

Can farmers extend their cultivation areas in urban agriculture? A contribution from agronomic analysis of market gardening systems around Mahajanga (Madagascar)

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ABSTRACT

The rapid urbanization in developing countries implies an increasing pressure on urban agriculture for production. As most perishable food products come from this agriculture in close proximity to population concentrations, we analysed from an agronomic point of view how market-garden farmers can meet this increasing urban demand. This work took place in the case of Mahajanga, a secondary city with high increasing demographic rate on the Northwest coast of Madagascar. Based on preliminary surveys to characterize the farming systems (on a sample of 91 farms), 11 market-garden farmers chosen in the three main agricultural zones of the urban area were surveyed during two years. Surveys aimed at understanding their decision rules in crop choices, crop allocation to land and resource management, and to estimate their room for manoeuvre to increase their leafy vegetable areas under cultivation. The wholesalers and retailers who buy the farmers' produce were also surveyed. A previous model of decision rules regarding crop location on farm territory was used to analyse the on-farm surveys and cartographic methods (GIS and on-farm manual representations) were used to quantify the land use. We highlight the following major points. (1) The leafy vegetable production in the surveyed farms already intensively uses land: farmers have complex decision rules largely depending on the water dynamics in the two main environments (lowlands and lakesides) where leafy vegetables are cultivated during the dry season. (2) The scarcity of farmers' resources (labour money and water) leads to very little internal room for manoeuvre to increase the leafy vegetable production in the farms. (3) At territorial level however, some land reserve exist in one of the lowlands, but not on lakesides. The water availability for agriculture must be better informed through specialized hydrologic studies, as one of the main constraints nowadays to extend the agricultural area. An extrapolation to other cases of urban agriculture is then discussed as well as the role of agronomy to help urban planners to consider the place of agriculture in the urban development.

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Introduction

The global phenomenon of urbanization is accompanied by a growing demand for food that raises the problem of securing urban food and nutritional supplies (Drechsel et al., 1999; Fleury and Moustier, 1999; Bakker et al., 2000; Griffon, 2003; Van Veenhuizen, 2006). In 2007, more than 50% of the world population lived in cities (Véron, 2007) especially in developing countries: in Africa, as shown by recent prospects (United Nations, 2006; Mougeot and Moustier, 2004), the percentage of people living in the cities will

rise from 41% in 2007 to 54% in 2030 (in Europe respectively 74% and 80%). This rapid urban growth affects big cities like capitals, but also secondary cities, which spread to rural areas and mostly to agricultural spaces (Parrot et al., 2008). In developing countries, where poor transportation between rural areas and cities generate important problems for food supply (quality, cold chain, and energy costs), this demand relies in part on agriculture inside or close to the cities (Bricas and Seck, 2004), called urban agriculture. The latter refers to “agriculture located within and around cities whose products are at least partly destined for the city and for which alternatives exist between the agricultural and non-agricultural uses of resources” (Moustier and Mbaye, 1999).

This urban agriculture often plays a major role in supplying perishable products to the cities (Moustier and Danso, 2006). The market-gardening products, and among them the leafy vegetables,

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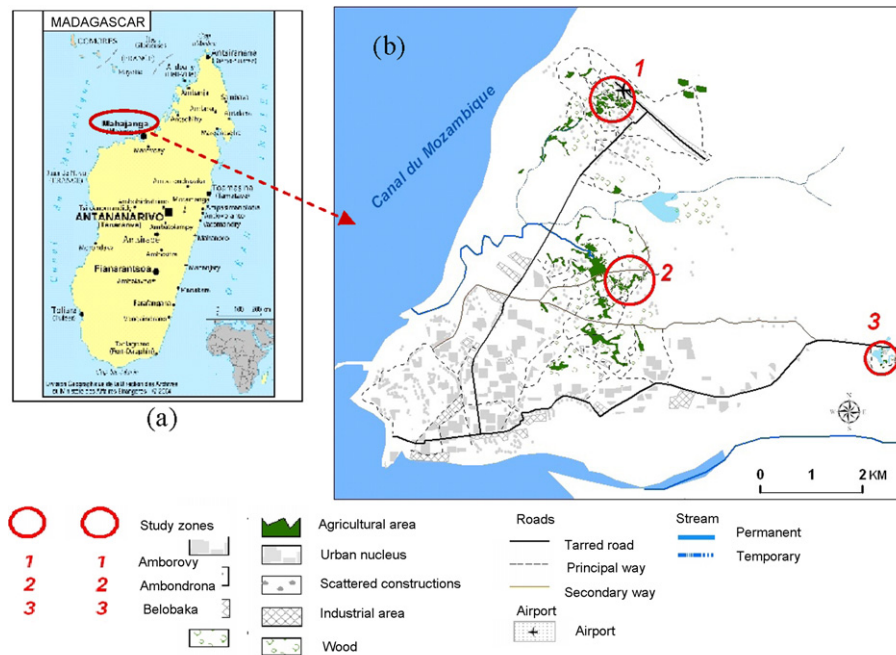


Fig. 1. The geographical location of Mahajanga (a) and the productions zones (b).

play an important role in the population's diets, filling an essential share of nutritional and medicinal needs (Gockowski et al., 2003; Kahane et al., 2005; Smith and Eyzaguirre, 2007). Thus, it is often observed that market-gardening farming systems including leafy vegetables are recently increasing inside or near the growing cities (Nguni and Mwila, 2007; Parrot et al., 2008; De Bon et al., 2010), which corresponds to a growing urban demand.

