the 60s, the southern villages are relatively recent as compared to the northern villages (Tapéré and Tiégana), which are founded in the 19th century. As a result, we have a sample of four villages representing population densities ranging from 14 to 40 inhabitants/km^2, i.e. a threefold increase.

3. Methodology

This intraregional diversity (Table 1) constitutes the basis of our methodology. As Jouve and Tallec (1996) observed in numerous cases, ''in Sub-Saharan Africa, due to interethnic conflicts [...] density of occupation of land is far from being homogenous and only partly reflects the agricultural potentialities of the land''. This is also the case for our region of study, where the distribution of the population is the result of a history of war during the nineteenth century. ''This heterogeneity of population translates into a diversity of farming systems, allowing tracking down the different evolutionary stages in function of population pressure''. Our methodology is inspired by these observations: it consists of ''valorising the geographic diversity of farming systems to reconstruct their historical evolution'' (p. 24). Comparing the villages provides a better understanding of the evolution of farming systems and identifies the key factors responsible for this process. The proximity of the four villages largely cuts out agroclimatological factors as a source of variation, and enables us to isolate the effects of factors that change from one village to another, such as population density and historical genesis.

In the first stage, following Ruthenberg (1980), the land use intensity of all arable fields is estimated, represented by the ''degree of residence'' or R-factor. This factor can be calculated in the spatial dimension by dividing the cultivated area, S, by the total usable area, U, i.e. $R = S/U$. However, whereas cultivated area is physically marked and hence relatively easy to measure, total usable area, i.e. cultivated and fallow land, is difficult to define and measure in the field. On the other hand, farmers easily remember the length of the cropping and fallow period of their fields. Therefore, we estimate the land use intensity in the temporal dimension by dividing the cropping period, C, of the field by the total length of a rotation cycle, i.e. $R = C/(C + F)$, taking into account the fallow period, F. The previous equation allows us to obtain an estimate of the total usable area, i.e. $U = S/R = S(C + F)/C$.

In the second stage, we estimate the investment levels and gross margins of the surveyed farms. The investment level is reflected in the fixed costs of non-divisible capital such as agricultural equipment. To estimate the fixed costs, we calculate the annual depreciation costs of agricultural equipment through linear depreciation, which diminishes the value of an asset by a fixed amount each period until the net value is zero. The total fixed costs of farm k are the sum of the annual depreciation costs of each piece of equipment, estimated by dividing the average purchase price, v_i, by the average lifespan of the equipment, n_i:

$$\mathrm{FC}_k = \sum_{i=1}^{m} v_i/n_i \tag{1}$$

for a set of agricultural equipment tools $i \in \{1, 2, \ldots, m\}$.

The gross margin per unit of labour of farm k is calculated as the gross product minus variable costs, divided by the total labour endowment:

$$\mathrm{GM}_k = \left(\sum_{j=1}^{n} p_j y_{kj} L_{kj} - \sum_{j=1}^{n} [\delta_j p_j L_{kj} + w_{kj}] \right) \Big/ W_k \tag{2}$$

for a set of crops $j \in \{1, 2, \ldots, n\}$.

To obtain gross production of farm k, crop yields, y_{kj}, are multiplied by the area sown, L_{kj}, and the market price, p_j. Variable costs of farm k consist of seed costs, i.e. average seed density (kg/ha), δ_j, multiplied by the market price, p_j, and the area sown, L_{kj}, and purchased input costs, w_{kj}, e.g. fertilisers, herbicides and insecticides. Total labour endowment, W_k, is expressed in annual work units, one AWU corresponding to the annual work performed by one person who is occupied with an agricultural holding on a full-time basis.

