

Review

Autonomy and sustainability: An integrated analysis of the development of new approaches to agrosystem management in family-based farming in Carnaubais Territory, Piauí, Brazil

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ABSTRACT

This paper seeks to analyze an endogenous development scheme implemented by farming families, involving innovations in the organic production of watermelons; this was a novel local initiative reflecting the creative drive of the farmers themselves, against a background marked by considerable political and institutional uncertainty. The scheme was evaluated in terms of a set of systemic properties measured by multidimensional indicators for farming systems. Data on the selected indicators were collected by field observations, monitoring of production units, and direct semi-structured interviews with farmers. In general terms, the innovations prompted improvements in the various components of extensive environmental and social sustainability, enabling a more sustainable land use through chemical, physical and biological improvements to the soil in the farming systems studied, ensuring increased incomes and the maintenance of family employment, strengthening the farmers' resources and improving their control over resources, and reducing the degree of dependency in relations between the farming unit and the broader context.

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1. Introduction

The current status of “conventional agriculture”, governed by what has been termed the “Modernization paradigm” (Sevilla Guzmán, 2006a, 2006b), clearly reflects the crisis faced by this model, and the precarious economic nature of reproduction in rural families (Altieri and Nicholls, 2010). The modernization of agriculture has involved a considerable degree of mercantilization, leaving the farmers themselves little scope for developing alternatives to the “dominant sociotechnical regime “in farming: social, economic and production-based relationships have become increasingly dependent on the remote dictates of leading stakeholders in global commodity chains (van der Ploeg et al., 2006; van der Ploeg, 2008). This was the case even when the model still succeeded in generating a considerable increase in production and productivity. More recently, since the 1990s, the social constraints (inequality and the maintenance of exclusive food-access structures) and the environmental crisis (CO₂ emissions, deterioration of soils, reduced biodiversity) prompted by this model have become increasingly apparent (Sevilla Guzmán, 2006a, 2006b; van der Ploeg, 2008). This crisis, in turn, has given rise to a decline in farmer incomes and to the greater economic and social vulnerability of farming families (Niederle and Wesz Junior, 2009).

Responding to the crisis, farmers have developed innovative strategies that, little by little, are improving this bleak situation. Marques et al. (2010) note that the process of developing innovations aimed at introducing sustainable changes in a specific production system is seen as both a technical and a socioinstitutional process, which seeks to create alternative working niches for farmers.

The term “novelty production” is used in agricultural research literature to denote local initiatives aimed at fostering sustainable changes in existing systems (sociotechnical regimes), by introducing new ways of thinking and acting, i.e. through institutional change (van der Ploeg et al., 2004; Roep et al., 2004). Novelty production differs from traditional innovation in two main respects: the way changes take place, and their outcome. Innovations are developed only by institutions belonging to the dominant regime, and are incremental in nature, i.e. their aim is to provide the solutions required to keep the regime going. By contrast, novelties imply radical change, and tend to arise at the margins of the regimes in power; they are often associated with networks, with social learning processes and with collective bargaining. Novelties provide new ways of tackling the restrictions and difficulties that farmers may face. van der Ploeg et al. (2004, 2006, 2007) report that novelties may take the form of processes, products, new practices, organizational forms, etc., that do not match the knowledge accumulated to date – that in a sense defy conventional wisdom – and are directly associated with the transition from an agricultural development paradigm to a rural development paradigm.

In the township of Jatobá do Piauí, in the Carnaubais territory of northern Piauí, farmers are implementing innovative practices through the introduction of a new crop – watermelon – using agroecological production technology based on the application of a mulch made of *bagana de carnaúba*, a straw-like waste product generated by the industrial extraction of wax from the film powder coating the leaves of the carnauba wax palm (*Copernicia cerifera* Miller).

Together, these highly-novel agroecological practices are playing a major role in local development for facing of the socio-environmental crisis experienced by the farmers which due to the new agrarian dynamics of land occupation has decreased the fallow period in the traditional production systems based on biomass accumulation in vegetation with subsequent burning. As a consequence, this biomass accumulation in the secondary vegetation has reduced over the last production cycles. Therefore, the continuous extraction of mineral nutrients and organic matter contributes to the soil degradation and can be considered the main ecological problem of the traditional fallow systems of the territory (Oliveira et al., 2008; Leite et al., 2010; Oliveira and Leite, 2010). In this sense, since the late eighty, family farms and the own region living a serious crisis, which is at the same time, economic, social and environmental, whose results are reflected in the impoverishment of the rural population and the difficulties of social reproduction of family farming.

This endogenous development scheme is taking place against a background of considerable political and institutional uncertainty, marked by deprivation and dependency; but at the same time, it is modifying and reshaping the potential for achieving local development goals.

