Conversion of specialised dairy farming systems into sustainable mixed farming systems in Cuba

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Abstract From the 1960s onwards, a ‘High External Input’ dairy production model was applied widely in Cuba. Overall milk production of the national herd increased considerably, but the system was inefficient from both a financial and energetic point of view. In the early 1990s, after the abrupt end of inflow of capital and other resources from Eastern Europe, the dairy sector collapsed. In the short term, the modern infrastructure of milk production deteriorated and the sector experienced profound vulnerability. However, in the longer term, this situation stimulated a search for more sustainable approaches, such as low external input Mixed Farming Systems (MFS). The current study aimed to evaluate two small scale prototype farms to assess the implications of converting ‘Low External Input’ Dairy Farming Systems into MFS. Fifteen agro-ecological and financial indicators were

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selected and monitored over a 6-year period. Two configurations of MFS, i.e. the proportion of the farm area occupied by arable crops, were tested: 25 and 50%. Productivity, energy efficiency and cost-effectiveness all improved following conversion. Total energy input was low for both farms and decreased over time, whereas energy efficiency was high and increased over time. Human labour input was high directly following conversion, but decreased by one-third over the 6-year period. This study demonstrates, at an experimental scale, the potential of MFS to achieve ecological, productivity and financial advantages for dairy production in Cuba.

Keywords Agroecological indicators · Crop–livestock integration · Energy efficiency · Farm finance · Livestock production · Low external input

1 Introduction

From the 1960s until 1990, cattle husbandry in Cuba was based on specialised ‘High External Input’ systems, in which advanced technology was applied to produce milk in intensive, industrial systems and development strategies were focused on three fundamental aspects: genetics, infrastructure and feeding (Pérez 1999). As a result, national milk production increased to about 1 billion (10^9) litres annually (ANPP 1991). However, production was inefficient, both financially and in terms of energy (Monzote et al. 2002). It has been estimated that in the 1980s, at the peak of industrial livestock production, the ratio of energy output to energy invested was 0.17, i.e. only one-sixth of the energy input was exported in the form of milk and meat (Funes-Monzote 1998). The major components contributing to the energy inputs were fertilisers and pesticides (40%), followed by molasses and other by-products from the sugar industry (25%), concentrates (20%), fuel (14%) and human labour (1%).

The ‘High Input’ model of livestock production was economically viable because of the favourable terms of trade with the socialist countries in Eastern Europe, in particular with the USSR. However, following political changes in the socialist block, Cuba plunged into a serious economic crisis (Funes et al. 2002). Moreover, the intensive livestock production systems, in combination with large-scale monoculture of industrial crops, had led to extensive deforestation, soil erosion and loss of biodiversity (CITMA 1997).

Awareness of the financial and energy inefficiency of the industrial specialised livestock production systems and of their negative environmental impacts, combined with increasing scarcity of capital and other inputs, triggered the development of new approaches in animal husbandry, aimed at on-farm feed and food self-sufficiency. The problems also challenged researchers to search for more efficient and environmentally sustainable milk and beef production systems (Monzote et al. 2002). In this search, various approaches have been attempted in order to develop more sustainable and self-sufficient cattle production systems, such as grass–legume associations, legume protein banks, silvo-pastoral systems, biofertilisers and selection of pasture species adapted to different regions. However, the main constraint for success was their isolated application and, in most cases, the lack of an integrative system perspective in technology development. A systems approach to development of a more productive and sustainable model of livestock production, based on principles of mixed farming, appeared a promising method.

Suitable environmental conditions for development of mixed farming systems (MFS) in tropical countries such as Cuba, include the high potential for biomass production because of the possibility of year-round production of highly productive (C_4) species and the high

diversity of species with potential use for agriculture. These natural advantages, exploited through the use of high-yielding energy and protein crops and the inclusion of multipurpose leguminous trees, allow the design of promising crop–livestock systems. Such MFS have been widely developed in situations where either environmental conditions or socio-economic conditions were conducive (Van Keulen and Schiere 2004). In less-favoured areas, lack of external inputs often forced farmers to adopt MFS to make a livelihood from the limited available natural resources (Altieri 2002; Pretty et al. 2003; Van Keulen 2005). MFS have also been developed in more favourable environments with market-oriented systems, mainly under pressure of socio-economic (boundary) conditions (Lantinga et al. 2004).

Despite many examples of successful diversified ‘Low External Input’ systems, in Cuba it appeared difficult to convert the large monoculture farms into smaller-scale integrated systems. Low population densities in the rural areas, lack of capital and other inputs and the absence of appropriate infrastructure for smaller-scale livestock production were major constraints. It also appeared difficult to convince the Cuban authorities (particularly the Ministry of Agriculture) of the need for MFS, not only as an ‘alternative’, but as a ‘leading’ strategy for future development of the livestock sector. This could be due to the scarcity of local data. Long-term studies are necessary to gain understanding of the performance of MFS, as well as for evaluation of different combinations of crops and animals in a spatio-temporal framework.

To support this strategy, the current study was designed as the first stage of a broader project at the national level. It aimed to evaluate the conversion of a ‘Low External Input’ dairy farming system (DFS) into an MFS by monitoring the dynamics of 15 agro-ecological and financial performance indicators (AE&FIs) over a 6-year period. The final goal is to identify potential integrated strategies for mixed farming, as a basis for sustainable livestock production in Cuba.

