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Environmental Damages Versus Economic Performance, Sustainability of Guadeloupean Banana Cropping Systems in Question: an Emergetic Approach

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ABSTRACT.

Banana is an important agricultural commodity in Guadeloupe (French West Indies) and, to increase their competitivity in the international market, banana growers have intensified their production systems during the last fifteen years by increasing the use of man-made technological inputs. Such intensification strategies, that require investment increases, are economically and environmentally risky. In order to assess the environmental performance of banana production in Guadeloupe, emergy synthesis methods were applied to six different types of banana cropping systems previously identified in the island. Additionally, aiming at improving farmers decision making, environmental performance results were compared with economic analysis for each cropping system. These analyses showed that the better the environmental benefit of any cropping system, the worse its economic performance. This main result was corroborated by an increased contrast among cropping systems as related to their dependence on purchased inputs, although all of them are based on the same intensive and arguably wasteful agricultural model. Therefore, the analysis point out that sustainable banana production in Guadeloupe depends on a shift from the high fossil imported input model to a local renewable resources intensive one. In this sense, emergy flow analysis shows that innovation towards environmentally sound practices that would enhance nutrient cycling; integrate weeds, pests and diseases control; and improve the banana packing process might result most positive impacts on overall sustainability. Economic analysis showed that the high labour costs contribute largely to the dependency of banana production on public subsidies. Nevertheless, reorienting the current European agricultural income policy to an environmental performance-based subvention might represent an opportunity to achieve the present social goals while promoting sustainability in banana production.

KEYWORDS: Banana; Guadeloupe; Cropping Systems; Environmental impact; Agricultural Economics.

INTRODUCTION

Banana production is a major crop for local economy and contributes to the typical landscape of Guadeloupe. It represents 24% of local agricultural production, 12% of the total cultivated area, and generates about 5,000 direct jobs (Insee, 2001) in this caribbean french island. This sector is facing severe environmental and economic crises (Dulcire and Cattan, 2002), mostly due to a market liberalization that has prevailed during the last fifteen years, causing the price of banana to decline by an average rate of 1.4% per year (Arias et al. 2003; FAO, 2003a) and compelling farmers to intensify their production systems in order to maintain their income (Heuze, 2005; Perret and Dorel, 1999). Looking for higher productivity, farmers increment the use of technological inputs such as intensive use of machinery, fertilizers, pesticides, and irrigation, that push energy flows through the agroecosystem to unsustainable levels (Giampietro et al., 1992a,b). In Guadeloupe the systematic use of ploughing and pesticides has lead to chronic contamination of soils and waters by organochlorine compounds (Bonan and Prim, 2001). The reported contamination problem has in turn contributed to a decrease in soil biological diversity and consequent reduction in fertility (Clermont Dauphin et al., 2004), while contaminating drinking water sources (Bonan and Prim, 2001).

In order to align banana cropping systems in Guadeloupe with societal requirements for environment friendly production, and to develop actions towards sustainable cropping systems, new assessment tools are necessary to highlight innovations that would effect most significant and positive impacts. Agriculture operates at the interface between nature and the human economy, and relies on a combination of natural and economic inputs to produce goods. Therefore, both economic and environmental contributions need to be accounted in equivalent terms when comparing resource uses in agricultural systems (Campbell, 1998).

The goals of the present study are: i) to compare the different banana cropping systems observed in Guadeloupe (FWI), with regard to resource use, productivity, environmental impact, and overall sustainability; ii) to evaluate the emergy signature of the banana production as a whole in the region; iii) to contrast an ecocentric analysis (emergy) with an anthropocentric analysis (economic) of the banana cropping systems and observe their respective tradeoffs; and iv) to highlight points where innovations might result in greater improvements towards overall sustainability of banana cropping systems in Guadeloupe.