In the third stage, relative technical efficiency of the farms is measured using standard techniques of Data Envelopment Analysis (DEA) following Charnes et al. (1978). DEA forms a non-parametric deterministic production possibility frontier, defined as the best practice observed, assuming constant returns to scale. If a farm lies on the surface, i.e. there is no other farm that can either produce the same outputs by consuming less inputs (input oriented DEA) or produce more outputs by consuming the same amount of inputs (output oriented DEA), it is referred to as an efficient farm, otherwise inefficient. DEA also provides inefficiency scores and reference units for inefficient farms. The inefficiency score indicates the percentage by which a farm should decrease its inputs (input oriented DEA) or increase its outputs (output oriented DEA) in order to become efficient. As in Färe et al. (1985), we assume that production is characterised by a non-parametric, piecewise-linear technology, so that simple linear programming techniques can be used. We further assume strong disposability of outputs and inputs. For each farm k we estimate total technical inefficiency, TTI_k, through input oriented DEA using the following linear program, allowing only for constant returns to scale (Mathijs and Swinnen, 2001, p. 104):

$$\begin{aligned} \min_{\lambda,\mathbf{z}} \quad & \boldsymbol{\lambda} \\ \text{s.t.} \quad & \mathbf{zY} \geqslant Y_k \\ & \mathbf{zX} \leqslant \boldsymbol{\lambda}\mathbf{X}_k \\ & \mathbf{z} \geqslant 0 \end{aligned} \tag{3}$$

where Y_k denotes the output of farm k, $\mathbf{X}_k$ is a vector of inputs employed by farm k (capital, land, labour and other inputs) and $\mathbf{z}$ is a vector of k intensities that characterise each farm. Finally, total technical efficiency can be calculated as $\mathrm{TTE}_k = 1 - \mathrm{TTI}_k$.

4. Results and discussion

Fig. 1 graphically illustrates how the average cropping mix of the farms changes under increasing population pressure. In the most sparsely populated village, the cropping systems are dominated by the rotation of three crops: yam, rainfed rice and groundnut. According to Le Roy (1983), these crops constitute the basis of the ‘‘ancient yam–rice–groundnut (YRG) cropping system’’, characterised by a 3-year cropping period followed by a long fallow of at least 20 years, dominating in sparsely populated areas. Under increasing population density, yam is gradually substituted by other food crops or cash crops such as cotton. What are the driving factors behind this diversification of the cropping mix?

Without doubt, population density directly affects the person–land ratio. Table 2 illustrates how total land endowment per unit of labour declines with increasing levels of demographic pressure. When moving from a sparsely to a densely populated village, the usable agricultural area, U, is halved, i.e. from 8.7 ha in Tapéré to 3.9 ha per family work unit in Tiégana. In contrast, the evolution of cultivated area, S, does not seem to run parallel with this trend. It is higher in the southern immigration regions (Ouattaradougou and Farakoro), due to the immigrants’ anticipation strategies, i.e. cultivation of land implies appropriation.

A direct consequence of a decline of usable land, due to increasing demographic pressure, and an increase of cultivated land, due to land appropriation anticipation strategies, is the intensification of cropping cycles, measured by the R-factor. Farmers increase the land use intensity in the spatial dimension, i.e. by converting more fallow land into cultivated land, and in the temporal dimension, i.e. by expanding

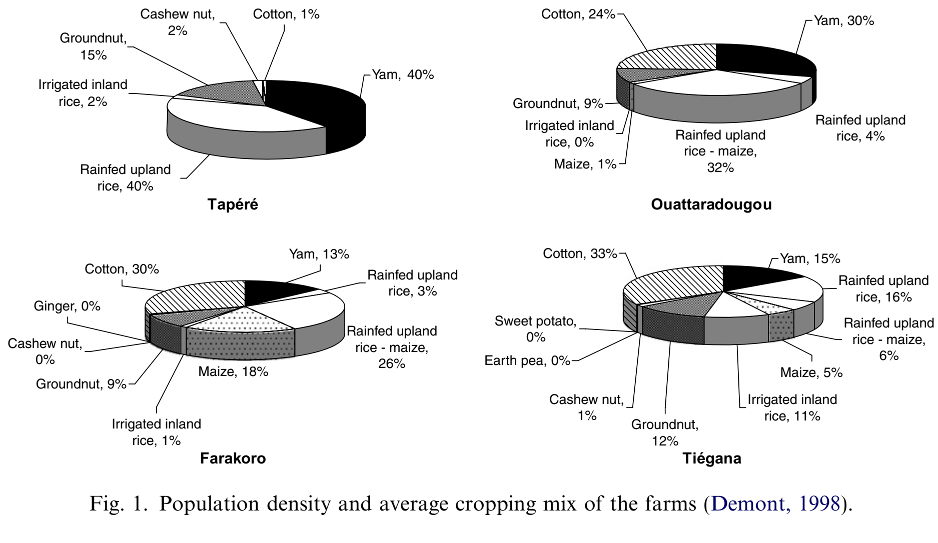

Fig. 1. Population density and average cropping mix of the farms (Demont, 1998).