We studied, in a secondary city of Madagascar, Mahajanga, how urban farmers use the land for leafy vegetable production, and how they could extend their production to meet growing urban demand. This question is relatively new for researchers. Recent geographic research has been undertaken in Vietnam (Thapa and Murayama, 2008) to evaluate the possibility of extending the surface areas of urban agriculture: these authors classify urban territories according to various criteria and they discuss their potential to be developed into urban agriculture. Although this approach is very useful for urban planners, it does not take into account farmers' capacities to manage these land resources. On the other hand, economic models allow quantifying the evolution of urban horticultural activities and their relationship with material and non-material resources (Parrot et al., 2008). However, the question of the technical capacities of farmers to meet growing urban demand remains open to study.

From an agronomic point of view, increasing the vegetable production on farms may be obtained through increasing yields per surface, within the limit of local farmers' technical capacities, and/or through increasing the cultivated surface areas (Agbonlahor et al., 2007). The latter possibility, which is the focus of the present research, is an important issue in urban agriculture where access to surface areas is particularly difficult because of the potential competition with urban uses (habitat, infrastructures, etc.) (Temple and Moustier, 2004). In such situations, it is necessary to analyse how the agricultural land is currently used for the different agricultural products on the farms: firstly by understanding how farmers decide where to locate crops over their farm territory, secondly by evaluating their room for manoeuvre to possibly increase these areas.

This paper aims to evaluate the determinants of the variability between farms of the cultivated surface areas cropped with leafy vegetables and of the potential extension for these areas, depending on farmers' decisions and/or of exogenous factors of land policy.

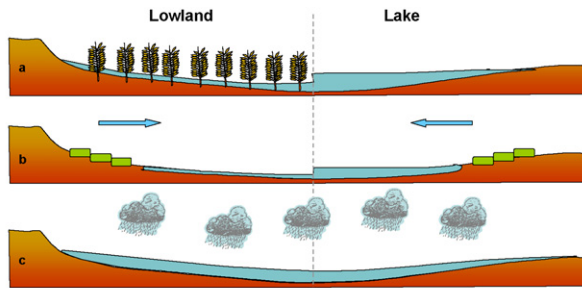
Methodology

Case study

This study was carried out in the periurban area of Mahajanga, a city located in the northwest of Madagascar ($15^{\circ}25$ south, $46^{\circ}11$ east) (Fig. 1a). Mahajanga is the third largest city and the second largest harbour of Madagascar. It is also the first touristic destination in Madagascar (PRD Boeny, 2005), with a high (no statistics available) frequentation by tourists from the capital Antananarivo and also European ones who come to Mahajanga, chiefly during July and August.

With around 230,000 permanent inhabitants in 2003 and an annual increase rate of 3%, Mahajanga is one of the most rapidly developing cities of Madagascar (PRD Boeny, 2005). Extended over 53 km², with a modal density of 76 inhabitants per hectare, the district of Mahajanga shows a great variability of population density between its 26 quarters (PUDI, 2003).

This zone has an arid, tropical climate with 1400 mm of annual rainfall mostly in the rainy season (80% of the rain falls between December and February). The average temperature is 25 °C, higher in the rainy season but with low thermal amplitude throughout the year (less than 10 °C). The soils in the urban district are mostly sedimentary: sandy soils near the sea, with salinity risks which prohibits agriculture in most of them and sandy-loamy red soils in other parts, with hydromorphism in the lowlands and risk of drought in the upper lands (locally called *tanety*). These sandy-loamy red soils are the mostly used by agriculture. Urban agriculture during the rainy season is dominated by rice, but in dry season by leafy vegetables with several productions (i) the traditional short cycle leafy vegetables (from 3 to 4 weeks between plantation and harvest) here called LVsc, like Fotsitaho (*Brassica*



a) During the rainy season, fields are flooded and cultivated with rice on the lowlands or left fallow on the lakesides; b) In the dry season, the soil gradually dries out (beginning in the highest areas and progressing down to low lying areas) which allows the establishment of market vegetable crops; c) the start of the rainy season involves a flooding of surface areas that marks the abandonment (gradual on lakesides) of market vegetable crops.

Fig. 2. Water dynamics and types of environment with market-gardening in Mahajanga: (a) During the rainy season, fields are flooded and cultivated with rice on the lowlands or left fallow on the lakesides; (b) In the dry season, the soil gradually dries out (beginning in the highest areas and progressing down to low lying areas) which allows the establishment of market vegetable crops; (c) the start of the rainy season involves a flooding of surface areas that marks the abandonment (gradual on lakesides) of market vegetable crops.

campestris var. *amplexicaulis* Lour.), Anatsonga (*Brassica Campestris* var. *peruviridis* Lour.) and Petsäi (*Brassica pекinensis* Lour.) (ii) the lettuce (*Lactuca sativa* L.), with a cultivation cycle from 4 to 5 weeks, more demanding in terms of labour, water and fertilizers than LVsc and more consumed by tourists than by permanent inhabitants (pers. comm. with the responsible of vegetable stand in the only one local supermarket), (iii) the traditional long-cycle leafy vegetables (3 months of cultivation at least, LVlc), which are harvested several times over the season and are represented by Mafane (*Splianthes acmelea* Rich) and Morelle (*Solanum nigrum* L.), (iv) other long-cycle vegetables, such as onions or cabbage, are also grown with a lesser extent.