2 Materials and methods

2.1 Experimental site

The study was carried out between 1995 and 2000 at the Pastures and Forage Research Institute (IIPF), located in Western Havana City. The soil is a Haplic Ferralsol (eutric, clayic, rhodic) (WRB 2006) or Ferralítico rojo típico eutricto in the Cuban classification system (Hernández et al. 1999). Annual precipitation at the experimental site ranged from 1,300 to 1,500 mm, of which about 70% fell between May and October (rainy season). Mean temperatures were 26.9 and 23.3°C in the rainy and dry season, respectively. Average relative humidity was between 82 and 85%, with the highest values during the rainy season.

2.2 Experimental design

Two prototype mixed farms of one hectare each were established on the pasture area of a 15-ha specialised dairy farm, previously managed for about 5 years with low external inputs (i.e. fertilisers, concentrates, fuel, machinery) and low levels of productivity (yields of about 1.5 Mg milk ha⁻¹ year⁻¹). For the purpose of this study, the data collected during the last year of operation of that farm, representing a typical dairy unit for the country, were set to year 0 of conversion. In the two mixed farms, 25% (C25) and 50% (C50) of the

total farm area, respectively, was devoted to arable crops. Descriptions of the mixed farm designs and management practices are given in Fig. 1. The livestock sub-systems included pure grass (A_1) and grass–legume associations (A_2) in both C25 and C50, while a silvo-pastoral system (A_3) was established in C25. Legumes in A_2 were established by band-sowing at 25 cm distance in the original swards with minimum tillage (Monzote 1982), and the silvo-pastoral system by planting leguminous trees in A_3 . Field A_1 in C50 was replanted with king grass (*Pennisetum purpureum*, Schum.) after plowing down the original sward and establishing living fences of leucaena [*Leucaena leucocephala*, (Lam.) de Wit.]. The forage areas in the livestock sub-systems (B_1 and B_2) of C25 and the annual crop sub-systems (E_1 and E_2) of both farms were established following plowing down of the grass sward after removal of the herbage by heavy grazing.

Siboney cattle, a 5/8 Holstein-Friesian and 3/8 Cuban Zebu cross-breed, was used. During the study, one or two cows, depending on herbage availability, were kept in a put and take system on farm C25, and one on C50. Calves, born annually, were reared for 4 months in a restricted suckling nurse system and subsequently sold. Milk consumed by the calf is not included in the production data, only the sold live weight. Veterinary treatments were based on conventional methods. In addition, natural practices such as the use of entomopathogenic fungi, *Verticillium lecanii* (Rijo 1996) and Gavac vaccine for cattle tick control (Boue et al. 1999) were implemented.

Collected manure (about 10 kg cow⁻¹ d⁻¹) and all available biomass, such as crop residues, animal feed refusals, weeds and some fresh legumes, were used for mulching or composted. Composting followed either of two methods: (1) static, aerobic or (2) vermi-

Farm type	C25	<div><div>A₁</div><div>A₁</div><div>B₂</div><div>A₁</div><div>A₁</div></div>						C50	<div><div>E₁</div><div>E₁</div><div>E₁</div><div>A₂</div><div>A₂</div><div>A₂</div></div>					
Farm area (ha)	1	<div><div>D</div><div colspan="4">C</div></div>						1	<div><div>D</div><div colspan="4">C</div></div>					
Stocking rate (AU ha ⁻¹) ⁽ⁱ⁾	1.8 (2.5)	<div><div>E₂</div><div>E₁</div><div>E₁</div><div>E₁</div><div>E₁</div><div>A₃</div><div>A₂</div></div>						1 (2)	<div><div>E₂</div><div>E₁</div><div>E₁</div><div>A₁</div><div>A₂</div><div>A₂</div></div>					
Reference	Land use type	FFA ⁽ⁱⁱ⁾		Management		Land use type		FFA ⁽ⁱⁱ⁾		Management				
Livestock Sub-system														
A ₁	Pure grass (mixture of star and guinea grass).	35%		Rotational grazing. Living fences of gliricidia.		Pure grass (king grass).		10%		Occasional grazing. Living fences of leucaena.				
A ₂	Grass/legume association (star and guinea grass-perennial soybean, centrosema, teramnus).	10%		Rotational grazing.		Grass/legume association (brachiaria, guinea grass-tropical kudzu, perennial soybean, centrosema, teramnus).		40%		Rotational grazing.				
A ₃	Silvo-pastoral system (Leucaena trees) and grass/legume association (guinea grass-teramnus).	10%		Occasional grazing. Pruning for fresh supplies the whole year and leaves for hay.		-		-		-				
B ₁	Sugar cane	10%		Cut and carry system during the dry season. Leaves remain in the field. Chopping of stems.		-		-		-				
B ₂	King grass	10%		Cut and carry system year-round.		-		-		-				
C	Corridor for the cattle. Free access to drinking water and grazing areas.													
D	Open stable with drinking facility. Supply of fresh forages and hay. Collection of fresh dung and storage for composting.													
Crop Sub-system ⁽ⁱⁱⁱ⁾														
E ₁	Annual crops (corn/beans, corn/squash, corn/beans/cassava) and green manures (canavalia and mucuna).	20%		Crop mixtures in rotation		Annual crops (corn/beans, corn/peanuts, corn/beans/cassava) and green manures (canavalia, mung bean and mucuna).		45%		Crop mixtures in rotation.				
E ₂	Diversified garden	5%		Vegetables, fruit trees, spices and medicinal plants fertilised with worm humus and compost produced from collected dung, crop residues and forage refusals. Compost heap.										