the length of the cropping period and shortening the fallow period. In Tapéré, 3-year cropping systems dominate, followed by a long fallow of 22 years on average, leading to the lowest observed land use intensity among the surveyed villages, i.e. $R = 12\%$ (Table 2). The cropping period seems to be doubled to 6 years in the southern villages of Ouattaradougou and Farakoro, and tripled to 9 years in the most densely populated village Tiégana. The intensification of cropping cycles does not seem to erode the length of the fallow period, which is maintained at about 20 years in the northern villages, despite the difference in demographic pressure. In the southern villages, the increase of the R-factor is also the result of a strategic shortening of the fallow period in order to mark and maintain land property. We also observe that irrigated inland rice cropping systems only significantly develop in the most densely populated village, i.e. Tiégana (Fig. 1). This system is highly labour-demanding throughout the whole agricultural season and features the highest land use intensity, i.e. $R = 100\%$. Therefore, it is only sustainable under high population density.

Since labour is the principal production factor in manual or low-mechanised agriculture, the real economic dimension of a farm is defined by the size of the available labour force and not by the cultivated area as assumed by many studies. Therefore, indicators of farm performance should be expressed per unit of labour and land. However, a logical correlation exists between both dimensions as the southern villages are endowed with larger labour forces than the northern villages (Table 2). Migrations waves to southern uncultivated areas temporarily mobilise a substantial labour force on an extended area. As soon as the effects of land saturation are perceived at the level of the village (decline of yields, proliferation of weeds and development of pests and diseases), this wave moves on to another region pushing further the pioneer front. In Farakoro, for example, the first signs of agricultural land saturation are already perceptible and the colonisation front is moving southwards past Ouattaradougou. Hence, migration can be interpreted as Malthusian "natural population control" in response to declining agricultural profitability levels.

The intensification of cropping cycles engenders a transformation of the biophysical environment and a substitution of crops, especially the ones on top of the rotation cycle. Fallow land gradually evolves from forest to savannah and grassland, losing little by little its capacity to control weeds. In response to increasing population pressure, the ancient YRG system evolves into a series of derived cropping systems. A first group of systems is simply based on the extension of the 3-year cropping period, a second one on the insertion of one or several years of cotton cultivation (Fig. 1).

What is the repercussion of these changes at the farm level? In the first part of Table 3 we compare the average crop yields, gross margins, and total technical efficiency scores of the farms among the four villages. We observe a gradual decline of the yields of the major traditional crops on top of the rotation cycle, i.e. yam and rice, under increasing levels of demographic pressure. Secondly, the gross margins also seem negatively correlated with population density. The highest gross margins per unit of labour and land are recorded in the most sparsely populated village, i.e. Tapéré, where almost exclusively the ancient YRG cropping system is maintained. Finally, since total technical efficiency scores are calculated as the ratio of

Table 3
Population density and farm performance

	Tapéré	Ouattaradougou	Farakoro	Tiégana
Population density (inhabitants/km^2)	14	17	28	40
Number of observations	21	34	35	35
Performance of the farms according to Malthus				
Yam yield (kg/cultivated ha)	9770	9758	8785	8219
Rice yield (kg/cultivated ha)	1301	1305	1288	940
Groundnut yield (kg/cultivated ha)	916	643	655	1040
Cotton yield (kg/cultivated ha)	–	1185	992	1004
Maize yield (kg/cultivated ha)	–	960	993	689
Gross margin (FCFA/AWU*cultivated ha)	242,229	189,729	157,359	173,381
Total technical efficiency (%)	73.5	73.5	59.9	53.3
Performance of the farms according to Boserup				
Yam yield (kg/usable ha)	1172	2342	2372	2548
Rice yield (kg/usable ha)	156	313	348	291
Groundnut yield (kg/usable ha)	110	154	177	323
Cotton yield (kg/usable ha)	–	285	268	311
Maize yield (kg/usable ha)	–	230	268	213
Gross margin (FCFA/AWU*usable ha)	31,713	41,021	39,836	50,788
Total technical efficiency (%)	65.7	72.4	64.9	60.3