The cropping season for market gardening ends with the first rainfall at the end of November, which indicates the beginning of the rice season on lowlands. Thus the cropping season for vegetables lasts 6–7 months, from April to the end of November, with inter-annual variations due to the rains beginning and ending: its real duration depends on the water dynamics in the different environments. Leafy vegetables are cultivated in two main types of environments (i) lowlands which are cultivated in rice during the rainy season, are then planted with leafy vegetables after the rice harvest in March, and when the water level gradually drops (ii) lakesides, uncultivated during the rainy season because they are under water and progressively cultivated following the progressive retreat of the lake water during the dry season (Fig. 2).

We worked on the three main leafy vegetables zones of Mahajanga (Fig. 1b). These zones, located between 3 and 7 km to the city centre, represent the diversity of the environment (lowlands and lakesides), especially on short-time leafy vegetable because they are the most demanded by consumers and they generally represent the majority of the farm land-use. These zones constitute the whole agricultural land extension inside and around the city, the other areas being impossible to cultivate because of great flood risks and/or high salinity of the soils.

Methodology of the surveys

One of the main problems of this type of study is the nearly total absence of initial data, mostly statistical ones, as in the majority of urban agriculture situations in developing countries (Cissé et

al., 2005; Dubbeling, 2009a,b; De Bon et al., 2010). Thus to select the urban farmers to be surveyed on their leafy vegetables systems, preliminary surveys were set up on a sample of 91 farms in order to identify the main farming systems of the region (Dumont, 2006): this sample consists in random sampling from lists established with administrative staff and old people from the quarters. The global data on farms (area, choice of productions, labour forces, etc.) as well as their history were the main information collected during this first phase. The domination of leafy vegetables in the farmers crop choices during the dry season in the urban area was then established and a typology was made that showed a strong diversity in terms of cultivated surface area, labour and activity systems.

Due to the length of the second phase of in-depth survey, a limited sample of 11 urban farms was constituted. The surveyed farms were selected inside the previous typology so as to explore in each of the three zones a diversity of types, taking into account also the diversity of marketing strategy. Table 1 shows the main characteristics of the selected farms.

In depth surveys were carried out on these farms during two campaigns (2006 and 2007) in order to analyse the decision rules of farmers regarding the choice and location of crops in the farm territory along the cultural season and the on-farm possibility of increasing the cultivated surface area in leafy vegetables. The first task was to record the farm territory. Based on this field pattern scheme, the second task listed the crop locations rules and the determinants of these choices, as well as the opportunities for, and obstacles to, a possible increase in cultivable areas. These surveys were complemented with observations made during regular visits (every 10 days) to record the number of plot planted with each leafy vegetable at the date of the visit and the cultural practices of the period.

The analysis of the marketing systems of the leafy vegetables consisted in two surveys (i) a general survey at the scale of the city (Audois, 2007), analysing the supply chains in the markets of the city (40 farmers, 34 wholesalers, 137 retailers and 107 consumers) (ii) specific surveys during the dry season with the retailers who supply the urban markets from the 11 surveyed farmers. These latter surveys carried on (i) the establishment of their farmer's network, (ii) the choices of various products on the farms, the quantity for each product and the price setting and their evolution during the season (iii) the logistics of transport from farm territory to urban markets and (iv) the modalities of deals and their potential influence on cultural practices.

Methodology of data treatment

Farmers' decisions about the crop locations inside the farm during the cultural season were represented through previous decision models, regarding decisions of crop management and crop allocation on the farm territory (Maxime et al., 1995; Aubry et al., 1998; Aubry and Dounias-Michel, 2006; Joannon et al., 2006). Without detailing these models, they express the decisions in terms of decisional variables, such as the *cultivable area*, that means the area that the farmer considers as suitable for each crop on his farm, or the *return time*, that means the minimum time span the farmer considers as suitable for cultivating again a same crop on a same plot (mainly taking into account the parasitism risks), as well as decisional rules and management units.

Here, all of the surface areas are expressed in number of "beds" (small-plots) (Fig. 3) because their size was found relatively stable from a farm to another (see below). The surface areas are calculated for each campaign (2006 and 2007) and for each farm (Fig. 4). All of the crops in the market vegetable systems studied are short-cycle crops. Due to the brevity of the cycles, several cycles of vegetables

Table 1
Main characteristics of the 11 surveyed market-gardening farms.

Farm	Type ^A	Environment		Total surface areas (m ²) ^B	Labour		Non-agricultural activity	Marketing strategy ^D	Main crops ^E
		Lowland	Lakeside		Permanent ^C	Temporary			
Ad1	II.3	X		1150	2	No	Yes	a	Lett, LVsc
Ad2	I.2	X		310	1	No	Yes	a	Lett, LVsc
Ad3	II.2	X		360	1	No	Wholesaler	b	Lett, LVsc
Ad4	II.3	X		1670	2	Yes (2007)	No	c	Lett, LVsc, LVlc, other
Ad5 ^F	IV	X		610	1	Yes	No	c	Lett, LVsc
Ab1	II.1	X		970	2	No	No	c	LVsc, LVlc, other
Ab2	II.3	X		900	2	No	No	a	LVsc, LVlc, other
Ab3	II.2	X		500	1	No	Yes	c	LVsc, LVlc, other
Bk1	III.3		X	1440	2	Yes	No	c	Lett, LVsc, LVlc, other
Bk2	III.3		X	950	2	Yes	No	c	LVsc, LVlc
Bk3	III.1		X	440	1	No	Yes	c	Lett, LVsc, LVlc

Adi, Abi: farms of two different Lowlands; Bki: farms on the lakeside.