Fig. 1 Design and management practices in the two mixed farms (C25 and C50); *open square* indicates livestock sub-system, *dark filled square* indicates crop sub-system. ⁱ⁾ AU animal unit of 450 kg live weight; between brackets AU per ha livestock area. ⁱⁱ⁾ Fraction of farm area. ⁱⁱⁱ⁾ Use of on-farm produced organic fertilisers (i.e. compost). Fruit trees planted between fields. Crop residues collected for animal feeding. Animal draught for soil preparation and cultivation

composting using Californian red worms (*Eisenia foetida*) based on the methods described by Ramón et al. (1987). Compost quality control included regular chemical analysis and temperature measurements.

2.3 Assessment of agro-ecological and financial indicators

Fifteen AE&FIs (Table 1) were monitored over a 6-year period. Selection criteria for their choice were derived from: (1) critical points for sustainable development of livestock production (De Wit et al. 1995), i.e. relevant aspects that may constrain performance of livestock systems, (2) principal environmental problems identified in the Cuban National Strategy for the Environment (CITMA 1997) and (3) earlier assessments by Monzote et al. (1999).

All AE&FIs were calculated (Table 1) on an annual basis for periods ending on October 31, more or less coinciding with the end of the rainy season. Calculations on system productivity (yields per commodity, i.e. fruits, cash crops, animal products, production of energy and protein per hectare, number of people that can be fed) and energy balances were performed with the computer system ENERGIA (Sosa and Funes-Monzote 1998), developed for the purpose of this study.

2.4 Data collection

Animal and crop products were weighed at sale for productivity calculations. Number of species and individuals of plant and animal populations were counted once a year for biodiversity calculations. Labour spent directly on production activities, and other aspects of farm management were monitored daily. Quantities of compost were weighed before application.

2.5 Soil analysis

Soil analyses were carried out according to Paneque et al. (2002): soil pH (H₂O) by potentiometry in a soil–water suspension (1:2.5), available P by the Oniani method, exchangeable bases (K⁺, Ca²⁺ Mg²⁺ and Na⁺) by the method of ammonium acetate, and soil organic matter (SOM) by the Walkley and Black method. In the latter method, commonly used in Cuba, dried soils are analysed for ‘easily oxidisable carbon’ using a wet chromic acid oxidation. Therefore, multiplication factors are required to obtain total organic carbon and subsequently SOM. A recovery factor of 77% is commonly used to convert ‘easily oxidisable carbon’ to total organic carbon (range 59–94%; Allison 1960) and it is generally assumed that SOM contains 58% carbon (range 30–62%; Houba et al. 1997). For interpretation of the soil fertility characteristics, we used the classification of the handbook for soil interpretation of the Ministry of Agriculture of Cuba (DNSF 1982).

2.6 Financial analysis

Total Cost of Production was calculated from expenses for salaries of hired labour, contract labour, purchase of animals, veterinary care, equipment and materials, energy and seeds. The *Total Value of Production* for crop and livestock products was derived from the top retail market price, established by the Cuban Ministry of Agriculture (MINAG 2003; Appendix 1). Crop product prices not included in this list were set to half the average-free

Table 1 Definition of the applied agro-ecological and financial indicators (AE&FIs)

Analysis criterion	Indicator	Unit	Calculation method
Diversity	SR	Margalef index ^a	Included are total number of species of crops, trees and domestic animals; excluded are soil biota, spontaneous vegetation or other plants and animals
	DP	Shannon index ^a	Included are the yield of each separate farm output and that of the total system
	RDI	Shannon index ^a	Included are both the numbers of tree species and individuals of fruit trees, timber and living fences
Productivity	MY	Mg ha ⁻¹ year ⁻¹	Total milk production of the farm
	MYF	Mg ha ⁻¹ year ⁻¹	Milk production per unit farm area directly used for animal feeding (i.e. grazing areas, grass-legume associations, cut forage areas and silvo-pastoral system)
	EO	GJ ha ⁻¹ year ⁻¹	Total energy in agricultural products
	PO	kg ha ⁻¹ year ⁻¹	Total protein in agricultural products
Energy use	TEI	GJ ha ⁻¹ year ⁻¹	Energy values of all inputs directly used for production purposes
	HLI	Hours ha ⁻¹ day ⁻¹	Time spent on farm activities
	ECP	MJ kg ⁻¹	Total energy used for production divided by total protein output: TEI × 1,000/PO
	EE	GJ output GJ input ⁻¹	Ratio between energy outputs and inputs
Financial performance	NPV		NPV = total value of production - sales taxes (5%) - post-harvest losses (5%) - on-farm price ^c
	GM	k€ ^b ha ⁻¹ year ⁻¹	GM = NPV - total costs of production (fixed costs + variable costs)
	BC		BC = NPV/total costs of production (fixed costs + variable costs)
Nutrient regime	OFU	Mg ha ⁻¹ year ⁻¹	Amounts of compost applied to crop areas

SR species richness, *DP* diversity of production, *RDI* reforestation index, *MY* milk yield, *MYF* milk yield per forage area, *EO* energy output, *PO* protein output, *TEI* total energy inputs, *HLI* human labour intensity, *ECP* energy cost of protein production, *EE* energy efficiency, *NPV* net production value, *GM* gross margin, *BC* benefit/cost ratio, *OFU* organic fertiliser use

^a For calculation procedures of Shannon and Margalef indices see Gliessman (2001)

^b one € is about 1 CUC (Cuban Convertible Peso); 1 CUC = 24 CUP (Cuban Pesos)

^c The wholesale price was set to 70% of the retailer price. Fluctuating product prices and difficulties to obtain reliable wholesale prices of agricultural products made these estimations necessary

market prices, in accordance with the general trend in the list of MINAG. Strongly fluctuating product prices and difficulties in obtaining reliable wholesale prices of agricultural products made it necessary to use these estimates. In the calculations, 5% post-harvest losses and 5% sales taxes were taken into account.