MATERIAL AND METHODS

In order to organize the diversity of existing banana cropping systems at the regional scale for emergy and economic analysis, a typology was applied according to three different dimensions: 1) Environmental: expressed by rainfall regime, solar radiation, soil category, and topography; 2) Technical: expressed by broad agronomic management aspects, and 3) Economic: expressed by financial input and output balances. Each cropping system type consolidated according to this typology regroups all individual farmers with high degree of similarity for all three dimensions. For the purposes of this study each type has been translated into an hypothetical farm that represents the average for all farms included in it. The cropping systems typology was based on farmers'interviews comprising 45 description variables for the three aforementioned dimensions. The statistical process for the typology comprised two consecutive steps. A Principal Component Analysis (PCA) then an Agglomerative Hierarchical Clustering treatment (AHC). The validity of the system of types obtained has been thereafter assessed by applying analysis of variance to the initial quantitative variables and a Discriminant Analysis (DA) to the qualitative ones (Blazy et al. 2008). Financial performances of the different cropping systems have been assessed by a set of economic indicators calculated from the average results for each type. These economic indicators were net income as the financial surplus over costs, profitability rate and the productivity of work measured as the surplus-value obtained from labour.

Emergy analysis is based on the works of Odum (1996), Ulgiati and Brown (1998) and Brown and Ulgiati (2004a, b). The procedure begins by drawing system diagrams to identify all inputs, outputs and internal components for the studied system. The studied banana cropping systems have been subdivided in two subsystems: subsystem I refers to the banana field and includes operations of fertilization; weed, disease and pest control; plant anchorage and bunch covering, and labelling; while subsystem II reports on the operations related to harvesting, sorting, packing and transporting bananas to market or port for export. This division corresponds to the usual rationale of banana production in Guadeloupe.

After quantifying annual flows for each component and cropping system in physical units (i.e., joules, grams, US$), these values were translated into emergy units (seJ) through previously calculated transformities for each item. For some components and products, different transformities had been derived in different contexts, so the transformity calculated under the most similar conditions to those observed in the studied situation has been selected (Lefroy and Rydberg, 2003). Furthermore, each component or production item was classified whether it is an endogenous resource (L) or a resource purchased from outside (P), whether it is a renewable (R) or non-renewable resource (N) or an exported product (Y). The percentage of renewable and non-renewable emergy supporting labour was determined based on previous studies (Ulgiati et al., 1994). In Sweden and Italy, 87 and 90%, respectively, of the emergy supporting labour was provided by non-renewable sources (Panzieri et al., 2002; Rydberg and Jansen, 2002). As the living standards in Guadeloupe are similar to those observed in European countries, 87% of the emergy supporting labour was assumed to be nonrenewable. In order to make the flows easily comparable among cropping systems and facilitate calculations, the amounts of the different components and items have been normalized both for area (1 ha) and time (1 year), for the various cropping systems studied. On the other hand, when the emergy synthesis of the overall banana production system was analyzed, the flows were expressed for the total area cropped with banana in Guadeloupe (2,350 ha), according to FAO (2008) and weighed by the respective area fraction for each cropping system type. Several performance and sustainability indices have been calculated for the different cropping systems. These indices were derived in Ulgiati et al. (1994), Odum (1996), and Ulgiati and Brown (1998) and summarize systems resource use intensity, process efficiency, economic-environment interactions and quantify sustainability.

RESULTS

Renewable flows (sunlight, wind, rainfall geopotential energy and rainfall chemical energy) were expressed for the emergy accounting of banana cropping systems mostly as evapotranpiration, which is the largest flow and integrates sunlight-derived flows. Little variation was observed in the inputs of renewable resources between the different banana cropping systems, mainly because of the high rainfall regime in all regions cultivated with banana in Guadeloupe (between 2.6 and 4.6 m, evenly distributed yearly rainfall average). As a consequence, crop evapotranspiration is near maximum and no water stress is generally experienced. Hence, as evapotranspiration (the main item of renewable flows) is similar among cropping systems, overall renewable flows are also similar. Differences were observed mainly in the fraction of human labour and organic matter amendment from discarded bananas attributed as a renewable source. Actually, only the type III cropping system farmers return the non-commercialized bananas as organic matter amendment to their fields, which means an additional emergy input of about $13.08E^{+13}$ $sej.ha^{-1}.year^{-1}$. Non-renewable resources used included important flows referred to soil erosion, which varied from 0.98 up to $6.19E^{+13}$ $seJ.ha^{-1}.year^{-1}$. The low levels of non-renewable emergy flow caused by soil erosion in the studied cropping systems are explained by the fact that banana crops provide good soil coverage (high leaf area index), and are cultivated mainly in the Andisols and at a lesser extend in Ferralsols areas of Guadeloupe.

