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Urban agriculture and land use in cities: An approach with the multi-functionality and sustainability concepts in the case of Antananarivo (Madagascar)

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ABSTRACT

Urban planners are increasingly interested in agriculture around cities and have to decide whether to maintain or not areas of agricultural land use within and close to growing cities. There is therefore a need for researchers to design tools to guide public decision-making on land use. Various approaches, originating from different disciplines, may be adopted in this respect. We designed an interdisciplinary research program in order to test two related concepts: the “sustainability” and the “multi-functionality” of agriculture. We show that these concepts provide a useful framework for obtaining appropriate knowledge about urban agriculture, which urban planners could apply in real situations. In close collaboration with urban planners, we applied an interdisciplinary research methodology, based on common farm surveys and territorial approaches, to the Antananarivo area (Madagascar). The main functions analyzed were the food production and environmental roles of urban agriculture. Two aspects of sustainability were assessed: the farm sustainability and the territorial sustainability, with expert scores. This approach identified a wide diversity of farming systems that performed differently, depending on their intra- or suburban location. The food supply function appeared to be important not only for fresh produce but also for rice consumption. The function of protection against flooding is now important and this importance will increase with climate change. A diagnosis of sustainability was made and discussed with urban planners: several farming systems and zones were identified in which agriculture was considered important as a means of maintaining or developing the food supply, employment and incomes, and even landscape or environmental quality. We also identified other areas in which poor production conditions and/or the negative effects of urbanization on agriculture jeopardized its sustainability. This methodology appeared to be useful for determining the most appropriate role of urban agriculture in the land-use planning of this city. Our study raises new questions on the subject and should lead to more focused research programmes. We discuss several points of interest and the limitations and possible extension of this method.

Introduction

Urbanization is increasing worldwide, but particularly in developing countries, which had an annual urban growth rate of 3.6% between 1950 and 2005, versus only 1.4% in industrialized countries (Mougeot, 2005). In both the North and the South, researchers and planners are increasingly focusing on the role of agriculture in growing urban spaces (Bryant and Johnston, 1992; Bryant, 1997; Mougeot, 2000; Bontje, 2001; van Veenhuizen, 2006). In the developing countries, in particular, the productivity of agricultural areas close to towns – which often produce mainly perishables such as vegetables (Bricas and Seck, 2004; Temple and Moustier, 2004; Moustier and Danso, 2006; Weinberger and Lumpkin, 2007) – must be increased to meet the growing urban demand for food. The conflict is however intensifying between the maintenance of local agricultural production in these areas and the rapid and often uncontrolled consumption of land by growing urban activities and infrastructures (Rural, 2006). At the same time, the status of agricultural areas within or near towns is changing: such areas are no longer considered simply as a reserve of land for future

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urbanization (Zeng et al., 2005), and instead are becoming a specific topic in urban planning, with the aim of the sustainable development of towns (Monédiaire, 1999; Fleury, 2005; Sullivan and Lovell, 2006). Urban farmers are increasingly considered as stakeholders, and local interactions between agricultural and urban stakeholders determine the precise pattern of development of urban and suburban spaces (Bryant, 1995).

Urban planners therefore have to determine the present and future roles of agriculture in urban development and to design zoning plans accordingly. Researchers can provide efficient methodologies adapted to specific cases to help them in their decision-making. We carried out such decision-oriented research in Antananarivo (Madagascar), where CORUS (Cooperation for Research, Science and Universities, a French Ministry of Foreign Affairs fund) supported our multidisciplinary and bi-national project[1] in close partnership with local urban authorities. In this research project, "urban agriculture" was defined as "agriculture located within a city or on its periphery, the products of which are at least partly destined for the city, and for which alternative agricultural and non-agricultural uses of resources are possible" (Moustier and Mbaye, 1999). We designed a research methodology based on two main concepts: sustainability and multi-functionality (2), applied to urban agriculture in general (2.1) and to the local context of Antananarivo in particular (2.2). We thus built a customized multidisciplinary research project in partnership with urban planners (2.3). This led us to propose a shared representation of the diversity of urban agriculture in the Antananarivo district (3.1) and to analyze the functions of these agricultures (3.2). We then worked with urban planners to diagnose the sustainability of urban agriculture in that district, which enabled us to make operational proposals to maintain or not some types of agriculture on some sites (3.3). In this paper we present some key points of this approach, and then discuss the value, limits and possible extrapolation of this method (4).

Materials and methods

Concepts and hypothesis

Two main concepts are mobilized here: the sustainability and the multi-functionality of agriculture.

In 1987 the Bruntland Report defined "sustainable agriculture" as agriculture based on an economically viable and socially accepted development process that preserves environmental resources for the present and the future. In view of the specific characteristics of urban contexts, urban agriculture can be considered to have two sustainability levels, what we call "dual sustainability":

(i) *Farm* (*or internal*) *sustainability* is dependent on the conditions of production on farms themselves: are they economically viable and socially acceptable, what resources do they use and are these resources renewable? It obviously depends largely on the production systems (which can vary – see below) and on the position of these farms in the urban context, in terms of localisation, commercial relationships, incomes, resource accessibility etc.

(ii) *Territorial* (*or external*) *sustainability* is what Godard and Hubert (2002) called the "territorial sustainability" of agriculture, that is, the participation of agriculture in the sustainable development of a territory. In an urban context, we suggest that this territorial sustainability can be linked with the vision that "the City" (its planners, inhabitants, etc.) has for the future of its agricultural spaces in comparison with the growing needs of alternative land uses (housing, roads, etc.). Internally "sustainable" agriculture, i.e. with economically viable, socially well-inserted and environment-friendly farms, may have to be sacrificed if urban planners give locally priority to urban infrastructures. Conversely, for landscape reasons for example (Donadieu and Fleury, 2003), urban planners may wish to maintain agricultural areas where farms are not internally sustainable. From an operational point of view, it is very important to identify such situations, because building on agricultural land is largely irreversible. On the other hand, maintaining agricultural land in a given space may be very expensive for the community if this activity cannot sustain itself.