^A Typology based on 91 farms sample (Dumont, 2006). Regarding path evolution, 3 types were identified (I, II and III) according to their conditions of installation (mainly land access). The subcategories (1, 2 and 3) are linked to (i) the evolution of the productive resources (especially labour forces and surfaces) during the life cycle of the farm, (ii) the presence or not of non-agricultural activities, and (iii) the marketing strategy.

^B For season 2006 (same area in 2007 except Ab3).

^C Temporary labour is frequently called upon, in variable frequency and duration depending on the farm.

^D a = farmer who makes direct selling and selling through wholesalers; b = farmer who sold his products and products from other farms to urban market; c = farmers only.

^E LVsc: short-cycle leafy vegetables (Anatsonga, Fotsitaho, Petsai); LVlc: long-cycle leafy vegetables (mafane, morelle); Lett: lettuce; others: onion or cabbage.

^F Plot survey not realized in 2007.

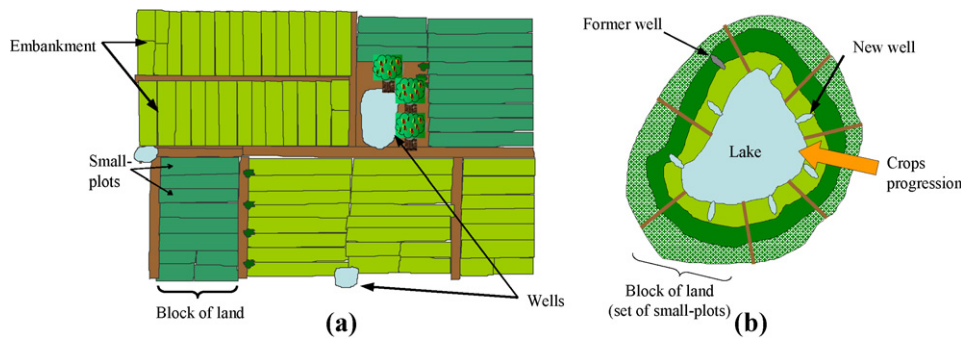


Fig. 3. The organisation of on farm land use, with wells and small plots on lowlands (a) and lakesides (b).

can follow each other on the same small-plot during a single campaign. The “cultivated area” is therefore the cumulative area of all of the areas cultivated during the various cycles; this is also called the *developed surface area* (Navarrete and Le Bail, 2007). However, to compare the different surface area variables in the model (developed surface area, exploitable area, and cultivable area, see below) over the time and between the farms, we created integrated surface area variables on the length of the cropping season.

Based on weather data and field observations, we estimated the range of the season to be from April 9th (average date of the end of the rains) to November 30th (average date of the beginning of

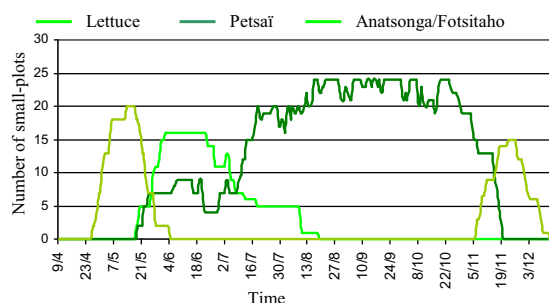


Fig. 4. Distribution of crops on small-plots in a farm (Ad5 – season 2006).

the rainy season). Thus for each variable V_h , $\sum_{i=p}^q V_h$ is the integrated surface area variable corresponding to the daily sum of areas V_h between $i = p$ (=April 9) and $i = q$ (=November 30). Furthermore, the processing of the surveys made it possible to map the market vegetable farm territory and to represent the cultivable areas of each type of vegetable, their possible evolution in space and time, and their effective use for each crop type.

To estimate the for manoeuvre for on-farm land extension possibilities, the actual values of some decisional variables inside the farm (Mawois et al., 2007) are compared to their potential values without modifying the farm resources (including their land resources); then the limiting resources are analysed and the farmer is questioned about how these limitations could be overcome.

We used GIS methodology based on aerial photographs allowing listing the cultivated and potentially cultivable surfaces. Moreover, due to the complex land use inside the farm, manual representations of the farm-land use during the cropping season were drawn. From these maps we can estimate the possibilities extending surface area for this agriculture.

To understand the commercial systems and to estimate the urban demand in leafy vegetable we quantified the flows of leafy vegetables between the sites of production and the selling places. An estimation of the evolution of the daily quantities sold by retail-

ers during the season was realized as well as the distribution of margins between various stakeholders.

A typology of the relations between farmers and retailers helped us to characterize the nature of the relations between retailers and farmers as well as the deal modalities.

Results

How does the intensity of land use vary between farmers?