The main differences between the cropping systems studied were observed in the use of purchased resources that varied 3 folds from the lowest value ($1.86E^{+16}$ seJ.ha-1.year-1 for type V) to the largest flow observed ($6.25E^{+16}$ seJ.ha-1.year-1 for type III) reflecting the cropping intensity levels observed in the typology. In spite of these differences, all banana production systems in Guadeloupe may be considered as highly dependent of purchased resources, since these represent between 89 and 96% of the total emergy use. When the overall banana production sector is considered, the emergy flow due to purchased resources nears the maximum value of 95%, because cropping systems types III and IV alone respond for 74% of the banana cropped surface. Of the purchased emergy inputs, between 37 and 46% is invested in the process of harvesting, sorting, packing and transporting the harvested products (Subsystem II) which represented an overall average of 39% of emergy flows among cropping systems. From this share, the largest amount is invested as emergy flow in financial resources for buying card boxes for packing. Actually, the card boxes represent the largest single item of emergy inputs for all systems studied except for the type V. Regarding the field operations (Subsystem I), the largest purchased resources are the fertilizers.

The emergy allocated to banana yield in the banana cropping systems in Guadeloupe varied 3.11 times from the lowest value observed of $2.10E^{+16}$ $seJ.ha^{-1}.year^{-1}$ (type V) to $6.52E^{+16}$ $seJ.ha^{-1}.year^{-1}$ for type III, resulting in transformities that showed little variation from $2.36E^{+05}$ to $3.15E^{+05}$ $seJ.J^{-1}$. As a whole, a total of $1.09E^{+20}$ seJ are assigned to the production of the $8.36E^{+04}$ tons of bananas, of which $7.85E^{+04}$ tons are placed in the market resulting in an overall transformity of $2.89E^{+05}$ $seJ.J^{-1}$. These transformity values for banana production in Guadeloupe are comparable to the $2.87E^{+05}$ obtained for fruit production (as an average) in Italy (Ulgiati et al., 1993); and the $5.97E^{+05}$ value obtained for tomatoes in Florida (Brandt-Williams, 2002), both representing intensive fruit production systems for which similar processing steps for market insertion can be assumed. By contrast, fruit production systems with much smaller ($7.03E^{+04}$ for oranges in Florida, Brandt-Williams, 2002) or much larger

($5.40E^{+06}$, tomatoes in Sweden, Lagerberg, 2000) transformities are related, respectively, to lesser or greater levels of purchased input flow and productive intensity.