Note: fixed conversion rate: 1 Euro = 656 FCFA.

weighted outputs over weighted inputs, the decline of yields and gross margins (Table 3) in combination with the increased fixed and external input costs (Table 2) translates into an overall decline of total technical efficiency. The efficiency scores in the first part of Table 3 suggests that farms in the most densely populated village, i.e. Tiégana, would have to decrease inputs by about 50% to be as efficient of the most efficient farms in the entire sample, or by about 20% to reach the efficiency level of the farms that are operating in the most sparsely populated village, i.e. Tapéré.

At the village level, our survey data seem to support the thesis of Malthus: decline of yields, gross margins and total technical efficiency under increasing levels of population pressure. However, in our sample different farming systems can be distinguished on the basis of cotton cultivation and the degree of mechanisation (Table 4). The manual YRG system is based on the ancient YRG cropping system and its derived systems. In the CRM system (mainly cotton and rice, based on manual farming), yam is gradually substituted by cotton. The CRA system (cotton and rice, animal traction) represents the mechanised version of the CRM system. Other manual farming systems are based on rice and monoculture of maize. How have these different farm types coped with increasing demographic pressure and does the analysis of farming systems support the thesis of Malthus?

In the seventh row of Table 5 we compare the economic performance of the observed farming systems. Other manual farming systems based on maize yield the smallest gross margins, due to the low price of maize. These systems primarily occur in the southern part of Dikodougou where maize is the staple food crop of the *Malinké* immigrants. Nevertheless, for the native people of the Dikodougou

Table 4
Typology of the farming systems in the Dikodougou region

	No cotton	Cotton
Manual farming	YRG (51), other systems (11)	CRM (13)
Animal traction	–	CRA (50)

Notes: number of observations between brackets. Y = yam, R = rice, G = groundnut, C = cotton, M = manual farming and A = animal traction.

region, yam is the preferred staple food crop. Here, the YRG system dominates as far as population pressure allows. This system features the highest profitability while it consumes a minimal amount of cultivated land. However, its sustainable reproduction requires low population densities.

The condition of low population pressure is not fulfilled everywhere. Migrations and religious wars have left their footprints on the geographic distribution of the population such that its density is far from being homogenous and differs considerably from one village to another (Table 1). Under increasing demographic pressure, usable area per unit of labour declines (Table 2) forcing the farmers to migrate, extend their cropping periods and/or cultivate a part of their fallow land. The ancient YRG system is in imbalance and a whole series of derived systems appear. Some of them are simply based on the extension of the 3-year cropping period, e.g. by doubling the cropping periods in the rotation (Table 2). As a result, sustainable reproduction of the ancient system is no longer possible and yields of the crops on top of the rotation gradually decline (Table 3). Only in sparsely populated villages such as Tapéré is the pure YRG 3-year rotation system observed. Since all observations in this village are based on this system, the results for Tapéré in Table 3 reflect the performance of the pure YRG-system, featuring the highest average gross margin among all observed farming systems.

Some innovators decide to substitute yam for another variety or another crop which is less demanding regarding soil fertility. Under increasing population pressure, the importance of yam decreases in relative terms, i.e. from 40% to 15% of the area (Fig. 1), but also in absolute terms, i.e. from 0.44 to 0.17 ha per family work

Table 5
Economic performance of the farms according to Malthus and Boserup

	Manual farming			Animal traction
	Other systems	YRG	CRM	CRA
Number of observations	11	51	13	50
Cultivated area (ha/AWU)	1.1	1.1	1.0	1.5
Usable area (ha/AWU)	5.1	6.9	4.1	6.3
Fixed costs (FCFA/AWU)	7635	9836	8062	25,917
Malthusian gross margin (FCFA/AWU*cultivated ha)	107,326	206,420	162,566	186,170
Boserupian gross margin (FCFA/AWU*usable ha)	28,750	36,249	40,726	50,568

Note: fixed conversion rate: 1 Euro = 656 FCFA.

unit. But also within the yam area, a shift towards less demanding varieties is observed. The share of the variety "Florido" in total yam area, for example, increases from 9% in Tapéré to 56% in Tiégana, due to its flexibility in the rotation cycle and planting time, the good storability and extended storage life of its tubers, and its resistance to most pests and diseases (Doumbia et al., 2004).