The 11 surveyed farmers have various orientations in terms of total areas, labour capacities and choice of leafy vegetable crops (Table 1). Farmers have one or several blocks of land in the same environment (lowlands or lake). In these environments, cultivating during the dry season is only possible under daily irrigation. Thus farmers dig wells near their block of land to access water; they also divide them into small plots (Fig. 3).

It has been shown through the deep surveys that the small plot is both a technical management unit on the farm and a marketing unit. It is a rectangle of stable width (1.5 m on average, standard deviation 0.4 m, data calculated on 1266 small plots of our 11 farms during the two seasons) which is a width adjusted for the manual watering of half a small plot by a worker walking along the separation embankment, with one watering can in each hand (Picture 1). Their length is more variable but the average is 8.8 m (standard



Picture 1. A farmer on an embankment watering two small plots.

deviation of 2.2 m). At the small-plot level, the farmer decides the crop allocation and the crop management (plantation, fertilizers, watering, etc.). It is by small-plot that he/she also negotiates with retailers the harvest date and the sale price. At the beginning of the cropping season, the farmers have to set up the small plots, a very time consuming task (one person sets up no more than 3 small-plots per day). Between two crop cycles during the season, the farmers have to clear off the residues of the preceding crops and to plough it manually (at least 2 h per small-plot) before planting the next vegetable.

As already pointed out, the short cycle of leafy vegetables (21–35 days) allows several successive cycle on the same small plot during the cropping season. Furthermore, farmer's decision rules do not restrict the maximum number of cycles of a same crop on a given plot, as it was also noted in other contexts (N'Dienor, 2006; Navarrete and Le Bail, 2007). Thus, in theory, the use of land by farmers could be very intensive: up to 9 successive cycles of LVsc or 5–6 of lettuce on the same small-plot. However, investigating their decision rules on this topic, we showed that the reality is more complex and the use of land less intensive.

The allocation of land to the crops inside the farm territory depends on several decision variables:

- The “*maximal exploitable surface area*” (S_{max}) is the set of surface areas, on the farm territory, sufficiently dried out at a t time for small-plots to be set up and potentially irrigated (proximity of functional wells). The maximal exploitable surface is limited by the “*total surface area*” (S_{tot}), or the surface area “*appropriated*” by the farmer for the market gardening season. We can also observe a gradual increase of S_{max} over the dry season due to the water retreat to reach a maximum corresponding most frequently to S_{tot} . So the “*maximal exploitable surface area*” (S_{max}) is often lower than the “*total surface area*” (S_{tot}) in term of integrated surface area: it varies from 49% to 98% of the total surface according to years and farms, due to the speed of draining water on farm territories. Once the soils are dried out, the cultivation of vegetables requires several operations, namely (i) the set-up or renovation of wells (ii) the establishment of plant nursery and (iii) small-plots that will hold the crops. A surface area is effectively exploitable (*Effective surface exploitable*, S_{eff}) only once these works have been carried out. The difference between these variables will be used to assess the room for manoeuvre at each farm level.
- The “*cultivable area of each crop*” $Cult.A$: for example, because it is the most demanding in water, the lettuce cultivable area is always near the functioning wells. For a given crop, this cultivable area thus varies during the season when the wells are drying.
- The “*interval of time for each crop*” IT : it is the interval of time during the dry season the farmer considers to be adapted for a given crop. If all the farmers consider that all the leafy vegetables could be cultivated during the whole dry season, most of them reduce IT for some crops. Two main reasons are presented (Fig. 5) (i) economical reasons, due to variation in the market prices. This is the case for the lettuce scarcely cultivated after September because mostly sold to tourists. However, all the farmers cultivating lettuce try to have a first harvest for the National Day (the 26th of June) because a majority of inhabitants want to consume this expensive vegetable on this day (ii) secondary, small weather variations inside the dry season, that makes the cultivation of some vegetables more risky.
- The “*instantaneous diversity of crops*”: it is a necessity, because of the supply chain organisation, to have in the farm, at each given time, a certain diversity of vegetables to satisfy the retailers and consumers demand. Thus, during July and August, even if the lettuce price is high, none of the farmers cultivates only lettuce; they have at least some of the small plots over the other crops. Fig. 6 illustrates the percentage of the developed surface area occupied by the various vegetables.
- The intensity of land use is also limited by the *length of intercrop period* $LICP$, which means the time between the harvest of preceding crop and the plantation of the next one. This length depends on the farmer himself (his/her speed to plough the small-plots) but mostly on the buyer who makes the harvest: according to the possibilities of sale and of the supply by other farmers, the harvest of a small plot in a given farm may take between 1 and 5 days, even more than a week between July and September when the offer of vegetables is highest. Thus, these lengths of intercrop periods ($LICP$), on which farmers have no real power, could represent a non-productive time of several weeks during a season.

Which are the effects of the commercial systems on the cropping systems of the leafy vegetables?