The present study sought to evaluate this organic management initiative via an integrated analysis of its agronomic sustainability, an essential requirement for overall sustainable development (Bezlepikina et al., 2011), and at the same time to examine its potential value for the study of novelty production in agriculture, since this initiative provides useful data for broader research into the development of transitions away from the dominant socio-technical regime towards new sustainability-oriented approaches (van der Ploeg, 2008).

2. Material and methods

Research into land use systems in the Carnaubais territory, in northern Piauí state, was carried out in the township of Jatobá do Piauí (04°46′6″S; 41°49′04″W). The local climate is classed as sub-humid tropical using Köppen’s classification, with two clearly-defined seasons (rainy and dry), and a mean annual temperature of 30 °C. Mean annual rainfall is 1000 mm; rainfall is heaviest from January to May. The soil is classified as dystrophic *Argissolo Vermelho-Amarelo* (Brazilian Soil Classification), of sandy loam texture.

Family production systems are based on polyculture and live-stock-raising, allowing the multiple use of local resources and thus the generation of the products and services required to meet the needs of farming families (Oliveira and Leite, 2009).

The study focused on both traditional and innovative strategies adopted by farming families to maintain agroecosystem fertility, and on the introduction of a new cash crop – watermelon – grown under two different systems: (a) an Innovative Mulch-based Agroecological Production System using *Bagana de Carnaúba* (SISPAB), in which topsoil is covered by a mulch of carnauba wax palm leaf straw and goat manure is used for fertilization, with a 15-year plant cycle; and (b) for reference purposes, the traditional shifting-cultivation system using slash-and-burn techniques to prepare the land, with 4 years under secondary vegetation.

The main crop grown under the new farming system is watermelon, in rotation with maize and black-eye beans. The soil is cov-

Table 1

Diagnostic criteria and sustainability indicators used in the evaluation of crop management systems in Carnaubais territory – Piauí, Brazil.

| Attribute | Diagnostic criterion | Indicator | Measuring method |
|---------------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
| Productivity | Yield and quality | 1. Yield | Field sampling |
| | | 2. Product quality | Laboratory analysis |
| | Profitability | 3. Net income | Survey/interview |
| | | 4. Cost/benefit ratio | Survey/interview |
| | | 5. Return on labor | Survey/interview |
| | | 6. Number of weeding sessions | Survey/interview |
| Stability, resilience and reliability | Land use | 7. Cover | Interview/participant observation |
| | | 8. Physical structure | Interview/participant observation |
| | | 9. Soil fertility status | Field sampling |
| | | 10. Organic matter content | Laboratory analysis |
| | | 11. Soil microbial biomass | Laboratory analysis |
| | | 12. Soil microbial activity | Laboratory analysis |
| | | 13. Carbon balance | Laboratory analysis |
| Equity | Environmental costs and benefits | 15. Biodiversity maintenance | Interview/participant observation |
| | | 16. Soil protection | Interview/participant observation |
| | | 17. Lower risk of forest fires | Interview/participant observation |
| | | 18. Atmospheric carbon absorption | Interview/participant observation |

ered with a layer of carnauba mulch over the fallow period (dry season), during which the powder film is scraped off the leaves for the subsequent production of palm wax; this industrial process generates the *bagana* (chopped-up straw waste), which is valuable for reducing nutrient loss over successive production and soil-cooling cycles.

Since neither of these farming systems makes intensive use of agricultural inputs, the study focused on production practices and on-farm biomass management, two elements essential to the smooth functioning of nutrient and energy cycles in local technical systems.

Progress towards greater agroecosystem sustainability was evaluated by means of a multi-criteria framework, using a set of systemic attributes.¹ Findings, in terms of the degree of sustainability of the agricultural subsystem, were duly collated and are shown below.

Two sets of indicators were identified: those relevant to the research team and those relevant to the resource users. The two sets were combined, and data on the selected indicators were collected by field observations, monitoring of production units, and direct semi-structured interviews with farmers following small-scale sampling. After data analysis, the most relevant indicators were selected and adjusted to the specific problems detected, in order to generate a multi-criteria evaluation of sustainability at local and farm level; this yielded a list of 18 indicators, as shown in Table 1.

For the collected socioeconomic data, a survey has been done in 18 family units where interviewed members of the family, using as script a semi-structured questionnaire, covering overall farm area, crop area, land use and agricultural operations throughout the season, as well as income, costs and use of inputs.

Surveys of land use, cropping systems and input utilization focused on various aspects of carnauba mulch application by farmers, and on the way that application has been passed down over the years. Field observations and sampling in five family units for a more detailed study were conducted in order to determine the benefits of carnauba mulch use in farming systems. The decisive criterion for selecting cases was the particular characteristics of the trajectories of the families which distinguish them with respect to the predominant activities in the region where they live and to innovative agricultural practices that develop.