Table 1
Possible futures of urban agriculture in different cases of double sustainability.

FS		–	+
TS	–	Disappearance	Loss of a high income activity
	+	Artificial maintenance by public subvention?	Self maintenance and/or development

FS, farm (internal) sustainability; TS, territorial sustainability.

The role of researchers is therefore to enlighten urban planners about this overall ("dual") sustainability of urban agriculture so that they can diagnose the consistency and/or conflicts between the two types of sustainability which lead to different futures for the agricultural spaces (Table 1). A collaborative approach with urban planners can therefore lead to better convergence between farm sustainability and territorial sustainability, for example by questioning the locations of urban projects, and in so doing make urban planning more coherent.

The second concept mobilized here is multi-functionality, a characteristic not only of most urban agriculture throughout the world (Donadieu and Fleury, 2003; Fleury, 2005; Zasada, 2011) but also of rural agriculture (Ilbery and Bowler, 1998). Food production, especially of fresh produce (Egziabher et al., 1994; Smith et al., 1996; Snrech, 1997; Temple and Moustier, 2004), prevention or absorption of environmental risks, contribution to cleaning up the city by recycling waste (Drechsel et al., 1999; Mougeot, 2005; N'Diénor, 2006), landscape and socio-educational functions (Ba and Moustier, 2010), and contribution to urban employment and the reduction of inequalities (Dubbeling et al., 2010) are some of the main functions of urban agriculture that researchers recognize. Yet the extent to which public policies acknowledge all these functions varies widely, particularly in the South (Laurent, 2002; Losch, 2002). As in the case of sustainability, the multi-functionality of urban agriculture can be considered from the point of view of farmers, on the one hand, and urban dwellers, on the other. Clarification and ranking of the functions of urban agriculture are crucial to more rational urban growth and to an understanding of the role of agriculture in urban environments (van Veenhuizen, 2006).

The links between these two concepts are complex. As empirical data worldwide show that urban farms are largely multifunctional, the question arises of whether multi-functionality is one of the preconditions for internal sustainability of urban farms and/or the reverse. We posit that territorial sustainability is strongly determined by multi-functionality: when urban dwellers and planners recognize that, in a given area, agriculture makes a contribution that cannot easily be replaced by other land uses, they may be more inclined to protect it against urbanization (Ba and Aubry,

[1] This project, called ADURAA (Analysis of Sustainability of Agriculture in the Metropolitan Area of Antananarivo), was carried out over a four-year period (2003–2007) and involved seven researchers and 20 students (from both Madagascar and France).

2010). Territorial sustainability may thus stimulate farm sustainability, insofar as the authorities' recognition of functions may create incentives for farmers to increase the internal sustainability of their farms (better access to markets, inputs, land tenure, etc.) (Vandermeulen et al., 2006; Jordan and Warner, 2010).

It follows that to study the role of agriculture in sustainable urban development, it is necessary for research: (i) to assess (qualify, quantify and understand) the multiple functions of agriculture, from the farmers' as well as the urban planners' points of view, and to compare their nature and hierarchy; and (ii) to diagnose the internal and territorial sustainability of farms in different situations. The ADURAA project was designed to obtain knowledge about these functions in the local context (Aubry et al., 2008; Dabat et al., 2006). The dialogue with urban planners on sustainability focused on their initial representation of the future of urban agricultural spaces in light of this shared knowledge.

Context of the study and local adaptation of the concepts

Antananarivo (18°55′South, 47°31′East) is a tropical mountain city in which human dwellings have traditionally been concentrated on the hills and mountains, leaving the valleys, plains and lowland areas for agriculture. Recent urbanization (late 20th century) has however extended urban infrastructures and habitat onto a part of what, historically, were rice plains. Today, agricultural areas extend right into the city centre and occupy the urban lowlands, a major part of the surrounding floodplain (with recently rebuilt hydraulic infrastructures) and the suburban hills. Agriculture accounts for 43% of the 425 km^2 of the Antananarivo district (Rahamefy et al., 2005), with rice production accounting for most land use in the suburban hills, on the irrigated plains around the city, and in some of the urban lowlands. The lowlands are also occupied by watercress, up to the very centre of the city (Fig. 1). Market-gardening with different species (mainly leafy vegetables and tomatoes) is found primarily on the banks of the lowlands and of the local river (Ikopa), and on the suburban hills. Cattle are also found, with small herds in the suburban areas, as well as pigs and an increasing number of chicken production units. Yet little is known about this agriculture: no statistics exist and it receives no technical support, as the interventions of the Malagasy Ministry of Agriculture focus on the “rural” zone, which begins about 35 km from Antananarivo. The urbanization and rapid industrialization of the capital of Madagascar are however directly encroaching on agriculture, affecting the use of soil and water resources (embankments on farmland, release of urban and industrial pollutants into water destined for agricultural use). Urban planning documents currently undergoing revision directly question the future of agricultural areas in and around the city (Cities Alliance, 2004).

In view of this context, we first selected some of the major functions and factors *a priori* influencing the degree to which farming systems are found to be internally (farm) and externally (territory) sustainable:

(i) food supply is obviously a major function: we studied it from the farmers' point of view (own consumption, sale of products) and that of the city supply, for various products;
(ii) in this tropical mountain city, the use and regulation of water by agriculture seems very important, for example to contain the recurrent flooding on the plain or on the lowlands during the rainy season;
(iii) the global economic function of agriculture has to be seen in terms of monetary income and employment for farmers, with a focus on its relationships with the urban employment basin;
(iv) the relationships between agricultural production and land reserve for building are important because part of the city land is officially considered as unsuitable for building (mainly due to flooding risks), and because agriculture also participates in the extension of building through dynamic brick production in agricultural areas (see below);
(v) the waste management function is complex[2]: liquid waste and industrial effluents directly affect some agricultural zones as the existing regulations for their treatment are scarcely applied and urban wastewater runs down to the agricultural lowlands (Fig. 2).