The commercial market-gardening activity in the UCM is relatively recent, as shown by the global investigations (Dumont, 2006; Mawois, 2009). During the decade 1980–1990, some households, who cultivated rice in the rainy season and vegetables only for their

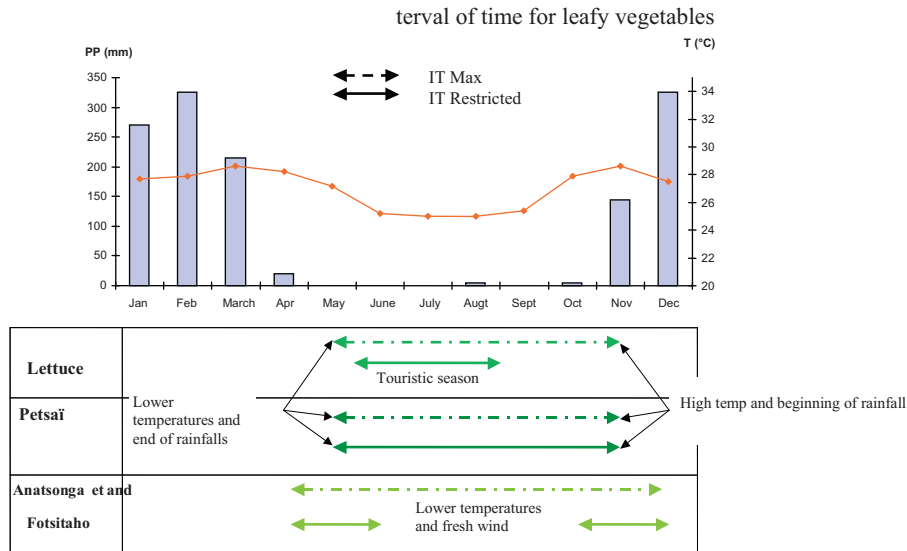


Fig. 5. The maximum and restricted interval of time for leafy vegetables.

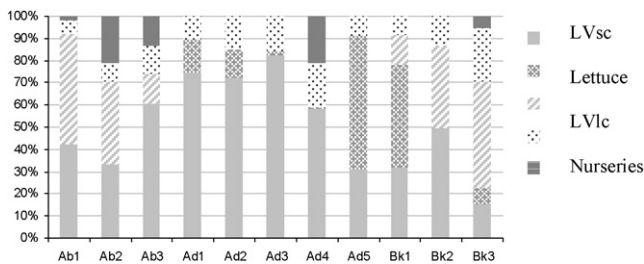


Fig. 6. Percentage of the developed surface area occupied by the various vegetables (2006).

own consumption, began to sell part of it in the markets and for the emergent tourists. Nowadays no statistical data is available in the city or regional documents neither on the percentage of the population involved in this activity, nor on its evolution during these years.

The leafy vegetables are sold to the urban markets, scarcely by farmers themselves (about 7%) and mostly (93%) through female buyers (Audois, 2007): 190 women were enumerated who can play a role of wholesalers or of retailers and generally both (60% of the total flow).

Three main points may be stressed according to their activity:

- These women carry out harvest work on the farms and they transport daily the bags of vegetables by foot and/or bus to one of the main or secondary markets of the city (Fig. 7). Their capacity of selling is limited by their transportation capacity, which can be estimated between 20 and 30 kg by day.
- They are related to certain cultivation zones where they live and from where they can transport their products directly (one bus line) to an urban market. They have verbal contracts with some farmers in their zone. To respond to consumers' demand, they request every day a certain diversity of leafy vegetables. They try to find this diversity on a single farm but also among a group of contracted farmers.

Most of these buyers do not have official register in the city markets: they are authorized to sell between 4 and 7 h in the morning in the urban markets. Then, when they are themselves retailers, they generally occupy informal places along the roads near the official

markets, where village authorities tolerate them even if this informal selling is in theory forbidden (Picture 2). It has been shown that the leafy vegetables supplying the Mahajanga's markets come essentially from the chosen 3 production sites (more than 95% for traditional leafy vegetables, more than 80% for lettuce), validating then the initial choice.

For the cropping systems it has been shown that the main influence of this commercial system are upon (i) the diversity of crops inside the farms at a given time (the buyer transmit to the farmer the urban demand) and (ii) the LICP variable, function of two mains factors: (a) their capacity of transportation and selling, (b) the stability of their relationship with the farmer. The more stable the relationship is the shorter is the time of harvesting on the farmer "beds" because this farmer is a priority for the buyer.

Is there room for manoeuvre to increase the area under leafy vegetables?

To answer this question, two levels were investigated by (i) analysing whether there is room for manoeuvre inside the farms without changing their land resources (ii) analysing at a territorial level whether additional resource (land, water, work) could be useable for vegetable crop production. A comparison will be made between farms and between the three selected agricultural zones and we will discuss the challenges and opportunities.

Inside the farms, without changing land resources

The upper representations allow us assessing the potential developed surface area ($S_{dev.max}$), represented by the cultivable area of the crop multiplied by the maximum number of cultural cycles. We can then compare it to the real developed surface (S_{dev}) register in farms.

We created integrated surface area variables on the length of the season. To assess the room for manoeuvre to extend surface areas inside the farms, we estimated two main ratios (Table 2):

The ratio between S_{eff} , the surface effectively exploitable along the season in vegetables crops (whatever they are) and S_{max} , the maximum surface that can be used taking into account the water dynamics (drainage at the beginning of the season, drying of wells, etc.), here called $R1$.