Prior to the watermelon harvest, soil samples were collected over an area of roughly 1 ha for each land use system, subdivided into four plots (replications). On each plot, 8 samples were collected at depths of 0–10 and 10–20 cm, in order to obtain a compound sample. Samples were subsequently sieved, air-dried and

passed through 2 mm-mesh filters for chemical and biological analysis.

Two indicators were used to estimate yield under the two farming systems: number of fruits per plant and fruit weight. For this purpose sampling was carried out in four 18 m² plots per system; total fruit output for six plants from the central portion of the plot was counted. Only fruits displaying no mechanical damage, blemishes or deformations, and weighing over 6 kg, were counted. Two representative fruits from each plot were selected for the analysis of fruit quality parameters.

3. Results and discussion by indicator

The results for the indicators evaluated for each production system as part of the local knowledge system are presented and discussed below.

3.1. Yield and product quality

Production counts (Table 2) showed that plants grown under the innovative system produced 51.8% more fruit than those grown under the reference system, and yielded 10% more product per fruit.

Data for yield per crop area – at a crop density of 3.333 watermelon plants per hectare – indicate that a farmer can obtain around 23.75 tonnes more of product per hectare (i.e. over twice as much) under the innovative organic system than under the reference system.

Mean results for quality parameters (Table 2) generally showed a slight improvement in fruit quality under the innovative system.

Table 2Phytotechnical sustainability indicators for watermelon crops grown under two production systems, Jatobá do Piauí, Piauí, Brazil, 2007/2008.^a

| Sustainability indicators | Innovative system | Reference system |
|--------------------------------|-------------------|------------------|
| Yield (t/ha) | 41.92a | 18.17b |
| No. fruits/plant (kg/fruit) | 01.39a | 0.67b |
| Mean fruit weight (kg) | 9.05a | 8.14ab |
| Fruit length (cm) | 27.75a | 25.00ab |
| Fruit diameter (cm) | 76.13a | 74.38ab |
| Total soluble solids (TSS) (%) | 11.10a | 11.40ab |
| Total titratable (TTA) | 0.20a | 0.22ab |
| Ratio TSS/TTA | 94.97a | 91.41ab |

^a Differences between systems were statistically significant for $p < 0.05$.

Table 3

Watermelon production costs and profitability under two production systems, township of Jatobá do Piauí, Piauí, Brazil, 2007/2008.

| Systems | Gross income | Costs (US\$/ha) | | | | Net income | C/B |
|------------|--------------|-----------------|--------|----------|---------|------------|------|
| | | Labor | Inputs | Services | Total | | |
| Innovative | 4904.64 | 752.73 | 840.90 | 346.50 | 1940.13 | 2964.51 | 2.53 |
| Reference | 2125.89 | 665.50 | 159.18 | 742.50 | 1567.18 | 558.71 | 1.37 |

Exchange rate: US\$ 1 = R\$ 2.20; Watermelon ex-farm selling price in early 2008: US\$ 0.13; Plant spacing: 3 m × 1 m; Planting density: 3.333 plants/ha; Labor costs: 1H/D = US\$ 5.50; Labor: Opening and fertilization of holes, planting, harvesting, phytosanitary control; Inputs: manure, carnauba straw mulch, biological insecticide, seeds; Services: irrigation and weeding.

Values for fruit chemical quality under both systems were higher than those reported by Andrade Júnior et al. (1997) for the same watermelon variety grown under the conventional system.

3.2. Profitability indicators: net income, cost/benefit ratio, return on labor, number of weeding sessions

The impact of innovative cropping practices on profitability generally displayed a trend similar to that recorded for physical yield, but the advantages of the innovative system emerged much more clearly. Data highlighted positive effects on profitability for both production systems (Table 3), with ratios above 1. However, the innovative system proved more profitable; the high cost/benefit ratio reflected the combined impact of carnauba mulch, goat manure and land preparation method on the intensification of the system.

Economic gains were much more marked in the innovative system, even compared to the intensified form of the traditional low-input system. The factors most influencing profitability were: (a) generally high watermelon yield; and (b) reasonable market prices. As the result show, the cost/benefit ratio highlights the advantages of smallholder-scale watermelon production.

Farming families are also interested in mulch application as an effective means of weed control and as a way of reducing irrigation; watermelon plants are usually hand-watered during the first month of the crop cycle, until the rains come, this being one of the most labor-intensive tasks. As Table 3 shows, the innovative system devoted 53% less labor to these tasks, prompting reduction in total production costs and thus a higher return on family labor.