In our research, two main factors were identified as crucial in the internal and external sustainability of farms:

(i) *Farmers' qualitative and quantitative access to water resources*, since the main crops (rice and market-garden crops) require large amounts of water. The topographical position and the relative proximity of farms with industries and/or dense housing may have considerable importance in the nature of farming, its performance, its global sustainability, and the possible role of urban farms to quantitatively and qualitatively regulate water for the city;
(ii) *The distance and accessibility of the city for farmers*: proximity to the city may favour the direct sale of agricultural products, thus potentially boosting local agriculture (Cour, 2004); conversely, it places pressure on agricultural land and may generate competition for the labour force between agricultural and urban activities. However, it can also allow farmers' households to supplement their income through employment in the town.

Research methodology

The ADURAA project was designed to qualify and/or quantify these functions and factors in the urban agriculture of Antananarivo. Knowledge on the diversity of this urban agriculture (a current phenomenon in diverse contexts, Moustier and Danso, 2006) is useful to understand the different functions and types of sustainability, to anticipate the possible futures, to determine the master plans, and to define the different forms of public policies.

The project brought together research specialists in agronomy, geography, economy and environmental chemistry (Fig. 3). Researchers from other disciplines such as animal science, sociology or landscape science could have made a useful contribution. Without them, certain functions of urban agriculture, such as landscape, preservation or recreation, were not analyzed but were nevertheless discussed with urban planners. We worked in direct cooperation with the Urban Planning Agency of Antananarivo (BDA), and the choice of the main functions to study and of the specific sites and/or farming systems to analyze in depth was made jointly. At least four annual meetings between researchers and the BDA served to exchange information and to make decisions for the continuation of the research. Our PhD student in geography directly participated in the development of the new master plan with the BDA in 2004.

The elaboration of a common typology of farms was our first step: 250 farms were surveyed in 9 areas. Sites and farms were chosen according to the two main factors of sustainability: access to water, and distance to/accessibility of the town. Each farm survey included: (i) a description of the family, including members living without working on the farm; (ii) a description of the farming production system (size, land tenure, types of soils, crops, livestock, labour force – permanent and seasonal –, equipment); (iii) the

[2] As for solid waste, it is put in a tip, where some is sorted. Urban gardens and parks are the main users of this compost but in the ADURAA project we tested its possible use in suburban market-gardening systems, with some success (N'Diénor, 2006). We will not describe this experiment here.

Fig. 1. The presence of agriculture in the Antananarivo district. (a) A watercress valley inside Antananarivo; (b) a rice lowland inside Antananarivo; (c) the North Rice Plain of Antananarivo; (d) a lowland in Antananarivo, aerial view.
Photos: C. Aubry (c).

Fig. 2. Degradation of irrigation water by industrial effluents. (a) Industrial effluents of a textile fabric going directly into irrigation canal; (b) milk cows grazing in an abandoned rice parcel at the exit of the industrial zone of the South Plain.
Photos: C. Aubry.

farmer's data about yields, proportion of own consumption, and selling modalities (where and when, direct selling or not, prices); and (iv) the other income activities of the whole family. Some of these farms were then used for investigations in other disciplines (for example measurements of chemical or organic pollution of water and repercussions on agronomic performance of rice in a diversity of rice farms), which are not reported here.

The characterization of farm and territorial sustainability was the main problem. A pragmatic approach was set up, based on our knowledge of the diversity and functions of farms and sites, and on our direct relationship with urban planners. We sought not to quantify but only to compare levels of sustainability. The analysis of dual sustainability was therefore not done farm by farm, but by cross-comparing farm types and sites.

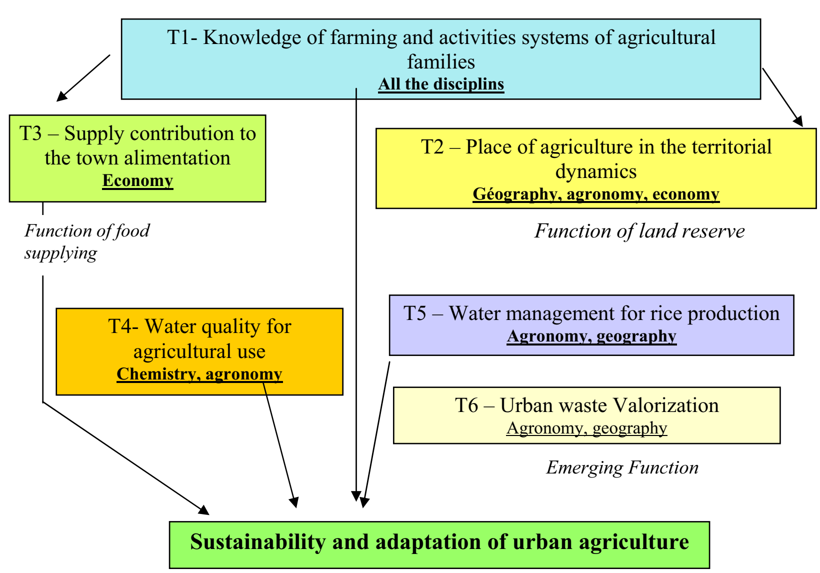

Fig. 3. The interdisciplinary building of the project. Ti: topics of the projects.