The ratio between the real developed surface S_{dev} (number of plots cultivated on each crop along the season) and the potential

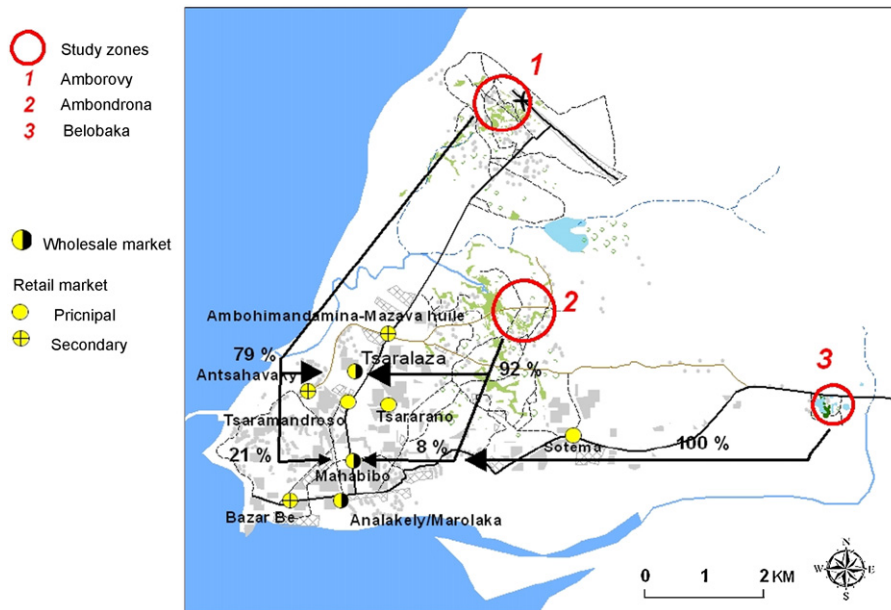


Fig. 7. The flows of vegetables through buyers from production sites to urban markets.

Table 2
Ratios between the potential and real vegetables areas inside the farms in year 2006.

Farm	R1 = S_{eff}/S_{max}	R2	
		LVsc = $(S_{dev}/S_{dev.pot})LVsc$	Lett = $(S_{dev}/S_{dev.pot})Lett$
Ad1	1.00	0.68	0.44
Ad2	1.00	0.55	0.19
Ad3	0.93	0.59	0.03
Ad4	0.47	0.33	0.01
Ad5	1.00	0.25	0.57
Ab1	1.00	0.29	–
Ab2	0.77	0.31	–
Ab3	1.00	0.39	–
Bk1	1.00	0.19	0.33
Bk2	1.00	0.33	–
Bk3	0.89	0.11	0.05

Adi, Abi: farms of two different lowlands; Bki: farms on the lakeside; LVsc: short-cycle leafy vegetables (Anatsonga, Fotsitaho, Petsai); Lett: lettuce; S_{exp} : surface really exploited along the season in vegetables crops; S_{max} : maximum surface that can be used in the dry season; S_{dev} : number of plots cultivated on each crop along the season, $S_{dev.pot}$: potential developed surface.

developed surface ($S_{dev.pot}$), represented by the cultivable area of the crop multiplied by the maximum number of cultural cycles. This ratio R2 will be presented here only for lettuce and LVsc for year 2006.

When the ratios are near 1, there are few possibilities of increasing production area inside the farm, but when it is less than 1, it is then necessary to investigate what the reasons are, according to the farmers, to have no larger area under production.

The R1 ratio allows assessing the possibilities to potentially extend the S_{eff} on the farms. The difference between these two variables comes from the farmer's possibility to quickly establish the small-plots once the soils are dried. Table 2 shows that a majority of farmers cultivate during the season all or nearly all the surface they can use taking into account the water dynamics (7 farms). There is no difference between the three zones: the main limiting factors seem thus not to be linked to the environmental conditions. The four cases where R1 is less than 1 are all due to restrictions encountered by the farmers in available labour resources: insufficient to dig wells (Ad4) or to set up the small plots at the beginning of the season (lack of money for paying additional workers for Ab2) and/or to watering the small plots during the season (Ad3 and Bk3).



Picture 2. Female retailers selling informally at the neighbouring of official markets.



Fig. 8. Land reserve for vegetables cultivation through uncultivated rice parcels in the dry season.

An illustrative case is presented by Ad4: in 2007, his nephew comes to work with him, both can dig a new well and then use a new part of the farm land, which was not useable before. Thus, his “R1” ratio changed from 0.47 (in 2006) to 0.82 (in 2007). Overcoming his labour force problem, this farmer has increased his surface really exploitable by more than 30%.

All the ratios $R2$ are far from 1, which is not surprising regarding the complexity of crops allocation along the season described in the upper part. Lettuce is only cultivated in one lowland and access to marketing facilities (retailers specialized in this product) is more determinant than environmental conditions. We notice that the $R2$ for lettuce is much smaller than the LVsc’s one: farmers confirm that the IT variable, restricted for lettuce (see Fig. 5), is the main reason for this situation. The working time for lettuce is another reason; farmers who are alone and/or have no money to employ

temporary workers cannot cultivate large surfaces of lettuce during its convenient interval of time (IT). In our sample, it is the case for Ad3, Ad4 and Bk3. For the two latter, the arrival in 2007 of a new family worker resulted in an increasing $R2$ for lettuce (from 0.01 to 0.13 for Ad4 and from 0.05 to 0.14 for Bk3). For the LVsc, the low $R2$ reflects mainly, according to farmers, the LICP influence, due to harvesting delay of a small-plot by buyers: it is mainly the case in one of the two lowlands, where buyers are rare and very busy, and in the lakeside site, for the same reason.