The results obtained for the different economic performance indicators of banana production in Guadeloupe indicate that the sector is able to survive as an economic activity only due to important governmental subsidies. Subsidies account for the totality of net income, while covering all net financial losses, for all cropping system types and farmer classes, and correspond to about 50% of farmers' gross income. Although all cropping system types would show net financial losses without subsidies, losses decrease with increasing investment in technological inputs. Profit rates increase from 4% for type V up to 41% for type III when subsidies are included as gross income. In the same trend, labour productivity increases with increasing input use. Although subjected to a 49% higher labour cost – US$ 83.62 and US$ 56.20 per man day for types III and V, respectively the most intensive farm type III produces about US$ 1.00 of net income for each dollar invested in labour while type V (the less intensive one) produces only US$ 0.08. The large differences observed in the costs per unit of labour (from US$ 50.91 to US$ 86.93) are basically explained by differences in the family workforce engagement, representing the percentage of labour provided by family members, considered costless in the farm budget analysis. Production costs of banana in Guadeloupe is high, varying from US$ 0.60 for type V to US$ 0.71 per kilogram for type I and labour represents the most important single factor in production costs. On average, 48% (varying from 40% for type III to 55% for type V) of the costs to produce each kilogram of banana is expended in labour. This represents an average of US$ 0.31 (from US$ 0.25 for type III to US$ 0.35 for type I) labour expenditure per kilogram of banana exported. The high labour costs may explain the dependency of the banana sector on public subsidy. On average, the market price obtained by the farmers is US$ 0.37 per kilogram of commercialised banana. This value is very close to the US$ 0.31 expended in labour costs alone.

DISCUSSION

Banana production in Guadeloupe is heavily dependent on purchased inputs. The fraction of renewable emergy flow varies from 4.05 to 10.9% according to cropping system type, and an overall average of 5.19% was estimated. Considering only the subsystem I (field operations), the renewable fraction increases to 9%, varying from 6 to 20% depending of the cropping system type. As most input-intensive agricultural systems, banana production in Guadeloupe depends heavily on fossil energy in the form of fertilizers and pesticides. Together, these two kinds of inputs respond to 31 and 43%, respectively, of all emergy flows in subsystem I. In fact, together with water, nutrients are key limiting factors for crop production (Pimentel & Pimentel, 1996) and the application of chemical fertilizers generally results in yield gains. This trend has been clearly observed in this study since a linear relationship between banana yield and emergy inflow through chemical fertilizers has been estimated. However, emergy investment in chemical fertilizers reflects negatively on sustainability, as expressed by the ESI. A similar trend is observed in relation to pesticide inputs. A clear trade-off exists between producers' interest on increased yields and income and the sustainability of their fields. Therefore, innovations in cropping techniques that would enhance nutrient cycling and the control of weeds, pests and diseases through management options such as cover-crops, buffer vegetation zones in the landscape, among others might represent promising practices to promote an adequate compromise between farmers' economic interests and systems sustainability, in a future scenario of limited access to fossil-origin resources. Farmers of cropping system types V and VI are the less dependent on purchased inputs. The renewable fraction in the subsystem I of these farmers reaches 17 and 20%, respectively. In fact, type V cropping system returns 26% of the invested flow of purchased emergy in the form of renewable resources emergy flow in the field (subsystem I). This rate decreases to 13% when the subsystem II is included, as this subsystem uses only purchased resources. As cropping systems types III and IV are at the same time the most dependent on purchased inputs, and respond to the largest share of banana production in Guadeloupe, the EYR of the overall banana production is as low as only 9 and 6% for subsystem I only, and subsystem II included, respectively.

Large differences were observed in the emergy invested in fuels and lubrificants across all types of cropping systems varying from 0.77 to $5.83E^{+15}$ $seJ.ha^{-1}.year^{-1}$ for types V (and VI) and IV respectively.The use machinery (and fuels) in agricultural production is intended to replace human labour and therefore to increase labour efficiency measured as the amount of harvested product per man day invested. Considering energy invested in work as the sum of energetic flows of human labour plus the energetic flows of fuels, the available energy of the harvested product per unit of energy invested in work increases as the contribution of the human labour in the energy invested in work increases. However, each joule expended on fuels costs US\$ $4.31E^{-08}$, while each joule of human labour costs US\$ $1.82E^{-05}$ (calculated by the average prices of diesel and labour in Guadeloupe). Hence, for the same quantity of energy used, human labour costs 422 times more than fuels. This result demonstrates that although human labour is more efficient in converting energy into work than machinery, it is financially more interesting for farmers to invest in mechanization because fuel is an energy source much less expensive than labour.