As regards farm economic sustainability, we had no access to reliable quantitative data on economic results. We therefore resorted to our survey data on production and prices, in cases where products were sold, and on extra activities like brick-making, external employment etc., for other incomes (see below). We compared these estimated global farming incomes with the minimum wage the agricultural family could have if the adults all worked off the farm (below, equivalent, over). As for social viability, we chose to highlight the farmers' opinions on the farm workload (workload may be a crucial point of non-sustainability, Petit et al., 2010) because it was also impossible to strictly quantify work load in our case. This globally estimated farm workload was also compared (below, equivalent, over) with work hours in offices and/or factories (the most common jobs in the city) for the whole household involved in agricultural and para-agricultural activities (see below). In some cases, farmers added qualitative assessments of their living conditions, especially in areas with serious pollution problems. For resources sustainability, the notation was based on our field results from agronomic and environmental chemistry measurements on water quality and input uses, for at least some of the production systems (rice systems on the plain, near industries, watercress production systems, market vegetable systems). These technical data are not detailed here (see in Aubry et al., 2008). For the "social" sustainability of a farm, other authors have proposed taking into account the farmers' involvement in professional groups; or for assessing the economic sustainability, taking into account the value of the farm land if it were sold for urbanization (Ba, 2007; Ba and Moustier, 2010). In our case both indicators were unfeasible because: (i) the social configuration of farmers near Antananarivo results in professional groups being very scarce and/or inactive; and (ii) the "value" of land inside and around the city totally lacks transparency (Ramamonjisoa et al., 2007).

Our direct cooperation with urban planners was our main way of assessing the "territorial sustainability". The first criterions used were the existence (or not) of urban projects by the BDA, and where relevant their types, with regard to the different agricultural sites and systems. We then discussed with urban planners the functions that they recognized (or not) for agriculture in each type of farming system and/or site, as well as their ranking of these functions. For some production systems or sites, it was possible to add to this territorial sustainability "from urban planners", a qualification determined by other urban dwellers (farmers' relatives living in the city, retailers or consumers on the markets). During surveys designed to quantify the alimentary function, for example, some of these dwellers stressed the importance of keeping these production systems inside or near the city, for reasons explained below on examples.

Determining "objective scores" to assess urban agricultural sustainability remains a scientific challenge. Nevertheless, our approach, without using rigorous indicators, may provide some useful decision-making support for the stakeholders.

In the following section we present a global review of the diversity of urban agriculture in the Antananarivo district (3.1). We quantify and qualify some main functions (3.2) and then show, through specific farming systems and sites, our dual sustainability and multi-functionality approach (3.3) as a direct support for local land-use policies.

Results

Diversity and flexibility of urban agriculture in Antananarivo

The spatial distribution of farming systems mainly depends on water availability. A low-input rice production predominates on the floodplain and lowlands and intensive market gardening predominates in the hills, with cattle kept for milk and manure production (N'Diénor et al., 2011). Small-scale animal production systems (duck, geese) also linked to water availability, are found in most of the rice fields (and watercress systems in some of the lowland urban areas). In total, 38 production systems have been identified, showing a high level of diversity of farming in and around this town (Aubry et al., 2008).

Fig. 4. The bricks activities in the Plain of Antananarivo: a farmer making bricks during the dry season.
Photo: C. Aubry.

As frequently reported in suburban areas (Mougeot, 2000; Bryant, 1997; Temple and Moustier, 2004), many of the farmers have other activities. Thus, an analysis of all the activities of the household (Laurent et al., 1994), rather than just agricultural production systems, is required to understand the strategies of the households and their relationships with the town. In our study, para-agricultural activities which supplement the farmer's income, using the farm's resources, were found to be both very frequent and diverse: some of them extracted value from the resources, equipment or labour force of the farm (renting out of teams of oxen, temporary employment for agricultural works on other farms), whereas others directly extracted value from the products and by-products (direct selling of vegetables, fish or bricks – see below). External activities were identified in all sectors of industry, commerce and services, and were more diverse and frequent when the city was easily accessible (N'Dienor and Aubry, 2004; Ramamonjisoa et al., 2007): salaried jobs (private companies, working as domestic staff), small businesses, building industry (bricklayer, carpenter) and local crafts (basketry, embroidery, sewing).

The typology of farms was based on the relative contributions of agricultural, para-agricultural and external activities to the family income, or the relative amounts of time devoted to these activities. Urban farms were classified into three groups of systems of activities combined with diverse agricultural production systems (Table 2). One of the most frequent systems in the floodplain is the "bricks-rice-duck-fishing" system, for small farms (less than 0.5 ha), combined with para-agricultural and external activities: on the same rice plot, one finds rice production (from September to February), duck farming and fishing after harvesting and during the long period of drainage (from February to June), and brick-making (bricks being the principal and cheapest construction material in Antananarivo) once the rice fields have drained (July–September, Fig. 4). This activity is inherently unsustainable: after four to five years of brick-making on the same plot, the farmers reach anaerobic layers of soil unfit for both rice cultivation and brick-making. At that point they often request authorization from the municipality

Table 2
Some activity and production systems in the agriculture of the Antananarivo district.

Zone	Main activity system	Main agricultural production system	Other agricultural productions	Para-agricultural activities	External activities
North rice plain	C–A	Irrigated rice	Poultry (cattle), fishing	Bricks, fishing, agricultural employment	Urban employment
South rice plain	C–B	Irrigated rice	Poultry (cattle for milk)	Direct selling, to factories	Industrial workers
Urban valleys	A–C	Watercress	Market gardening, rice, poultry	Direct selling to markets, agricultural employment	Urban employment
Peri-urban valleys	A (C)	Vegetables (tomato, leafy vegetables)	Rice, cattle (milk, manure)	Agricultural employment	Selling of crafts

A, B, C: groups of activity systems. A: only agricultural and para-agricultural activities for the whole family; B: an external activity for at least one of the family's member (not the farmer him/herself); C: external activities of the farmer him/herself. The first letter indicates the *main activity system* in this site: A–C means that A is major, C also present but B is absent; A (C) means that C can be encountered but very scarcely.

for embankment, so that they can prepare the plot for building in the future. The para-agricultural activity of brick-making is often seen by farmers as the first step towards a radical change in land use.

The diversity of farm households' activities enables farms to adapt to the urban environment and increases the role of agriculture in urban life. For example, during a political crisis in Madagascar in 2002,[3] farms were used as "refuges" of work for family members temporarily unemployed and surviving on agriculture (N'Dienor and Aubry, 2004). However, the level of re-investment of non-farm incomes in agriculture is very low, as the combination of agricultural and non-agricultural activities is a survival strategy for most households. Only landowners with high incomes from well-paid external activities re-invest their earnings in farming (dairy cows and/or land purchases for rice or watercress systems).