It should be noted that the calculation of system costs did not include depreciation for environmental costs or exhaustion of natural resources (e.g. soil, water and nutrient loss), since for practical reasons these had not yet been calculated by the farmers; as a result, real income was overestimated under the reference system and underestimated under the innovative system, leading to an even more marked contrast between the two. Maintenance of physical stocks of natural resources was thus greater under the innovative system.

3.3. Effects on soil physical properties: cover and physical structure

Although data on these variables were not taken into account here, humic substances are known to play a major role in binding inorganic soil particles to form stable aggregates (Costa et al., 1995), thus increasing water retention capacity; in addition, the colloidal properties of humic substances favor the absorption and retention of large amounts of water and the formation of hydrogen bonds with water, part of which is then made available to plants. The dark color of most agricultural soils is due to the structure of humic compounds rich in conjugated double bonds, which enhance the absorption of infrared rays, thus favoring heating, germination, growth and microbial activity (Fernández et al., 2008).

Table 4

Soil chemical characteristics, at depths of 0.0–10.0 and 10.0–20.0 cm, under two different management systems. Township of Jatobá do Piauí, north-eastern Brazil, 2007/2008.

| Management systems | Chemical characteristics ^a | | | | | |
|--------------------|---------------------------------------|--|--|--|--|---------------------------------------|
| | pH H ₂ O | Al ⁺³ cmol _c dm ⁻³ | Ca ⁺² cmol _c dm ⁻³ | Mg ⁺² cmol _c dm ⁻³ | K ⁺ cmol _c dm ⁻³ | P ⁺ mg dm ⁻³ |
| <i>0–10 cm</i> | | | | | | |
| Innovative system | 5.07b | 0.50a | 1.21a | 0.80a | 0.18a | 6.34a |
| Reference system | 5.83a | 0.32b | 1.33a | 0.55b | 0.08b | 5.99a |
| <i>10–20 cm</i> | | | | | | |
| Innovative system | 4.68b | 0.85a | 0.34ab | 0.25a | 0.08a | 4.43a |
| Reference system | 5.40a | 0.56b | 0.66ab | 0.29a | 0.09a | 1.48b |

^a Measurements followed by the same letter within each plot did not differ statistically from each other (Tukey's test; 5% probability).

Farmer interviews and field observations suggested that soil structure and porosity were improved under the innovative system. The most common view was that mulch application favored moisture conservation; the added moisture in soils covered with a layer of mulch helped watermelons and following crops to withstand drought periods during the growing season.

The reference system is associated with soil-compaction reactions. Primavesi (1984) has reported that densification in tropical soils limits rooting capacity and thus impairs plant nutrient absorption, leading inexorably to declining harvests, since the natural fertility of the soil is intrinsically linked to its biostructure.

3.4. Effects on soil chemical properties: fertility status

Soil pH values were significantly higher ($p < 0.05$) under the reference system than under the innovative system, at both depths studied (Table 4), probably due to the presence of ash on the soil surface. Exchangeable acidity analysis (Al⁺³) showed lower soil aluminum levels in burnt lands, again due to surface ash.

In general terms, higher levels of nutrients, calcium (Ca⁺²), magnesium (Mg⁺²), potassium (K⁺) and phosphorus (P) were found in the innovative system, probably due to the constant supply of organic matter (mulch and manure), the greater abundance of crop residue on the soil surface, and the closed-cycle non-till system used, which is associated with a significant reduction in nutrient loss.

Studies by Menezes and Sampaio (2002) in traditional agroecosystems in north-eastern Brazil report that loss of phosphorus (P) through erosion in croplands may be as high as 6.0 kg ha⁻¹ year⁻¹. Another author has identified phosphorus as a production-limiting nutrient in systems where burning is not used (Bünemann et al., 1998).

With regard to soil fertility, farmers reported that the innovative system – in which no land burning was involved – required greater use of organic fertilizers, mainly at the start of the season, and that the longer a plot was cultivated, the better the results. This may be because nutrients in the mulch become available only

over the long term, after decomposition, contributing to increased productivity in later crop cycles.

3.5. Soil nitrogen and organic carbon

Results obtained at both soil depths (Fig. 1) revealed higher carbon pool values under the innovative system.

This is linked to the constant supply of plant residue with no soil tillage, and to the constant use of carnauba mulch and manure, which forms a plant cover serving as a source of carbon and nutrients in the middle and long term, as reported by other authors (Sherrad et al., 2005; Berner et al., 2008). These practices ensure a greater abundance of organic matter, prompting the accumulation of liquid TOC stocks (Kong et al., 2005; Majumder et al., 2008).

Higher values under the innovative system are associated with higher watermelon yield, underlining the increasing return of organic substrates to the soil through shoots, roots and exudates, in comparison to the reference system.