For livestock products, i.e. milk and meat, farm gate prices were set to CUP 1.00 per litre of milk and CUP 2.05 per kg of beef. See Table 1 for conversion factors of CUP.

2.7 Data analysis

Agro-ecological and financial indicators were presented using time series analyses of averages for the 6-year study period, with their respective standard deviations. Soil data were evaluated by ANOVA multiple comparison tests, using HSD–Tukey (Tukey 1977). Statistical analyses were carried out with SPSS (SPSS 1999).

3 Results and discussion

3.1 Biodiversity

The selected biodiversity indicators focus on three aspects: *species richness*, *diversity of production* and *reforestation*. These indicators are closely related to two of the major environmental problems associated with mono-cultural patterns of agriculture identified by the Cuban government, i.e. loss of biodiversity and deforestation (CITMA 1997).

The converted farms were characterised by the presence of large numbers of plant and animal species, i.e., about six times those at the beginning of the study (Table 2). Grain crops, root and tuber crops, vegetables, tree species, and new pasture and forage species were introduced in the design of the mixed farms. This allowed adaptation of the animal ration in the course of the year in response to seasonal climate patterns, especially rainfall, and the associated fluctuations in pasture production, one of the major problems in tropical livestock production systems (Funes 1979).

The Margalef index, as a measure of *species richness*, combines the total number of species in the system and the total number of individuals and reached values of 9.1 and 10.4 on the converted farms, thanks to the large number of species present (44 and 52,

Table 2 Performance of agro-ecological and productivity indicators in the specialised farm (year 0) and for the two mixed farms (C25 and C50) averaged over the 6-year period

Indicators	Units	Farm system				
		Year 0	C25	SD	C50	SD
Species richness	Margalef index ^a	1.6 (8) ^b	10.4 (52)	0.55	9.1 (44)	1.59
Diversity of production	Shannon index	0.2 (2)	1.7 (23)	0.37	2.0 (17)	0.17
Reforestation index	Shannon index	0 (0)	1.7 (204)	0.06	1.5 (131)	0.10
Milk yield per unit farm area	Mg ha ⁻¹ year ⁻¹	1.8	2.4	0.95	2.0	0.50
Milk yield per unit forage area	Mg ha ⁻¹ year ⁻¹	1.8	3.1	1.25	4.0	0.99
Energy output	GJ ha ⁻¹ year ⁻¹	7.2	16.4	2.63	27.1	5.89
Protein output	kg ha ⁻¹ year ⁻¹	91.0	133.5	36.94	191.3	42.90
Labour intensity	Hour ha ⁻¹ day ⁻¹	1.9	3.9	1.50	5.7	1.17
Total energy input	GJ ha ⁻¹ year ⁻¹	3.1	2.0	0.93	2.8	0.59
Energy cost of protein production	MJ kg ⁻¹	34.1	14.8	4.98	14.9	2.06
Energy efficiency	GJ output GJ ⁻¹ input	2.3	9.6	3.43	9.8	2.10
Organic fertiliser use	Mg ha ⁻¹	–	5.3	1.59	5.0	1.98

^a For calculation procedures of Shannon and Margalef indices see Gliessman (2001)

^b Between brackets, absolute number of trees, species and products

respectively), compared to only eight pasture species in year 0 and a corresponding index of 1.6 (Table 2). This index provides a more meaningful measure of the diversity at farm level than one only accounting for the total number of species. The large number of plant and animal species was associated with a large diversity in production (17 and 23 products, respectively), compared to only milk and beef before the conversion (Table 2).

Both farms were characterised by large numbers of trees per hectare (131 and 204, respectively), due to the establishment of trees as forage sources for animals, as well as for living fences and fruit production. Trees are an important component in MFS in the tropics. Research in Cuba and the Central American region (Benavides 1998; Hernández et al. 2001) has revealed increases in milk and meat production, and improvements in animal welfare in livestock systems following introduction of trees, especially leucaena and other leguminous species. Our results indeed indicate that trees, as major components of MFS diversification, had a positive effect on farming system productivity in terms of milk yield, energy and protein output, as tree products such as leaves, were essential components of the animal ration. Moreover, due to the deeper rooting of trees, nutrients can be ‘pumped’ from the sub-soil (Breman and Kessler 1995).

The indicators of *diversity of production* and *reforestation* are both expressed in the Shannon index, which combines either the number of products or of tree species (diversity) with the yield per product or the number of individuals per species (abundance). Shannon indices tend to be higher when the distribution of species and individuals is more even, and for relatively diverse natural ecosystems may rank between 3 and 4 (Gliessman 2001). In our mixed farms, high values of the indices of *diversity of production* (1.7–2) and *reforestation* (1.5–1.7) were attained, compared to year 0, when *diversity of production* was 0.2 and trees were absent. They were also appreciably higher than the values (up to 0.48) calculated for hypothetical multicropping agro-ecosystems, with two or three species and high evenness (Gliessman 2001).

Application of the Shannon and Margalef diversity indices, originally developed for evaluation of natural ecosystems, for analysis of agro-ecosystem diversity might lead to increased insight in the contribution of crop and animal diversification to the improvements in productivity, efficiency and financial indicators of mixed systems.