The largest environmental loading ratio (ELR) among all cropping system types was observed in type III. Taking ELR is a measure of the ecosystem stress due to production (Ulgiati and Brown, 1998) - because most purchased resources cause environmental degradation during their production, use and environmental assimilation (Martin et al, 2006) - the global environmental impact caused by cropping system type III is 4 times higher than that observed for type V. As the larger ELR are observed among the cropping system types that correspond to the larger surfaces of production in Guadeloupe, the ELR of banana production in this island is 18.28, which is higher than the ELR observed for the French economy, estimated as 5.19 (SAHEL, 2008). This clear unbalance between the amount of non-renewable (including purchased) and renewable resources for banana production, with strong dependence on purchased resources, reflects an important degree of potential environmental stress. In general, the processes of harvesting, sorting, packing and transporting contribute to nearly 40% of the total emergy of banana production, varying from 38 to 45% according to cropping system type. Of this share, the highest contribution comes from the card boxes used to pack the product which, alone, respond to about half of emergy used in the subsystem II. As these boxes are a one-way use material, substantial improvements in the sustainability of the banana production in Guadeloupe could be achieved by replacing them by more durable ones that could be used several times. All banana exports from Guadeloupe have the European Community as destination. There, quality standards for bananas are normalized. This regulation impacts strongly on the sustainability of banana production. For instance, established quality standards for bananas rely basically on aesthetic aspects of the product, and most of the discarded bananas have the same organoleptic and nutritive characteristics as the marketed ones. Comparing the emergy-net income ratio (ENR) and the rate of discarded bananas, it is possible to realize that the economic sustainability of farmers would be improved in direct proportion with the marketed production. Therefore, an acceptance for a product with the same nutritional and taste qualities but with aesthetic characteristics slightly out of the standards would represent a step towards sustainability of the sector. Furthermore, substantial non-renewable and purchased emergy inflows in banana production aim at increasing the compliance with aesthetic quality regulations and not necessarily improve productive efficiency.

Banana production in Guadeloupe depends on EU subsidies to remain in business (Frémeaux, 2003). Alone, the activity consumes 70% of all public subsidies paid to agricultural production in Guadeloupe, which is disproportional with spatial and economic weight in the region (Chia and Dulcire, 2005). On average, production costs are 81% (varying from 34% for cropping system type III to 145% for type V) higher than returns paid by the market, and this difference is been covered by public subsidies. This dependency on the EU agricultural income policy may be explained by the high costs of production. While the average banana production costs amount to around US$ 0.17 per kg in Costa Rica, US$ 0.16 in Equator, and US$ 0.20 in Colombia (Paggi and Spreen, 2003), the cost in Guadeloupe was estimated as US$ 0.65 per kg in the present study (average of all cropping system types), close to the US$ 0.67 per kg reported by Paggi and Spreen (2003) for Martinique, another French overseas department. The key factor explaining this much higher production costs in Guadeloupe seems to be the high cost of labour. Actually, labour costs in Guadeloupe represent 48% of the total costs of banana production on the average of all cropping system types (varying from 40% for type III to 55% for type V) while in Costa Rica it represents 28%, in Equator 31% and in Colombia 39% (calculated from Little, 2000). Additionally, while each kg of banana produced in Guadeloupe needs an average investment of US$ 0.31 in labour, only US$ 0.05 is necessary in Costa Rica and Equator, and US$ 0.08 in Colombia (calculated from Little, 2000). Therefore, to increase profits (including subsidies), farmers should increase the productivity of labour. The higher the investment in external inputs, the higher the profit and the productivity of labour. Hence, following the current agricultural model adopted by Guadeloupean banana growers, improvements in economic performances depend on the rate of investment in external inputs. However, Pimentel and Giampietro (1994) stated that though human-made technological capital such as fertilizers, pesticides, and irrigation may be used to substitute for natural capital to increase yields, as well as to substitute for human labour to increase labour productivity; the heavier use of technological inputs causes environmental damage and push energy flows through the agroecosystems to unsustainable levels (Gianpietro et al., 1992a,b). Increasing the investment in external inputs increases yields, profits and labour productivity but, at the same time, it reduces FR (fraction renewable) and ESI while increasing ELR. As a general rule, the better the economic performance of banana production in Guadeloupe, the worse is the environmental performance. This result is most probably due to the fact that though differing in the amount of purchased inputs, all cropping system types follow the same intensive and arguably wasteful agricultural model. This approach is being presently strongly criticized due to its reliance on non-renewable resources. Therefore, the improvement of sustainability of banana production in Guadeloupe will depend on a change of the agricultural model used, shifting from a high fossil input model to a natural resources intensive one that enhances the contribution of local renewable resources.