At both depths, total nitrogen stocks were also higher under the innovative system (Fig. 1), due to the use of carnauba mulch and manure, with a greater C content than would be obtained with crop residue alone (Triberti et al., 2008), prompting a rise in existing rates.

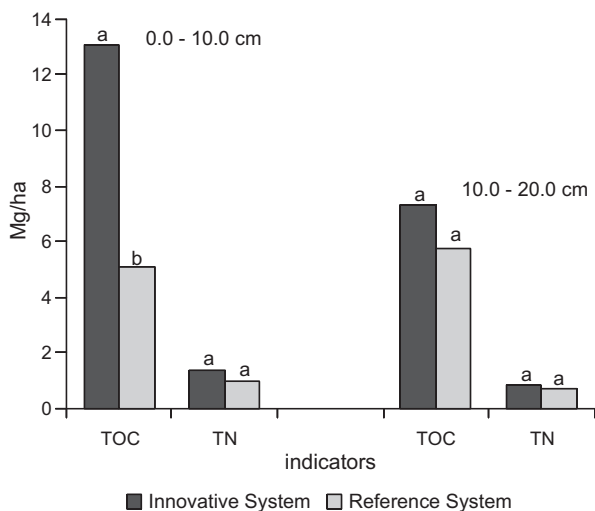


Fig. 1. Influence of soil management system on soil stocks of total organic carbon (TOC) and total nitrogen (TN) at two depths: 0.0–10.0 and 10.0–20.0 cm.

The innovative system provided a greater recovery of soil organic-matter content by maintaining crop residue and adding mulch straw; this helped to improve and maintain soil quality, as well as protecting crops against solar radiation, reducing the impact of raindrops and maintaining soil moisture levels.

3.6. Effects on soil biological properties

3.6.1. Soil microbial biomass

Soil microbial biomass (Cmic) is a key factor in regulating the recycling of nutrients (Merino et al., 2004), and provides a highly-unstable source of nutrients for plant growth. It is therefore widely used as an early indicator of changes in soil physical and chemical properties resulting from soil management strategies in various agroecosystems (Sparling, 1997). The practices applied in organic production systems favor an increase in organic matter content and have a marked impact on soil microbial biomass (Fig. 2). At both soil depths studied, mean Cmic was higher under the innovative system.

Data showed that the immediate microbial biomass was significantly greater in the organic system, due not only to the annual input of organic matter (manure and mulch) but also – in all probability – to the microbial biomass generated by organic amendments. A number of studies highlight the positive influence of organic residue production factors, with high C content, on soil microbial biomass (Tu et al., 2006; Araújo et al., 2008), noting that microbial biomass growth and activity is linked to the input of C substrate into the system.

In a long-term experiment conducted in the United States, Tu et al. (2006) evaluated the impact of switching from conventional to organic management on microbial biomass and activities. Microbial biomass was found to be significantly greater in organic than in conventional plots. The authors attributed that difference to the cumulative impact of organic inputs over a period of years under the organic management system.

In the present study, microbial biomass increased by roughly 100% with the switch from agriculture to organic farming. Fließbach and Mader (2000) report that microbial biomass is significantly affected by the long-term management regime selected and by regime intensity. They note that microbial biomass carbon is between 45% and 64% higher in organic plots than in plots using conventional chemical fertilizers.

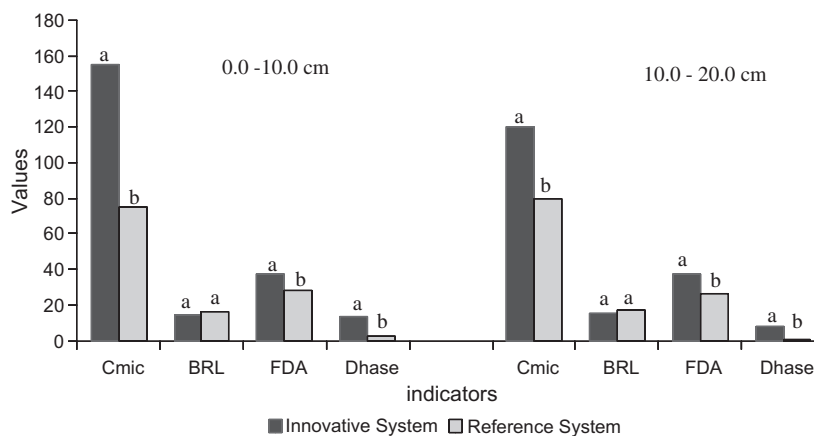


Fig. 2. Effects of soil management systems on microbial biomass carbon (mg C/kg), baseline soil respiration levels – BRL ($\text{mgCO}_2 \text{ kg}^{-1} \text{ soil day}^{-1}$), FDA hydrolysis ($\mu\text{g FDA/g h}$) and dehydrogenase activity ($\mu\text{g TTC/g h}$) at depths of 0.0–10.0 and 10.0–20.0 cm. Means followed by the same letter displayed no statistically-significant difference (Tukey's test; $P = 0.05$).