The increase in plant diversity also affected diversification in other aspects. In our two mixed farms, 15 natural enemies controlling potential pests have been identified (Pérez-Olaya 1998). Perennial crops, such as grasses, gliricidia [*Gliricidia sepium*, (Jacq.) Kunth ex Walp.] and leucaena acted as alternative hosts for natural enemies of crop pests. These observations are in line with those of Vandermeer et al. (1998) and Altieri (1999), i.e. system diversification stimulates emergence of natural enemies controlling pests, contributing to sustainability of agricultural systems.

Moreover, soil fauna biodiversity and the activity of soil biota (diplopods and worms) have been shown to increase following conversion to MFS (Rodríguez 1998).

3.2 Productivity

Productivity is probably the most extensively used indicator in agronomic performance analyses. This study took into account four indicators for productivity of the farm: milk production per unit farm area and per unit forage area, and total energy and protein output.

Milk yield per unit farm area was somewhat higher than before the conversion to mixed farming (Table 2), although up to 50% of the total farm area was used for arable and horticultural crops, and therefore not directly for producing animal feed. This increase was

the result of the introduction of various innovations in the mixed farms; e.g. cultivation of high-yielding perennial forages, grass–legume associations and leguminous trees and use of crop residues as animal feed, resulting in more and better quality animal feed throughout the year. This also led to a high *milk yield per unit forage area* after conversion (Table 2).

Given that the Cuban government has defined the social mandate of the dairy sector as: ‘to produce milk for children, elderly and sick people’, increasing milk production is a political priority. However, biophysical and socio-economic constraints have reduced current total milk production in Cuba to about one-third of that in the 1980s (González et al. 2004) and present-day average annual yields in specialised commercial dairy production units do not exceed 1 Mg of milk per hectare of farmland (MINAG 2006). In commercial dairy farming, based on pasture and medium levels of concentrates, under ‘outstanding management’, production up to 3 Mg per hectare is possible (García Trujillo 1983). In year 0 of this study, the original specialised system produced 1.8 Mg ha⁻¹, while in the mixed farms, annual yields of 3.1 and 4 Mg per hectare forage area were attained (Table 2).

In terms of total production (expressed in energy and protein, the two main components in human nutrition), livestock products in the mixed farms exceeded the yields in year 0, on top of which crop products were harvested. The highest *energy* (27.1 GJ ha⁻¹ year⁻¹) and *protein* (191.3 kg ha⁻¹ year⁻¹) outputs (Table 2), achieved at farm C50, were associated with high ‘additional’ crop production.

Productivity can also be expressed in terms of the number of people that can be fed from the protein or energy output of a system. Averaged over the 6-year period, in farm C25 the energy produced was enough to adequately feed four people, with protein for up to five, while in C50 these numbers were six and eight, respectively. These numbers are about twice as high as reported in literature for medium-intensity specialised milk production systems (Spedding 1988; Beets 1990) and at least four times higher than currently achieved in the ‘Low External Input’ specialised dairy systems in Cuba.

3.3 Energy use

3.3.1 Labour

Human labour productivity is an essential indicator in performance assessment of MFS strategies in dairy farms in Cuba, because of the scarcity of this ‘resource’ in rural areas. Although labour-intensive designs were implemented, in practice labour input gradually decreased over time on farm C25, while on farm C50 it showed a parabolic pattern with a maximum in year 3 (Fig. 2a). Concurrently, production was maintained and therefore labour productivity increased. The higher labour demand of both mixed farms in the first years can be attributed to the initially higher number of farm activities, such as sowing legumes in grazing areas, conversion of pasture into arable land, fencing, planting of trees, establishing the crop rotation system, weed control, etc. Over the 6 years, total labour input was lower in C25 than in C50, due to the smaller cropping area.

Our results are relevant for the three major segments of present livestock production in Cuba: (1) the growing sector of small producers that received land from the state in usufruct, currently about 400,000 (Granma 2006), each with up to 5 ha of land, managed with labour-intensive methods; (2) the small farmers sector, cultivating private land and producing individually or organised in cooperatives such as Credit and Services Cooperatives and Agricultural Production Cooperatives at intermediate levels of productivity, but

Fig. 2 Dynamics of human labour intensity (a), total energy inputs (b), energy efficiency (c) and energy output (d) on mixed farms with 25 and 50% crop area, following conversion from a pasture-based dairy system. Dotted lines indicate C25 and straight line indicates C50

in most cases at low levels of crop–livestock integration and (3) the Basic Units of Cooperative Production (UBPC) that started in 1993 under Law 142. This law regulated partitioning of previous state cattle holdings into smaller units, encouraging diversification and adopting a family farm model. In total, these three segments affect about 4.2 million ha of Cuba’s agricultural land. However, recent estimates set the area of abandoned land at roughly three million hectares, i.e. about half of Cuba’s agricultural area, belonging for the greater part to the UBPC and state enterprises. Two possible directions to reverse this development are promotion of either extensive or small-scale intensive livestock-crop-tree mixed farming with low environmental impact. Under both scenarios, many of the ‘Low External Input’, low labour-intensive and high-efficiency natural resource management practices implemented in the current study are applicable. However, further simplifying managerial activities continues to be a goal, considering that labour availability remains a primary constraint, as the population has moved out of the rural areas.