However, the Malthusian perspective is not free from criticism. Firstly, in the literature, indicators of economic performance of farms are typically estimated proportionally to the cultivated area. Comparing performance in terms of cultivated area means adopting Malthus' perspective, and, not surprisingly, uncovers typical Malthusian effects. Boserup contrasts with the Malthusian pessimism by taking into account farmers' agricultural practices. Farmers follow a production strategy in time and in space. Shifting cultivation and fallow are the result of farmers' historical observations and experiences such that too intensive and overly repetitive cropping cycles lead to soil exhaustion, weed proliferation and the development of pests and diseases. Fallow periods constitute efficient tools to attenuate these risks. This knowledge leads Boserup to reject the concept of "cultivated area" in favour of "total usable area" which integrates the totality of land contributing to agricultural production, i.e. cultivated and fallow land.

Boserup's perspective on agricultural performance fundamentally alters our conception of the dynamics of the farms in the Dikodougou region. The latter adapt to demographic pressure by increasing the value of their entire production area, i.e. including fallow land. In the second part of Table 3, we present the Boserupian indicators of farm performance. Expressed per unit of usable land, Boserupian crop yields and gross margins are increasing as a function of population pressure, rather than decreasing. In other words, per unit of return, farms consume less land. While Malthusian technical efficiency monotonically declines 20%, Boserupian technical efficiency does not follow this trend, displaying a small variation of maximum 12% and an overall decline of only 5% under increasing levels of population density. As a result, this evolution is not simply to be considered as a Malthusian decline of profitability, it also constitutes a Boserupian attempt to compensate for this decline and prevent any further erosion of profitability levels.

The final row in Table 5 suggests that the evolution of the ancient YRG system to the most specialised and mechanised CRA system translates into a progressive increase of Boserupian gross margins. Under the Boserupian perspective, the ancient YRG system is highly land-consuming and is only sustainable in the long run under low population pressure. If we move from the most sparsely to the most densely populated village, total usable land allocation of yam declines from 3.5 to 0.6 ha per family work unit, i.e. by a factor of 6. Hence, this decline is even more dramatic than the decline of cultivated yam area, mentioned before. This means that for yam alone, total land consumption per unit of cultivated land decreases from a factor of 8 to a factor of 4.

Secondly, the theory of Malthus ignores the effect of innovations, such as (i) the use of productivity-enhancing inputs and (ii) mechanisation, allowing farmers to escape the vicious circle of declining yields and increasing labour costs. According to Boserup, agricultural equipment is a "key indicator" of the evolutionary stage of an agrarian system. To assess and compare farm investment levels, we estimate the total annual depreciation costs of the equipment per unit of land (Eq. (1)) to reflect the real fixed production costs perceived by the farmer. The increase of farm investment levels under increasing population pressure, shown in Table 2, is in line with the thesis of Boserup. This increase is essentially the result of the increase in fixed costs related to the equipment of animal traction. The increasing intensification of cropping cycles progressively raises the labour costs of manual farming (land preparation, weeding and fertility restoration). The adoption of animal traction enables farmers to combine bedding and weeding operations, which dramatically smoothes down the labour peaks of manual farming (Pingali et al., 1987).

Cotton plays an important role in this observed evolution. This crop is not an innovation *per se* in northern Côte d'Ivoire, where it has been cultivated for a long time (SEDES, 1965). The innovation consists of new farming practices exogenously introduced, diffused and subsidised by the Compagnie Ivoirienne de Développement des Textiles (CIDT) since 1974: monoculture, sowing in rows, mechanisation and use of fertilisers, herbicides and insecticides. These external inputs allow an extension of the cropping period in response to increasing population pressure. This partly explains the correlation between population density, the importance of cotton in the cropping mix (Fig. 1) and the evolution of input use (Table 2). Nevertheless, food crops also benefit from this evolution as some farmers grow cotton to have access to inputs which are entirely or partly used for food crops. Hence, at the village level, our survey data seem to support the World Bank's "complementarity thesis" on the relation between food and export crops (Bassett, 1988a).