Main functions of urban agriculture

The functions of these diverse agricultural systems were analyzed under the ADURAA project (Aubry et al., 2008). In this paper we illustrate only two of the most significant: the food supply function and the city flood-protection function.

An important and changing food supply function

Our analysis of the food supply function focused on the adjustment between supply and demand of agricultural products in the markets of Antananarivo, in terms of quantity, quality, variety, availability, preferences and choice. We also analyzed the structure and dynamics of supply chains, assuming that the spatial location of production and the length of marketing channels affected their performance. We combined this supply chain analysis (from the city point of view) with an analysis of the roles of these products on the farm itself. We focused on rice and vegetables, more particularly tomato and watercress, because these products represent a significant proportion of the diet of the inhabitants of Antananarivo and are produced by various farming systems.

Antananarivo needs around 175,000 tons of rice per year, one fifth of all the rice sold in the country (Minten and Dabat, 2006; Dabat et al., 2008). Urban agriculture provides a significant proportion of this amount, about 24,000 tons per year (14% of total consumption). This rice is essentially consumed by the farmers and their families, but up to 15,000 tons may be sold on the market, depending on the year and the yields. This consumption includes the farmers' extended family living and working in the town (Dabat et al., 2004). Only some large farms on the northern plains contribute significantly to the rice sold on the market every year. The local rice, harvested mainly from January to February, helps to regulate the market at times when other sources fail, particularly during the early lean period (December and January). Thus, the urban rice of Antananarivo, despite low mean yields (1.5–2.5 t ha^{-1}) due to the scarcity of inputs and a lack of water management, contributes substantially to the diet of farmers and urban households and plays a significant seasonal role in the market (Dabat et al., 2006). This food role of agriculture has also been demonstrated for several horticultural products, including tomatoes, carrots and cucumbers. The surface areas under tomato have significantly increased close to Antananarivo over the last 15 years, to meet the growing urban demand. Presently, 91% of consumers in Antananarivo buy tomatoes several times a week. Tomatoes are considered no longer as a seasonal product but as "all season", for the altitudinal gradient of the land around Antananarivo allows for almost continuous production (N'Diénor et al., 2005). As in other regions of Madagascar, tomatoes have become a profitable product for the diversification of an agriculture traditionally based on rice (Moustier and David, 1999).

A comparative analysis of the incremental production costs related to the proximity of the city was conducted on rice and tomatoes. It showed the suburban location to be the best for both. Rice cultivated inside the town is disadvantaged compared to suburban rice, due to the scarcity of land, the cost of labour and the irregularity of the water supply. On the other hand, tomato production in the more remote areas suffers from high transport costs and product losses during transportation. These findings demonstrate the economic efficiency of some forms of urban agriculture, based on the optimal location of production areas in terms of input costs (Dabat et al., 2010a). Farmers fully understand these relative values: agronomists and geographers have shown that in the suburban hills, farmers are now turning to market gardening on the lateritic hills (called "*tanety*"), formerly devoted to basic food crops (cassava, sweet potato) or to pastures for cattle.[4]

Urban systems producing watercress (a product that Madagascans relish) strongly question the food supply function: at least 90% of the watercress consumed in Antananarivo comes from urban agriculture on 37 spots in the city, with a total surface area of around 7 ha and some 340 producers. However, environmental chemistry studies have shown that some watercress is produced with water of poor hygienic quality that may even be dangerous for public health. The ADURAA project has shown emerging segmentation of the watercress market: individual consumers and some

[3] After a controversial presidential election in December 2001, a major political crisis paralyzed Madagascar and especially Antananarivo for six months. Many small private companies (many of the employees of which are also farmers) were closed during this crisis, resulting in high levels of unemployment in the city. Another crisis started at the beginning of 2009.

[4] This recent spatial dynamic (for the past 10 years or so) has led farmers to develop a multiple-year system for increasing the fertility of these inherently unfertile *tanety*, based on the use of large amounts of manure and fertilizer (N'Diénor et al., 2011).

supermarkets prefer watercress produced in suburban areas with clean water. A specific study (project QUALISANN, 2007–2010) is underway to analyze these phenomena by means of a combined technical, nutritional and economic approach (Dabat et al., 2010b).

The increasingly recognized function of protection against flood risks

Urban expansion in Antananarivo has mainly affected urban agriculture, with the building of embankments on the rice plain, the easiest site to urbanize. Squatters on slopes and on flooded urban lowlands have also encroached on agricultural land recently. The agricultural plain historically acted as a buffer zone, preventing or limiting the flooding of slums, but the chaotic embankments on the plain and the unofficial brick-making activities (leading also to embankments) have profoundly disrupted the hydrological system. The rice plain is now flooded irregularly by the Ikopa River, which borders Antananarivo, with negative consequences on rice yields and with longer periods of drainage in the dry season, according to surveyed farmers. Urban planners now consider there to be a risk of dam rupture and flooding in the capital. In the town, agricultural lowlands also act as a buffer zone: our geographic studies show that they can store large amounts of water, using a system of bunds managed by farmers. For example, a valley of 287 ha can store up to 850,000 m^3 of water, corresponding to three successive days of heavy rains. These findings argue for a limitation of infrastructure projects on the lowlands, as tropical storms or hurricanes occur every year and, according to surveyed farmers and urban planners, are becoming more frequent and powerful with climate change.

However, the maintenance of an agricultural use of these areas raises other problems: the agronomists, chemists and geographers of the project showed that the urban lowlands collected mostly urban wastewater, in a city largely devoid of sanitation structures. When the organic content of the lowlands water exceeds a certain threshold, rice remains in a vegetative state and cannot produce grains, whereas watercress thrives in these conditions (production levels are double those of suburban zones, in which water is clean). Farmers can then often switch from rice to watercress in organic polluted lowlands. Watercress may thus be considered as a “product of urbanization”. Chemists have moreover shown that watercress production helps to clean the water downstream, but to the detriment of the sanitary quality of the product. The maintenance of these agricultural lowlands is potentially important because of their ability to contain floods and to buffer the city against the risks of erosion. They are also very profitable for farmers’ incomes, but they raise complex issues of public health, calling into question their “territorial” sustainability.