Several initiatives are on-going elsewhere to endorse the adoption of environmentally friend cropping systems for banana and other crops. However, such efforts are still not in the banana production agenda in Guadeloupe. In order to promote such change in the agricultural model, innovative cropping systems with environmentally sound practices have to be developed and the innovations adopted by the farmers. Innovation adoption, however, will depend on their financial attractiveness. This represents an opportunity to reorient current European agricultural income support policies and may lead to a system of subsidies based on environmental performance, and hence decoupled from agricultural commodity production levels, albeit likely to reward most of the same farm political constituency (Zinn, 2005; Swinton et al., 2006).

CONCLUSION

As emergy analysis quantify natural and man-made, as well as renewable and non-renewable inputs to agricultural systems on a common basis, it helps comparison across different cropping systems and allows the identification of the critical elements to be improved in order to achieve greater sustainability. In the present case, emergy indices show that banana production in Guadeloupe has very low environmental performance and that, as a general rule, increases in environmental performances would imply decreases in yields, profits and labour productivity. The most probable reason is that the six different types of banana cropping systems identified in Guadeloupe, represent simply a gradient in the use of purchased inputs following the same intensive model. This model prises the augmentation of land and work productivity by the use man-made technologies in the form of fertilizers, pesticides, machinery, and other purchased resources associated to financial investment and potential environmental damage, due to reliance on non-renewable resources. Therefore, innovative production systems based on ecologically intensive cropping techniques are necessary to improve the sustainability of banana production in Guadeloupe. The emergy analysis of the different banana cropping system types highlighted several points were environmentally sound innovations would effect most positive and significant impacts. First, fertilizers and pesticides alone are responsible for 74% of all emergy flows in the field operations and therefore, cropping techniques aiming to enhance nutrient cycling; and weeds, pests and diseases integrated management should be regarded as priorities. Second, although field practices are more frequently emphasized and criticised, the processes of sorting, packing and transporting represent 40% of the total emergy in the banana production system. The one-way card boxes used to pack the product correspond to near half the emergy used and, hence, improvements in the material used for packing bananas may have significant positive impacts on overall sustainability. And last, the EC regulation on quality standard for commercial bananas, by imposing strict aesthetic benchmarks, have a negative effect on the sustainability of banana production because substantial non-renewable and purchased emergy inflows into banana production systems aim to improve aesthetic standards over sound ecological management. Besides, an acceptance for a product with the same nutritional and taste qualities but with aesthetic characteristics slightly out of the established standards would increase the ENR and therefore the financial profit of farmers. The economic analysis shows that, under the current agricultural model, increasing investment in external inputs would lead to increased profit and labour productivity. Nevertheless, the sector depends heavily on EU subsidies. This dependency stems from higher production costs, mostly related to high labour costs. Agricultural subsidies aim to promote equity in income levels between agriculture and other sectors of the French society and are therefore a political instrument for the country's and for Europe's social cohesion. However, as subsidy is coupled with banana production levels, it encourages farmers to intensify their cropping systems in order to increase yields. This intensification, however, brings potential environmental damage. Therefore, a reorientation of the European agricultural income support policies towards a system of subsidies based on environmental performance would be an opportunity to enhance the adoption of ecologically intensive agricultural innovations, while warranting and reinforcing their economic and social goals.

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