Anyhow, the adoption of cotton engenders a profound change of the traditional production system. However, field preparation and weeding tasks in cotton cultivation are highly labour-demanding and time-specific. As a result, the adoption of cotton in manual farming translates into a profitability drop (Table 5), as the average cotton price is lower that the average yam price, and there is an exacerbation of labour bottlenecks as cotton competes with food crops for labour. The result is that non-mechanised cotton farms (CRM) are generally smaller than traditional YRG farms and any sustainable reproduction of this system is severely limited. In the Dikodougou region, CRM systems are practised by the poorest group of farmers. These farms produce the lowest amount of calories, barely covering the nutritional requirements of the household (Stessens, 2002). Hence, for manual cotton farms, our survey results do not support the World Bank's "complementarity thesis". In this stage, the evolution of farming systems is typically characterised by Malthusian effects and, accordingly, we generally observe migration, i.e. Malthusian natural control of population, rather than Boserupian intensification.

However, by cultivating cotton the farmer aims at accumulating revenue to finance the investment in animal traction equipment, which translates into a 3-fold increase of the fixed costs (Table 5). This innovation allows smoothing down the labour peaks of manual cotton farming (Bassett, 1988b; Stessens, 2002). Thanks to the switch from manual farming to animal traction, farmers are able to surpass the technical limits of manual farming and increase the cultivated area per unit of labour considerably. Some refer to this Boserupian response as "agrarian transition", representing sustainable management of resources as a function of increasing levels of population density through an U-shaped curve (Jouve, 2004).

During the Boserupian agrarian transition, access to labour plays a crucial role. According to a probit adoption analysis, farms endowed with abundant labour forces adopt animal traction with a significantly higher probability (Stessens, 2002). In densely populated villages, the emergence of a small group of large and highly specialised CRA farms is observed. Due to unequal land distribution, some of them are able to expand their cultivated area to 2.2 ha per annual work unit, owing to the use of external wage labour. This expansion accentuates the emerging polarisation in the village, especially in the southern immigration region where social control is weaker than in the northern native villages. In the future, due to strengthening of land property rights, two new social classes might emerge: (i) the landowners and (ii) the agricultural labour force recruited by the first group. But these are long-term trends; in the short run, farmers in northern Côte d'Ivoire continue to migrate in search of uncultivated land.

5. Conclusions

A survey of farms in northern Côte d'Ivoire offers an interesting perspective on the theories of Malthus and Boserup. First, the two theses coexist rather than contrast. In a first stage, demographic pressure engenders Malthusian mechanisms (degradation of biophysical environment, proliferation of weeds, decline of fertility and profitability of the ancient production system) leading to migrations and, hence, Malthusian natural population control. However, at the same time favourable conditions are created for Boserupian intensification of cropping systems, and mechanisation of labour tasks, through the adoption of animal traction.

In a second stage, the change of the production system clearly illustrates the Boserupian response to a situation where the traditional system is not adapted anymore to its changing socioeconomic environment (increased demographic pressure and decline of the land–person ratio). Our survey data reveal how farmers respond to an increase of population pressure. Access to labour is the key factor that enables farmers to escape Malthusian mechanisms and adopt innovations that are crucial for the sustainable reproduction of the transforming farming system. The Malthus–Boserup debate can be partly reduced to a divergence of opinions concerning the comparative analysis of farm performance. Following Boserup, we propose total usable area as the correct denominator of the true economic performance perceived by farmers operating under shifting cultivation systems in Sub-Saharan Africa.

Our case study suggest that Boserupian innovation in both the scale of operation, e.g. through animal traction and improved cropping techniques, and intensification, e.g. through the use of external inputs (herbicides, insecticides and fertilisers), has been largely able to compensate for the Malthusian repercussions of increasing demographic pressure. However, the process of Boserupian agrarian transition only seems to be unleashed when a critical population density of about 30 inhabitants per km^2 or a land use intensity of about 30% is attained. At this threshold, population pressure seems to be constrained by Malthusian principles of population control, i.e. migration. Up to date, owing to unequal geographic distribution of population in the Dikodougou region, the option to migrate has always been kept open. Young and dynamic northern farmers with large families progressively colonise sparsely populated areas in order to extract the rents of freshly exploited fertile land. Remote from social control in their native villages, these farmers intensify their cropping cycles in order to achieve short run objectives, i.e. accumulating revenue and appropriating land, jeopardising the long-term sustainability of the transforming farming system.