3.6.2. Soil microbial activity

Soil microbial respiration rates can be used as a measure of microbial activity. Here, respiration rates were similar on all plots, at depths of both 0.0–10.0 and 10.0–20.0 cm (Fig. 2), indicating that the different management regimes prompted no change. Soil respiration is a measure of biological activity, and may indicate crop residue decomposition and the release of nutrients for plant growth. However, soil respiration may also be interpreted as an indication of stress in the soil microbial biomass (Anderson and Domsch, 1990). The metabolic quotient (qCO_2) measuring respiration per unit biomass (Anderson, 2003) was determined in order to facilitate comparison between systems. Results for the plots under the reference management regime showed an increase in qCO_2 (0.22 and 0.21 g CO_2 -C/g Cmic day at depths of 0.0–10.0 and 10.0–20.0 cm, respectively), suggesting stress in the soil microbial biomass.

By contrast, the lower values (0.09 and 0.13 g CO_2 -C/g Cmic day at depths of 0.0–10.0 and 10.0–20.0 cm, respectively) recorded for the innovative system are indicative of a highly efficient use by the soil microbial biomass of the C available for biosynthesis. Behera and Sahani (2003) report that greater microbial biomass efficiency indicates greater C uptake and lower loss of C through respiration.

Enzyme activity responds almost immediately to changes in the soil environment (Kandeler and Murer, 1993; Dodor and Tabatabai, 2003), because it is closely linked to microbial biomass. Here, FDA hydrolysis and dehydrogenase activity (Fig. 2) were significantly greater under the innovative system at both soil depths, suggesting that soil microbial activity – as indicated by enzyme activity – increases under this kind of regime. According to Aon and Colaneri (2001), increased soil enzyme activity can generally be expected in response to: (i) increased microbial synthesis and release of extracellular enzymes, and (ii) an improvement in environmental conditions prompted by changes in soil physical and chemical properties. The results obtained here show that enzyme activity responded to an organic management regime, suggesting a link between increased enzyme activity and increased microbial biomass under this regime.

3.7. Carbon balance: estimation of carbon release and sequestration (C-CO₂)

Total organic carbon stocks (TOC) were used to calculate the contribution of the two management systems to the release or sequestration of C-CO₂ by soil at depths of 0.0–10.0 and 10.0–20.0 cm. The C to CO₂ conversion factor was taken as 3.67 (molar mass of CO₂/molar mass of C), following Leite (2002).

Carbon emission and sequestration were calculated by subtracting forest carbon stocks (8.65 and 6.47 Mg ha⁻¹ respectively, at

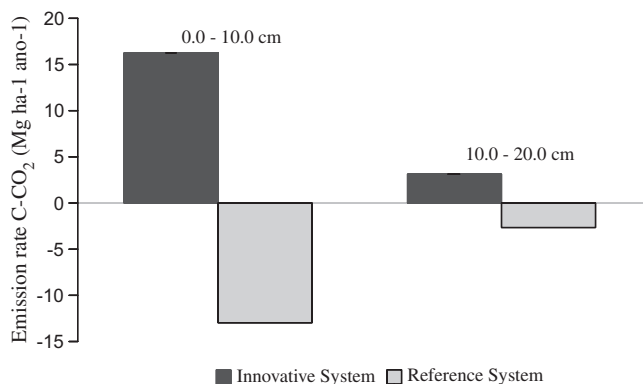


Fig. 3. Estimated emission (–) or sequestration (+) of C-CO₂ at two soil depths under two different management regimes.

depths of 0.0–10.0 and 10.0–20.0 cm) from stocks under the two management systems, and multiplying the result by 3.67 (C-CO₂) (Fig. 3).

Carbon stocks represent the balance of inputs and release through the decomposition of soil organic matter. Sequestration of C-CO₂ requires either increased C input or reduced decomposition, or both (Leite et al., 2003).

Total forest carbon stocks (used for reference purposes) were lower than total stocks under the innovative system, indicating sequestration of carbon, or more specifically of C-CO₂. Forest values higher than those of management systems are indicative of carbon loss, i.e. release of C-CO₂; this was the case under the reference management system. This may be due to the poor quality of regional soils under native forest (acid, relatively infertile soils), involving species with low net primary productivity or low biomass production. C values in the innovative system were higher than forest values, indicating that the crop practices used improve soil quality by ensuring a greater supply of crop residues compared to that provided by forest species (savannah-*caatinga* transition areas). Improved supply of crop residues or biomass leads ultimately to greater organic matter input and thus to larger C and N pools, demonstrating effective carbon sequestration.