3.3.2 Energy inputs

Increasing the efficiency of input use was identified as an important objective in the management of the prototype mixed farms. The small sizes of the two experimental farms allowed use of animal traction and intensive human labour, instead of mechanised

Fig. 3 Average energy input use on mixed farms with 25 and 50% crop area for the 6-year period following conversion from a pasture-based dairy system. Error bars indicate the standard deviation of the mean

operations. Human labour was the largest component in energy inputs on both mixed farms that were designed as labour-intensive management systems, with the other components (i.e. diesel and feedstuffs) accounting for about 20% of the total (Fig. 3). Energy input linearly decreased with time since establishment on farm C25, while on farm C50 it showed a parabolic pattern with a maximum in year 3, in parallel to the labour inputs (Fig. 2b), and was lower on farm C25, due to the smaller area devoted to crop production. Realizing high levels of production, at the lowest possible level of inputs (Hilhorst et al. 2001) would indeed be an advantage under the conditions of scarcity and uncertain supply of inputs prevailing in Cuba. This is a strong argument in favour of continuation of MFS, even when the economic situation improves.

3.3.3 Energy efficiency

Higher energy efficiencies on the mixed farms were primarily the result of transformation of part of the pasture area into arable crops, leading to an increase in total energy output and a reduction in total energy input (Table 2). *Energy efficiency* shows an increasing trend with time after conversion on both farms, associated with decreases in total energy input, mostly in the form of human labour, while energy output was stable (Fig. 2a–d).

In energy terms, protein was produced more efficiently in the mixed systems (i.e. lower *energy costs of protein production*) than in the specialised system. Moreover, although energy efficiencies in animal and crop production systems have a different biological basis (Spedding 1988; Stout 1990), our results indicate that higher production of animal protein per unit forage area can be attained using MFS strategies. This type of farm-scale energy efficiency analyses is consistent with studies of Pimentel (2004) and Giampietro et al. (1994) who in sustainability analyses, focused on energy flows in food production at system level. Energy conversion analyses should not be considered as an alternative to financial analyses, but rather as a complement to better cover the complex web of inter-relationships between finances and the environment in which food systems operate (Giampietro et al. 1994).

In countries where fossil energy is abundantly available or where the use of high energy inputs is subsidised, energy-intensive farming systems do not face many technical constraints. However, for countries such as Cuba, where energy and/or capital are scarce

resources, energy efficiency is a critical issue for national food security (Funes-Monzote and Monzote 2001). Furthermore, economic considerations such as high oil prices on the international market and environmental issues such as global warming associated with CO₂ emissions, and the pollution of water and air, are leading societies worldwide to demand more responsible use of fossil energy. High dependence on fossil fuels is generally considered an indicator of low sustainability. Renewable energy alternatives such as biogas, wind power, solar energy, biomass and biofuels, have high potential applications for the development of energy self-sufficient agricultural systems (Pimentel et al. 2002).

3.4 Financial results

Our two mixed farms achieved higher gross margins and higher *benefit-cost* ratios than the specialised farm (Table 3). This is the result of the inclusion of arable crops, the high productivity per unit farm area, and the higher prices for crop products than for milk and meat (Appendix 1). Therefore, increasing whole farm income by selling crop products in regions where arable farming is possible, might be a suitable strategy for supporting cattle operations and making dairy farming more attractive. This is in line with the results presented by De Koeijer et al. (1995) and Thomson et al. (1995) who have indicated financial advantages of MFS, as a result of a more intensive use of natural resources and beneficial interactions between crop and livestock production.

The *total value of production* was higher in the two mixed systems than in the specialised dairy system in year 0, but the *total costs of production* were also higher, associated with the higher labour costs and the capital demand to establish the crop production activities (Table 3). Economic incentives are important to sustain or to increase the population in rural areas. However, lack of incentives and centralised top-down decisions constrain development of the dairy sector. The price of milk for the consumer in the vulnerable sectors of the population is set to 0.25 CUP/litre by the government, the only

Table 3 Performance of financial indicators in the specialised farm (year 0) and the two mixed farms (C25 and C50) averaged over the 6-year period

Financial indicators (kCUP ha ⁻¹ year ⁻¹)	Farm system				
	Year 0	C25	SD	C50	SD
Total value of production	2.49	8.65	2.03	15.25	5.34
Value of crop production	–	6.03	2.09	13.02	5.15
Value of livestock production	2.49	2.62	0.92	2.23	0.59
Net production value	2.49	6.11	1.31	9.93	3.29
Total costs of production	1.87	3.51	1.15	4.86	0.81
Salaries	0.79	1.64	0.64	2.38	0.49
Purchase of animals	0.50	0.20	0.32	0.20	0.32
Veterinary treatments	0.04	0.06	0.02	0.04	0.00
Equipment and materials	0.20	0.52	0.02	0.59	0.02
Diesel	0.25	0.17	0.01	0.42	0.02
Seeds	0.09	0.91	0.32	1.23	0.32
Gross margin	0.62	2.60	0.67	5.07	2.83
Benefit-cost ratio (-)	1.33	1.74	0.38	2.04	0.50

One € is about 1 CUC (Cuban Convertible Peso); 1 CUC = 24 CUP (Cuban Pesos)

official milk processor and retailer, while the producer price is set to about 1.00 CUP/litre, which is low, considering the costs of production. Therefore, milk production is a low-income activity, not economically attractive for producers. While a reduction in the cost price of milk is difficult to realise in low external input DFS, in MFS, milk production tends to become more feasible when combined with other, highly profitable activities such as cash crop and fruit production.