Farm and territorial sustainability of urban agriculture: implications for urban planning

The farm and territorial sustainability of urban agriculture in Antananarivo were cross-analyzed as a function of the diversity of the production systems and sites that we surveyed during the project. This analysis was shared with BDA. In this section we present only three of the cases studied (Table 3).

The dual sustainability diagnosis in three cases

The rice systems of the northern plain of Antananarivo have only low or moderate farm sustainability. Their poor agronomic and economic performances, due to very small size and rice yields, often result in little or no monetary income, so that farming families have to take on para-agricultural (Type A) or external additional occupations (Type C) to ensure the economic survival of the household. The global household economic activity is then lower than (when A) or equivalent to (when C) a whole family involved in urban work. Farmers are not overloaded by their farm work (except at precise

Table 3
Diagnosis of sustainability and recognized functions of agriculture in three sites and farming systems.

Sites and types of systems	Farm sustainability			Territorial sustainability				Remarks
	Economical	Social	Resources	Urban projects	Functions recognized by urban planners	Other stakeholders	Balance	
North plain rice systems	– to + (A–C) Low rice yields	+ to ++ Some housing problems	+ to ++ No water pollution A few Bricks-making	None	1. Buffer against flood 2. Landscape 3. Food supply	+ Rice Farm = refuge and traditional values	FS + TF ++	Increasing economic balance for A types
South plain rice systems	– to + (B–C) External activities and direct selling	– Unhealthy living environment	– Polluted water A lot of Bricks-making	Indus-tries, roads, office and housing building	None	– Negative view because of pollution	FS – TS –	What future for farmers?
In-town valleys water-cress systems	++ (A) High productivity	++ An efficient work system (production-selling with family, she-retailers)	– Polluted water, chemical inputs	Roads, housing but flood risks	1. Food supply 2. Buffer against flood, water depollution 3. Social (work for farmers)	+ Fresh product supply	FS ++ TS ++	How limiting organic pollution?

Legend: A, B, C: types of activity systems. Notes of sustainability from – (low), + (medium) to ++ (high). For example in economical aspects:–means that farm activity (production and para-agricultural activities) lower rentable than a minimum salary wage, + more or less equivalent, ++ better than working for minimum wage (see text).

times of the year – transplanting, harvesting – when they resort to temporary labour) and therefore develop a complex combination of activities. However, some farmers noted that their living conditions could be improved, particularly concerning housing. As regards resources, water is not polluted by agriculture because no inputs are used, but brick-making (more by Type A than Type C farms) has a negative effect on land maintenance. Concerning territorial sustainability, urban rice production on this plain is socially well accepted by urban members of the agricultural families, for whom the farm is a refuge in times of hardship and a family tradition, with the fields often being seen as a heritage. Urban planners strongly recognize the fact that the production systems in this area have a critical environmental function in the absorption of floods. Secondly, and more recently, they also consider their contribution to the town's food security (as shown in the ADURAA project) and landscape (the northern rice plain is the first view one has of Antananarivo on leaving the airport and is considered very attractive – something that urban planners now consider to have some importance).

The territorial sustainability of these production systems is therefore high. As a result, both the systems and the areas in which they are located currently receive some protection from urban infrastructure projects.

The rice production systems of the southern plain are technically very similar, although with a lower productivity because yields are affected by industrial discharge and stiff competition for land from growing industries. Their economic results (direct selling of poultry to the employees of the industries in the area, brick-making, external incomes) are generally lower when they are in Type B than in Type C. Social sustainability is low because these areas are not really suitable for human habitation, due to harmful fumes from industrial discharge and high levels of pollution in the fields, often resulting in the abandoning of these fields and many health problems (malaria, undrinkable water). In terms of resources, the soil quality is damaged by brick-making, and the water quality by industrial waste. Water has become a limited resource, in terms of both quality and quantity, for agricultural activities as well as human needs. As for territorial sustainability, urban projects are numerous here, with the foreseen extension of the existing industrial area, housing and roads. Urban planners consider the food supply, environmental protection and landscape maintenance functions of these systems to be less important than on the northern plain. Farmers' neighbours have a bad opinion of these farming systems because of the visible pollution. This low territorial sustainability is consistent with our findings highlighting the health risks of agricultural production in these conditions.

The watercress systems within the city show a discrepancy between farm and territorial sustainability, and a possible evolution of the latter. In terms of farm sustainability, their economic performance is very good (many families have only agricultural activities – Type A), as is their social sustainability, because the workload is shared among farmers and retailers. The drawbacks could stem from the use of resources, but whereas these systems use polluted water and sometimes pesticides, they also absorb the organic pollution of urban water and their continuous cultivation protects the lowlands against brick-making or excessive informal housing. Territorial sustainability is not so good: many infrastructure projects are implemented in the urban lowlands (roads, housing). Nowadays, however, local authorities, interacting with the ADURAA project, recognize the major contribution of watercress systems to the urban food supply. The consumers surveyed in the markets likewise acknowledge this contribution but are now also concerned about the risks to human health that these systems may generate. They nevertheless take into account their important environmental functions: flood absorption and the cleaning of wastewater. To highlight the questions of health risks, the first results of the Qualisann research programme confirmed the variability of microbiological contamination of the watercress itself, linked to the variability of the water quality in the lowlands. They also showed however that consumers have adapted by cooking the product and using it as they do other leafy vegetables, even though traditionally it is consumed raw (Dabat et al., 2010b). Thus, while the sanitary quality of used water must indeed be improved, we note a limitation of risks owing to consumers' attitudes. This confirms the positive roles of watercress production for the farmers and the city.