A number of studies suggest that changes in soil use may give rise to C loss and accumulation of CO₂ in the atmosphere; however, it is widely recognized that the many environmental benefits of organic management include C sequestration and mitigation of the effects of atmospheric CO₂ (Moreno et al., 2007; Oelbermann et al., 2004).

3.8. Environmental costs and benefits: Indicators related to biodiversity maintenance, soil protection, reduced risk of forest fires and absorption of atmospheric carbon

Growing social concern at the increase in the mean temperature of the planet due to the emission and accumulation of greenhouse gases has created an environment conducive to family-based farming seen as means of conserving natural resources and the rural landscape.

Within this context, there is a growing demand for a new system of incentives to foster rural production, a system that addresses popular concern for the conservation of natural resources and at the same time ensures the economic viability of family production units. In this respect, family-based farming has specific features which make it a multifunctional model in terms of the labor force employed by the production unit, the diversification of productive activity, the acquisition of knowledge and its transmission to succeeding generations, and the provision of environmental services resulting from the rural location of the production unit.

Under the innovative system, by improving production techniques – replacing the earlier cut-and-burn system prior to planting, and wholly avoiding the use of fire – farmers are contributing directly to the improvement of environmental services; new crop practices are ensuring, among other things, the conservation of biodiversity, a lower incidence of forest fires, reduced loss of soil and nutrients, and increased absorption of atmospheric carbon.

As well as increasing carbon uptake and storage, the innovative and sustainable land-use system can improve farmer subsistence through the conservation, protection and improvement of agrobiodiversity.

Adoption of the innovative production system by a few individual farmers generates a negligible environmental impact; however, when individual adoption gives way to general adoption throughout the territory, environmental benefits are considerable and benefit society as a whole.

4. Integrated discussion

This case study highlights the sustainable strategies adopted by farmers with a view to intensifying land use by implementing innovative sustainable practices, limiting the use of external inputs and strengthening the resource base of the production unit. According to the integrated analysis held, showed in the previous section, can be observed that practices oriented towards farmers' objectives clearly opened up new approaches and heralded fresh perspectives for the development of more sustainable agrofood systems. After that we provide some aspects and discussions related to empirical data from this research.

4.1. Reflections on the autonomy and sustainability of production systems

Historically, the main strategy adopted by farmers for the regeneration of agroecosystem fertility in the Territorio de Caraubais was to allow cropland to lie fallow over a certain period. As in other parts of the world (Petersen et al., 2002; Petersen and Almeida, 2008), this traditional strategy is no longer valid, due to the need for a more intensive use of arable land.

The diversified Innovative Mulch-based Agroecological Production System using *Bagana de Carnaúba* (SISPAB), implemented by local farmers, consisted in the introduction of watermelon as a new crop and the implementation of new approaches for ensuring the sustainability of the traditional, natural fallow system, as an alternative to current management trends which involve a reduction of the fallow period and thus a reduction both of the soil's natural fertility and of farmer incomes.

The perceived need for an alternative to current solutions thus gave rise to this farmer-led experimental innovation based on sustainable elements of the traditional system (Sosa et al., 2010).

Under the new system, farming resources – e.g. cropland, manure and biomass – are unraveled and remolded in order to create combinations that are as productive and sustainable as possible. Evidently, this unraveling and remolding requires fine-tuning (van der Ploeg, 2003; Verhoeven et al., 2003). Because of mutual improvement of resources as well as mutual adjustment of relevant growth factors, specific endogenous development trajectories and potentials emerge and are sustained (Verhoeven et al., 2003).

By increasing the nutrient pool in the biological compartment of the innovative agroecosystem, farmers can simultaneously minimize losses and balance nutrient supply and demand. The biological immobilization of nutrients through their incorporation in plant organic components reduces nutrient loss; moreover, nutrients are more biologically available, since they are more readily released into the food chain (through the action of decomposing organisms in the soil) than if they were immobilized by physical or chemical processes (in soil minerals or in the air).

In the innovative agroecosystem biomass plays an essential role in the self-regeneration of soil fertility. As elements of manageable biomass, nutrients are deliberately stored and transferred to production subsystems. It is in this context that management practices which prompt an overall increase in the production and storage of agroecosystem biomass and ensure the effective transfer of biomass between production subsystems emerge as central elements of technical strategy in the agroecological transition process (Petersen, 2003).