The results of this study are not in contradiction with the national policy of prioritisation of the dairy sector. To be politically acceptable, any diversification strategy should first demonstrate that it does not negatively affect the 'main goal' of producing milk, associated with the 'social mandate' given to livestock enterprises. Hence, any MFS strategy should be able to produce milk with 'minimal environmental damage' and at low costs in external inputs.

Moreover, if economic or political changes lead to price increases for milk and meat, other goals, related to environmental protection and sustainable rural development will be sufficiently important to retain mixed farming on Cuba's future agricultural agenda.

Farms in the UBPCs are increasingly turning towards prioritising diversification for self-sufficiency (feeding workers and their families at low costs and selling possible surpluses in local or external markets to improve their financial sustainability), which makes these results even more relevant. Other emergent activities that might be combined in diversified MFS such as agro-tourism, nature conservation and education are also attractive options and need to be seriously considered. However, as indicated before, structural changes and economic incentives are necessary to stimulate the return of people to the rural areas and make economic use of available land. Our results show that the importance of the financial impact of adopting MFS to promote changes in Cuban agriculture should not be underestimated.

3.5 Soil fertility

Soil fertility of the Ferralsols in year 0 was classified as medium. According to DNSF (1982), the content of SOM was low and pH moderately to slightly acid. Levels of available P and exchangeable K^+ were medium, while the sum of exchangeable cations (SEC = base saturation) was half the 'typical' values for this type of soil (around 20).

After conversion to mixed farming, SOM contents tended to increase. Although in some fields this increase was statistically significant, these data should be interpreted with caution. In the Walkley and Black analytical method it has been assumed for the calculation of SOM that 77% of the organic carbon is oxidised and that SOM contains 58% carbon. Since these are average values that may vary widely, depending on soil type and management practices, respectively, the results in terms of changes in SOM over time after adaptations in soil management, are highly uncertain.

Soil pH increased slightly and remained moderately to slightly acid, except in the cash crop (C_1) and the diversified garden (C_2), where it increased significantly. Available P decreased to low in A_1 and A_3 , remained medium in A_2 and B_2 and increased to high in B_1 , C_1 and C_2 ; however, the differences were not statistically significant. Exchangeable K^+ changed very little, except in sugar cane (*Saccharum officinarum*, L.) (B_1) and in king grass (B_2) where it declined. SEC hardly changed, and remained low for all land use types (Table 4).

The application of on-farm produced compost and vermi-compost at annual doses of between 4 and 6 Mg ha⁻¹ in the crop sub-system, and other soil-restoring practices such as

Table 4 Initial soil fertility status in year 0 and 5 years after conversion, soil layer 0–20 cm (mean values with standard errors between brackets)

Land use type	No. of bulk samples ³	Soil characteristics						
		pH (H ₂ O)	SOM (%)	P (ppm)	K ⁺ (cmol ⁺ kg ⁻¹)	Ca ²⁺ (cmol ⁺ kg ⁻¹)	Mg ²⁺ (cmol ⁺ kg ⁻¹)	SEC (cmol ⁺ kg ⁻¹)
Year 0 ¹								
Pure grass	20	5.6 ^b (0.14)	3.0 ^b (0.14)	7.7 ^b (1.32)	0.44 (0.03)	8.0 ^b (0.10)	1.35 ^c (0.05)	9.78 ^c (0.10)
After conversion ²								
A1	2	6.1 ^{ab} (0.10)	3.6 ^{ab} (0.65)	6.0 ^{ab} (0.00)	0.48 (0.03)	7.9 ^b (0.10)	1.35 ^{bc} (0.15)	9.73 ^{bc} (0.28)
A2	2	6.1 ^{ab} (0.05)	4.0 ^{ab} (0.07)	7.5 ^{ab} (1.50)	0.42 (0.07)	8.4 ^b (0.05)	2.15 ^{ac} (0.15)	10.92 ^{bc} (0.27)
A3	2	5.7 ^{ab} (0.10)	3.4 ^{ab} (0.00)	6.0 ^{ab} (0.00)	0.36 (0.15)	6.7 ^b (0.15)	2.35 ^{ab} (0.05)	9.36 ^c (0.15)
B1	4	5.9 ^{ab} (0.10)	4.2 ^a (0.31)	15.0 ^{ab} (1.78)	0.28 (0.06)	8.3 ^b (0.43)	2.30 ^{ab} (0.45)	10.83 ^{bc} (0.21)
B2	2	6.5 ^{ab} (0.25)	3.9 ^{ab} (0.13)	8.5 ^{ab} (1.50)	0.18 (0.04)	8.3 ^b (0.25)	2.75 ^a (0.25)	11.18 ^{bc} (0.04)
C1	4	6.8 ^a (0.18)	4.6 ^a (0.04)	17.5 ^{ab} (7.01)	0.37 (0.04)	9.3 ^{ab} (0.72)	2.90 ^a (0.04)	12.57 ^{ab} (0.72)
C2	8	6.7 ^a (0.12)	3.6 ^{ab} (0.15)	24.9 ^a (3.51)	0.30 (0.05)	11.1 ^a (0.70)	2.55 ^a (0.18)	13.95 ^a (0.73)

Mean values with different letters in superscripts differ significantly between farm systems components (HSD–Tukey; $P < 0.05$)

A1 pure grass, A2 grass/legume associations, A3 silvo-pastoral system, B1 sugar cane, B2 king grass, C1 cash crops, C2 diversified garden

¹ Soil fertility status before conversion

² Soil fertility status 5 years after conversion

³ For each land use type at least five samples were bulked into one sample, from which a sub-sample (about 2 kg) was taken for chemical analysis (Hernández et al. 1995)

planting legumes and trees, and mulching, might allow maintaining or even slightly increasing SOM in the arable land (De Ridder and Van Keulen 1990). However, roughly 40 Mg of compost per ha should have been added annually during 5 years to increase SOM by 1% (B. H. Janssen, Group Plant Production Systems, Wageningen University, pers. comm.). Such quantities were certainly not incorporated in the mixed systems, confirming the uncertainties associated with the Walkley and Black method.