Decisions on land use in Antananarivo

The land use decisions in Antananarivo have been largely inspired by this common analysis of the functions and dual sustainability of urban agriculture (Fig. 5). In this figure the red zones represent the new zones to urbanize as a priority (housing essentially).

On the northern plain, it was decided to create a protected agricultural area of 2000 ha of extension so that its role as a buffer zone against flood risks could be recognized. Rice farming systems are considered to be "the most effective and cheapest way to achieve this protection" (Rahamefy et al., 2005). Second, in 2004 the city council of Antananarivo decided to suspend authorization for the embankments, a decision still in force today. Third, the landscape function of this northern plain was recognized through the creation of a "living museum of plants" which includes the existing farms, and of footpaths so that inhabitants and tourists can travel through and enjoy this beautiful landscape, obtain information about rice production, and buy crafts. The logical consequence of this recognition of a "buffer" function of rice production on the plains is the reversion to the previous development pattern of building on the hills, provided for in the new urban plans. However, urbanization on the hills requires measures to prevent erosion, which are of course only possible if housing developments are controlled.

Conversely, the southern plain agriculture is heavily "sacrificed" to urbanization as the authorities consider that, in these zones of poor agricultural sustainability, the construction of industrial infrastructure can be pursued. To alleviate the problem of industrial effluents, a collective sewage plant for the whole industrial area has been planned. The status of brick-making has not yet been decided: the local authorities, aware of its role both in urban construction and for farm household income, do not want to definitively ban it, yet are aware of its destructive impact on farmland and the water system. As far as we know, only one municipality near Antananarivo has made a clear choice by zoning brick-making permits and thus authorizing them only near a main road under construction.

Road projects in some watercress system lowlands are still on standby, as risks of flooding, erosion or even landslides (as we demonstrated in the ADURAA project) on future roads are now taken into account. The authorities are also reluctant to sacrifice the watercress farms because of their multiple functions (food, economic and environmental). Reflection on this subject has moved up to regional level, with a search for possible nearby suburban areas in which cleaner water sources could be used to produce watercress for consumption raw, in less risky conditions, as a partial alternative to the current production systems within the city.

In the Malagasy capital, the recognition of urban agriculture as a part of the urban landscape is therefore under way. A "green spaces and urban agriculture" Directorate was created in 2008 in the municipal services. In 2009, the city authorities requested joint action by the ADURAA research team and the RUAF (Resource Centre on Urban Agriculture and Food Security), to define the strategic planning of agriculture in the city. A platform of various stakeholders concerned by urban agriculture has now been set up and a FAO project to support urban agriculture has been revived.

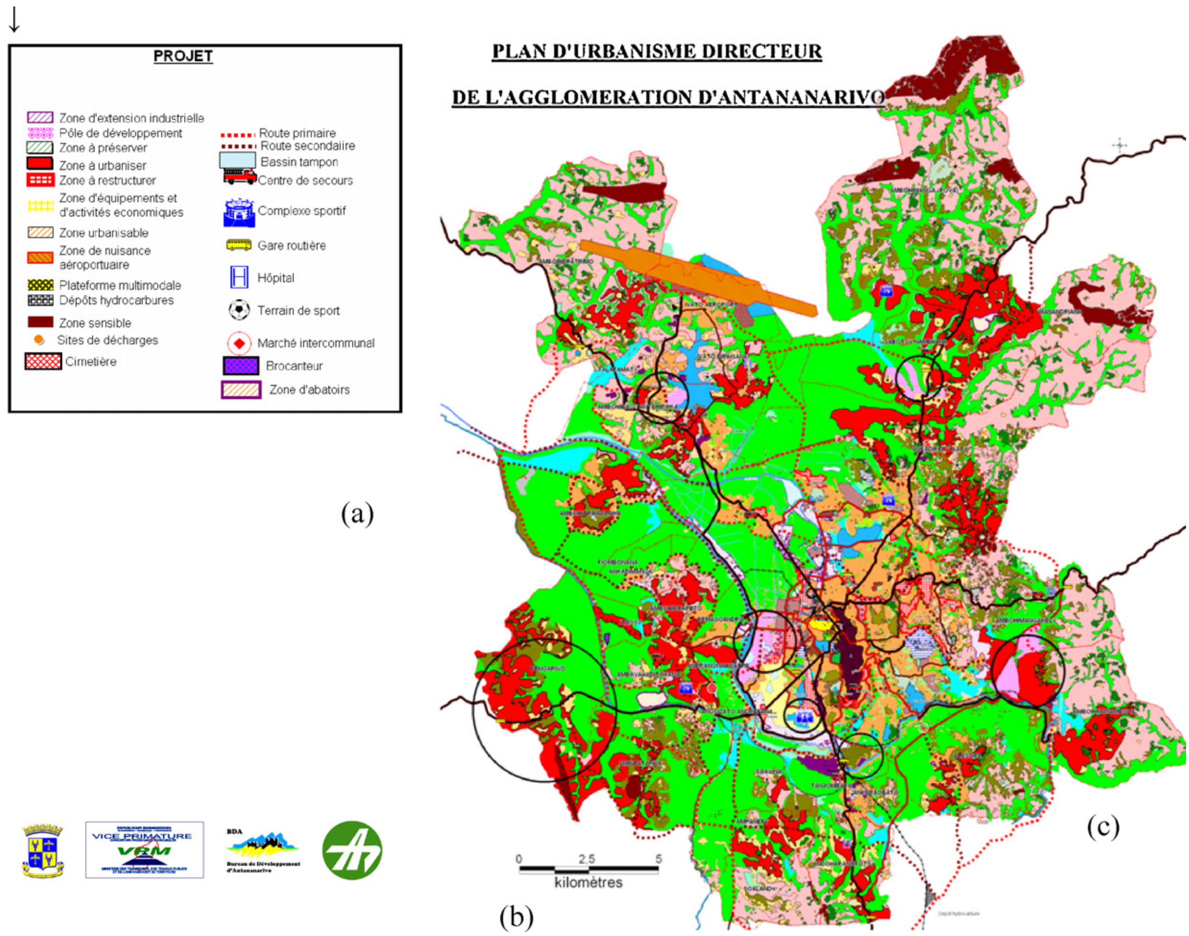

Fig. 5. The master plan of Antananarivo of 2004 (PUDi). (a) The north plain: to maintain in agriculture; (b) the south Plain: to urbanize; (c) inside lowlands with different futures (in blue in the map). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Discussion and conclusion