Despite the bleak economic conditions and adverse climate conditions in the region, those smallholder farmers who supported novel agroecological strategies can now point – as the data obtained here show – to greater productivity and more extensive social and environmental sustainability (Calle and Gallar, 2010). The innovative production system proved to be more efficient – both per unit

earth and per worker – as well as more economical and more stable. As Funes (2009) and Altieri and Nicholls (2010) have reported, agroecological management strategies enable food to be produced in accordance with the level of diversity and management of each farm, without the need for costly external inputs or petroleum, and provide greater drought resistance.

All these aspects confirm that the innovative system is the one with greater sustainability level and that is essential to have the participation of the local community and its knowledge to eliminate the causes of the degradation process and to improve production, and therefore, the life quality (Delgadillo and Delgado, 2003).

It can thus be asserted that the active intervention of social actors enhances their ability not only to withstand adversity, but also to suggest, shape and implement alternative approaches to rural development projects (Schneider and Niederle, 2010).

4.2. Considerations regarding the social nature of the novelties implemented

In practice, the production and adaptation of agricultural innovations take place largely at individual farmer level, in a single plot, herd or production unit. Decisions, implementation and impact are linked to the intensity of individual action. Consequently, innovative processes can grow, intensify and achieve greater scope if they are enhanced by institutional methodological support (i.e. public action) or by learning processes involving whole groups and/or organizations, that foster dialogue, exchange of experience and socialization (Sabourin, 2002).

In the present case, novelty production lay at the heart of the strategies developed to tackle the crisis facing farmers. The novelties in question have prompted changes in farmer-market interactions and in adding of value through new crop practices, giving rise in turn to new forms of social organization – the creation of a producers' cooperative – and to changes in the production process; the use of fire to prepare farmland for planting has been replaced by the integration and management of biomass transfer among subsystems.

The main grounds for change, i.e. for the transition towards production systems based on agroecological principles, were the socioeconomic and environmental crisis threatening the traditional slash-and-burn system, and the lack of economic resources for the modernization of agricultural production units in the early 1990s. The major novelty involved in the new strategy was the development of SISPAB – the Innovative Mulch-based Agroecological Production System using wax-palm straw.

Watermelon production, due to their volume and destination characteristics, is negotiated and sold directly in the production units to wholesalers, these being responsible for the costs derived by of the harvesting operation. This system has been particularly advantageous, because the sale is made in full and have as a result in an aggregate value of the equal magnitude for the family, since production is sold with the average price equivalent to market. This equality of the price is attributed to the time of production, i.e. the period which the market has a low supply of this product.

This new reality starring by family farmers also revealed several weaknesses and is at these points where there is the new form of organization, composed by the Association of Small Farmers of the Watermelon in Township of Jatobá do Piauí, which at the time and in the current context favors the cooperative side of the peasantry in the territory. This organizational strategy allow to share knowledge among farmers, promoting the novelty of production and dissemination of new promising results.

The results showed and discussed in this paper indicate the importance of the peasant innovation, which represent the local contribution and the policies to promote sustainability of the family system production (Almeida and Fernandes, 2002).

In most cases, the development of agroecological innovations is based on existing farmer knowledge, i.e. practical know-how (van der Ploeg, 2003). As innovative approaches progress, therefore, farmers will gradually acquire greater knowledge – including contextual and scientific knowledge – which will support and enhance their experience of novelties. The high level of knowledge of information developed locally and coupled with analytical research processes may be significantly optimized (Petersen and Silveira, 2002). The pooling of farmers' knowledge with that of other players will give rise to numerous novelties, and will enable new strategies to be developed to tackle current problems and crises (Schneider and Niederle, 2010).

5. Conclusions

In general terms, the innovations improved in various respects the sustainability of the system, enabling a more sustainable use of the land through improvements in the chemical, physical and biological properties of the soil, and thus ensuring increased yields, higher incomes and the maintenance of family employment. All this contributed to the productive re-structuring of smallholder farming, and to the mitigation of the socioenvironmental crisis in the Territory.

The innovations implemented by farming families – the introduction of a new crop and innovative management of the agroecosystem – served to strengthen their resource base and their control over resources, and at the same time to reduce the degree of dependency in relations between the farming unit and the broader context. The innovations introduced also played a key role in the process of agroecological transition towards extensive sustainability,² providing the basis for new strategies designed to tackle the crisis faced by farmers.

As a reactive strategy developed by farmers faced with the need to survive in a context of growing social vulnerability, the innovative system contributed significantly to the diversification of the means of subsistence and to the achievement of autonomy. In this respect, it should be noted that the new system provides greater productive autonomy by reducing reliance on external inputs and taking greater account of local skills and knowledge.

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² It refers to social and environmental sustainability (Calle and Gallar, 2010).

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