As long as the option to migrate is kept open, Malthusian population control will generally dominate Boserupian mechanisms of induced innovation. However, with a pioneer front moving at a speed of 2 km per year and an annual population growth of 1.5% in 2004 (World Bank, 2006), in the long run it is expected that the saturation of sparsely populated regions will induce intensification and mechanisation in farming systems in northern Côte d'Ivoire. Finally, taking into account an urbanisation level of 45%, the agrarian transition in Côte d'Ivoire will not only be induced by local demographic pressure, but also by the increase of urban food, feed and fibre demand, and the development and expansion of marketing systems.

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References

Bassett, T., 1988a. Development theory and reality: the World Bank in northern Côte d'Ivoire. Review of African Political Economy 41, 45–59.

Bassett, T., 1988b. Breaking up the bottlenecks in food crop and cotton cultivation in northern Côte d'Ivoire. Africa 58 (2), 147–174.

Boserup, E., 1965. The Conditions of Agricultural Growth. George Allen and Urwin, London.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. European Journal of Operations Research 2, 429–444.

Demont, M., 1998. La trajectoire d'évolution des systèmes de production Sénoufo: Le cas de Dikodougou, Nord Côte d'Ivoire. Master Thesis, Ghent University and Centre National d'Etudes Agronomiques des Régions Chaudes (CNEARC), Ghent and Montpellier.

Demont, M., Jouve, P., 2000. Évolution d'agro-écosystèmes villageois dans la région de Korhogo (Nord Côte d'Ivoire): Boserup versus Malthus, opposition ou complémentarité? In: Jouve, P., Cassé, M.-C. (Eds.), Dynamiques agraires et construction sociale du territoire, Actes du séminaire, 26–28 avril 1999, Montpellier, France. CNEARC/Université Toulouse Le Mirail, Montpellier, pp. 93–108.

Doumbia, S., Tshiunza, M., Tollens, E., Stessens, J., 2004. Rapid spread of the Florido yam variety (Dioscorea alata) in Ivory Coast: introduced for the wrong reasons and still a success. Outlook on Agriculture 33 (1), 49–54.

Färe, R., Grosskopf, S., Lovell, C.A.K., 1985. The Measurement of Efficiency in Production. Kluwer-Nijhoff, Boston.

Jouve, P., 2004. Transition agraire et résilience des sociétés rurales. Courrier de l'environnement de l'INRA 52, 101–106.

Jouve, P., Tallec, M., 1996. Une méthode d'étude des systèmes agraires en Afrique de l'Ouest par l'analyse de la diversité et de la dynamique des agrosystèmes villageois. In: Budelman, A. (Ed.), Agricultural R&D at the Crossroads: Merging System Research and Social Actor Approaches, Royal Tropical Institute (KIT), Amsterdam, pp. 43–59.

Le Roy, X., 1983. L'introduction des cultures de rapport dans l'agriculture vivrière Sénoufo: Le cas de Karakpo (Côte d'Ivoire), ORSTOM, Paris.

Malthus, T., 1798. An Essay on the Principle of Population. Printed for J. Johnson, in St. Paul's Church-Yard, London.

Mathijs, E., Swinnen, J., 2001. Production organization and efficiency during transition: an empirical analysis of East German agriculture. The Review of Economics and Statistics 83 (1), 100–107.

Pingali, P., Bigot, Y., Binswanger, H.P., 1987. Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa. John Hopkins University Press for World Bank, Baltimore.

Ruthenberg, H., 1980. Farming Systems in the Tropics. Clarendon Press, Oxford.

SEDES, 1965. Région de Korhogo: Etude de développement socio-économique. SEDES, Paris.

Stessens, J., 2002. Analyse technique et économique des systèmes de production agricole au Nord de la Côte d'Ivoire. Doctoral Dissertation, Katholieke Universiteit Leuven, Leuven.

World Bank, 2006. Key Development Data & Statistics. Online database accessible from http://www.worldbank.org.