The growing urbanization in developing countries directly calls into question the future of urban agriculture for enhancing urban food security, alleviating urban poverty, and contributing to cities' resilience to climatic changes. As urban agriculture in these countries has frequently developed along with increasing urbanization (Bryld, 2003; Cour, 2004), its status has gone "from marginalization to legitimization" by local authorities (Cissé et al., 2005). Its role in feeding the city and employing the poorest urban dwellers appears to be accepted more and more (Howorth et al., 2001; Ruel and Garrett, 2004), even if precise data to assess these trends are often lacking (Zezza and Tasciotti, 2010). For urban planners, the real challenge is to decide which, where, how, and for what reasons urban agriculture has to be preserved or even developed as a buffer against urban spatial extension.

Urban planners urgently require methods and tools to determine as rationally as possible the most appropriate roles for urban agriculture in the development of cities (Wilson, 2006). Some such methods and tools have recently been proposed by geographers, based on GIS zoning (Zeng et al., 2005; Nguendo-Yongtsi et al., 2007; Thapa and Murayama, 2008), and by economists (Parrot et al., 2008), sociologists and political scientists (Parra-Lopez et al., 2009; Turpin et al., 2009). The methodology built in the case of Antananarivo is a complementary one: based on a detailed analysis of the functions of urban agricultural systems, through a multidisciplinary approach, it diagnoses the farm and territorial sustainability of these systems in direct partnership with urban planners. Some significant results have been obtained. First, the diversity of urban farmers' activities is very clear in Antananarivo, as it is in many other urban agricultural settings in the North and in the South (Aubry et al., 2005; van Venhuizen, 2006; Ba, 2007). The description of this diversity, of its determinants, and of the relationships between location and technical and economic performances of urban and peri-urban agricultural systems are therefore necessary before taking any decision. Second, the concepts of multi-functionality and dual sustainability have proved their relevance when applied to real decision-making situations. For urban planners, they are useful tools for comprehensive planning and for assessing the potential value of urban agriculture, even if more detailed studies are required at a specifically local level. We have verified the importance of urban planners' recognition of the functions of urban agriculture, to help them in reconsidering its role. Third, some functions appear to be diversified: food is a major function of urban agriculture in Antananarivo when it comes to perishable horticultural products, – as in many developing countries (Moustier and Danso, 2006; Parrot et al., 2008; Aubry et al., 2010) – although the production of urban rice for local consumption also appears to be significant, both quantitatively and qualitatively speaking. This fact is seldom reported for this type of starchy food (potentially transportable over long distances) even though it has already been shown in other contexts for cassava (Cour, 2004). The ADURAA project has contributed to changing the authorities' point of view with regard to urban agriculture, by highlighting the diverse relationships between agriculture and the city.

However, this method does have some limits. The small number of surveys reduces the statistical representation of our study and underlines the real and worldwide need for reliable statistical data on urban agriculture (Zezza and Tasciotti, 2010). Some systems and/or functions have not been taken into account, due to the lack of adequate competencies in the research group. Certain farm characteristics (precise cultural practices and yield levels, economic balance for each type of farm) could not be informed without monitoring a sample of farms, which was not materially possible in our case. The way the methodology was designed to assign a score to the different items of dual sustainability and to reach conclusions is also debatable: we still lack consistent indicators for the quantification of both "farm" and "territorial" sustainability. Nevertheless, our experience shows that an expert approach (based on surveys, farm typology and a set of disciplinary researches) and dialogue between researchers and urban planners (or even other stakeholders) for reaching agreement on sustainability levels and the hierarchy of functions may be acceptable in the short term, to maintain agricultural spaces or not. Moreover, it may lead to new attitudes and programmes in the more uncertain cases, those where there is a discrepancy between "farm" and "territorial" sustainability. In Antananarivo, that was the case of the urban watercress systems. For us as researchers, our uncertainty led to new research programmes about environmental and sanitary risks which are now yielding new knowledge about these systems and the reality of the attendant risks; for urban planners, the decision was to suspend a possible road programme. The proposed methodology therefore leads to new questions, where the decisions (taken or postponed) reflect the trade-offs made by stakeholders at a given point in time. Cases where stakeholders have a fuzzy vision of what could be a desirable sustainable development of the city and its agriculture are probably frequent in urban agricultural strategic planning; but even in these situations, research may enlighten the possible hierarchy of functions and thus contribute to the debate.

A follow-up step of this methodology would be to examine the expected future of urban agriculture if technical, organizational or marketing innovations were applied. For example, in relation to the use of resources, the sustainability of watercress production systems could be enhanced if efficient water treatment in the lowlands allowed for the risks of organic pollution to be limited. More generally, the assessment of the dual sustainability of these urban agricultural systems and their consequences on land use should include a prospective analysis of their potential improvements. For example, the possible health and/or environmental risks of urban agriculture need to be weighed up against the benefits for farmers and urban dwellers, and the need to be properly supervised, without always prohibiting agriculture but rather adapting it (Dubbeling et al., 2010).

Finally, the integration of urban agriculture into urban planning, a hot topic in developing countries and worldwide (Vandermeulen et al., 2006), is less a question of global land shortage in and around cities than one of political will and of adequate knowledge and methods – which, in turn, need the involvement of applied research. Our experience in Madagascar shows that research can spawn some valuable expertise, through extensive multidisciplinary work. But it also underlines the fact that helping urban planners to assess urban agriculture futures implies a real scientific challenge nowadays to manage concepts and propose methodologies and indicators.

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