The slight decrease in available P in the grazing sub-system may be attributed to the continuous phosphorus export through sales of milk and meat, and manure collected in the stable (about 3.6 Mg annually). Increases in SOM, pH and available P have been reported in a silvo-pastoral system in Cuba (Crespo and Rodríguez 2000). Hence, there was no reason to expect P depletion in the silvo-pastoral sub-system. However, studies in Australia and New Zealand have shown acidification effects as a consequence of biological N-fixation of legumes, leading to a reduction in availability of some nutrients such as P (Haynes 1983; Helyar and Porter 1989; Ledgard and Steele 1992). In the king grass sub-system, apparently K is being depleted and needs to be restored. This process has been extensively documented (Herrera 1990) and maintenance of a favourable soil K-status in high-yielding forage areas should be a goal in any MFS.

The overall picture arising from these data is that as a result of nutrient exports from the farm in the form of products, and the redistribution of nutrients via organic transfers, nutrients accumulate in some of the arable fields, while some other fields (particularly pastoral) are 'mined' (Hiernaux et al. 1998; Archard and Banoin 2003). This is especially true for P and K. The information on carbon dynamics is inconclusive, as there is doubt about the quality of the analytical data. However, accumulation seems to take place in the arable sub-systems, especially the annual crops and the sugar cane. Medium-term rotation (5–7 years) of the crop and livestock sub-systems might be a solution to this problem. However, longer-term research is necessary to establish the long-term effects of rotations and in general of agro-ecological management on soil fertility at farming system level.

4 Conclusions

More intensive use of the available natural resources at the farming system level, through diversified MFS in terms of both crop and milk production, contributes to food self-sufficiency and to efficient production of marketable products that contribute to household incomes without degrading the resource base.

Despite the small scale of the current experiment, its potential impact is large. More than two million hectares of land in Cuba are used in specialised milk or meat production systems, managed essentially according to the same principles used prior to 1990, while the institutional environment, in terms of infrastructure and availability of inputs, has changed drastically. Moreover, current livestock developments take place on small- and medium-scale family farms (in both individual and cooperative forms of production), to which the results of this study are potentially applicable.

The lack of capital to maintain conventional high-input systems, the necessity of increasing the level of national food self-sufficiency and the need to restrict negative impacts on the environment are not only issues for Cuba, but also for other developing and developed countries.

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Appendix 1

Retail prices in the free market and regulated by the Ministry of Agriculture (MINAG) of Cuba

Product	Price (in CUP kg ⁻¹ equivalent)		Product	Price (in CUP kg ⁻¹ equivalent)	
	Free market	MINAG 2003		Free market	MINAG 2003
Anonna	11.1	5.6	Okra	11.1	<i>4.4</i>
Avocado	10.0	<i>2.0</i>	Onion	22.2	<i>11.1</i>
Banana ‘burro’	2.0	<i>1.3</i>	Onion leaves	6.7	2.2
Banana ‘fruit’	4.0	<i>2.0</i>	Orange	4.0	<i>1.3</i>
Beans	22.2	<i>13.3</i>	Oregano	4.4	2.2
Cabbage	2.5	<i>0.5</i>	Papaya	8.9	<i>4.0</i>
Carrot	11.1	<i>3.3</i>	Parsley	4.4	2.2
Cassava	5.3	<i>1.8</i>	Passion fruit	10.0	5.0
Corn, grain	8.9	<i>4.4</i>	Peanuts	22.2	11.1
Coriander	4.4	2.2	Pineapple	15.4	<i>4.4</i>
Cucumber	8.9	2.2	Plantain	10.0	<i>4.9</i>
Custard apple	6.3	3.1	Pumpkin	4.4	<i>1.1</i>
Garlic	16.7	8.3	Radish	33.3	2.2
Garlic leaves	6.7	3.3	Red pepper	11.1	<i>6.7</i>
Grapefruit	2.2	1.1	Rollinia	6.7	3.3
Green bean	11.1	<i>4.4</i>	Seville orange	3.3	1.7
Guava	8.9	<i>5.6</i>	Soursop	10.0	5.0
Lemon	5.0	<i>3.5</i>	Spinach	6.7	3.3
Lettuce	11.1	<i>3.3</i>	Sweet potatoes	5.3	<i>1.6</i>
Mango	11.1	<i>1.3</i>	Swiss chard	5.0	2.2
Meat	2.1	<i>2.1</i>	Tomatoes	11.1	5.6
Milk	1.0	<i>1.0</i>	Water melon	6.7	2.2
Mung bean	22.2	<i>13.3</i>	Yam	6.7	<i>4.4</i>

The Ministry of Agriculture established maximum retail prices due to the high demand for food products. Prices in italic were published by MINAG (2003). The other prices are those in the free market regulated by supply and demand, located at street 19 and B, Vedado, Havana

One € is about 1 CUC (Cuban Convertible Peso), 1 CUC = 24 CUP (Cuban Pesos)

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