Then, inside the farm, the majority of farmers use the land as intensively as they can, according to their resources and their dependence to buyers. An increase of the land use intensity often questions their working capacity, inside the family or with temporary workers. The water dynamics are also a shared constraint: the maximum surface (S_{max}) they can use is strongly dependant on

the drainage at the beginning of the season, on which they have no room for manoeuvre, and of the drying dynamics of wells from September to November. The relative weight of these two constraints depends on the environment: on lakesides, the drainage is strongly lower but, and in lowlands, the main problem is the rapid drying of the wells. On this last point, some farmers think that water could be available during a longer period, if they had working forces to deepen the existing wells, to dig new ones and/or to water crops from distant wells. These reasons point out the global question of the territorial resources of land, water and work.

Are there additional territorial resources available for vegetable crops?

The cartographical studies at the territorial level of the Urban Community of Mahajanga showed that (i) the lakesides are totally saturated with vegetable crops during the dry season, (ii) the lowlands have different rooms for manoeuvre.

In lowlands, as leafy vegetables come after rice cultivated during the rainy season, are there rice parcels staying uncultivated after harvest in the sites? In the zone 1, the oldest one being cultivated, only 7% of the territory consists of rice parcels not cultivated during the dry season and 9% of the territory belongs to a private religious community. But it seems that a land reserve exists at least in the second lowland, where 57% of the territory is made of rice parcels not cultivated in the dry season (Fig. 8). To explain this difference, we firstly thought about land tenure problems in zone 2, a very frequent problem in urban and periurban contexts: but farmers argue that the oral contracts for locating or loaning rice parcels for the dry season is the general rule to have access to land and that there is no major problem to obtain it from a landowner who is not himself/herself a market-gardener. They most evoke the two other limiting resources: sometimes available water (there is no well near these parcels) and more frequently labour force (cultivating them would imply additional labour forces in the farms). This latter limiting resource comes from the fact that numerous urban farmers have a non-agricultural activity in city, as it was also shown in the 91 farms surveys (Dumont, 2006).

In the same way, the upper lands (the *tanety*) are almost saturated (Fig. 8). A possibility to extend the cultivated area in these lands could be to extend the cropping duration (tanety are drying very soon in the season because of their topography). This temporal extension also relays on the same limiting factors: water availability and labour force.

Moreover, the room for manoeuvre to extend the cultivated area does not only rely on the environment and labour resources, it also depends on the marketing system.

It has been shown that the current selling capacities of the buyers are generally low because of (i) their limited transportation means and (ii) their limited access to the urban markets. Their informal status is not favourable to an increasing of their logistics and economics performances: for example, they were not considered in the recent urban markets renovation plans.

Table 3 summarizes the various rooms for manoeuvre in the three surveyed zones at farm and territorial level. At farm level, the room for manoeuvre essentially depends in the possibility to extend S_{eff} to S_{max} . Our results highlight that there are more possibilities in lowlands than in lakesides for this extension. At territorial level, we show that there are differences between the environments due to the availability of uncultivated rice parcels and/or upper lowland but no more in lakesides. The distance between the surveyed zones and the urban market implies few rooms for manoeuvre in lakesides due to the lack of appropriate mean of transport. Thus lakesides appear as being almost at their maximum point of their leafy vegetable contribution to the city supply.

Discussion and conclusion

Several studies showed that the increasing urbanization would require in the next decades an increase in leafy vegetables production (Parrot et al., 2008; Temple and Moustier, 2004). The combined phenomena of growing urban demand in vegetables and extension of urban agriculture are particularly pronounced in Madagascar (Dabat et al., 2006; Aubry et al., 2008). It is the case in Mahajanga where this study intended to answer the question: can farmers adapt themselves to this increasing demand?

Results show that the exploitable surface areas on the market-gardening farms in the periurban area of Mahajanga change over time mainly due to the farms' special environments (lowland or lakeside) but also to the productive resources available to them. The limits on farm territory are therefore variable over the cropping period. This observation is not necessarily limited to our study. Indeed, numerous works regarding the analysis of complex territorial dynamics have been undertaken in other contexts. Among these, we may quote works on pioneering issues (Léna, 1992; Duvernoy et al., 1996; Albaladejo et al., 2005; for example), flood recession crops (Mathieu et al., 2003) or rice farming on lowlands (Jamin et al., 1993). However, although these works demonstrate clearly the spatial and temporal evolution of land use, they were undertaken on vast spaces such as a village territory and over annual or supra-annual time periods. Other works gave a deeper analysis of spatial organisation of crops at the field level, but only for arable crops (Mathieu, 2005). Nevertheless, the evolution of the farm territory during the crop season has not been the focus of much research in flood recession situations. Understanding this evolution is important to estimate farmers' room for manoeuvre to increase cultivated areas, particularly in the case of short-cycle crops with a succession of several cycles in a single season.

Moreover, our results show that the cultivated surface area also depends on to the relationship with the buyers. Some research studies have been undertaken on the coordination between several stakeholders implied in supply chain (producers, retailers and transformers) and their consequences on cultural practices and farm management (Everingham et al., 2002; Hansen et al., 2002; Le Bail and Makowski, 2004; Wunsch, 2004; Navarrete et al., 2006). These studies were mostly carried out in situations where an identified operator centralizes and collects the agricultural harvests. But, this question is much less informed in situations where coordination is less structured and involves numerous buyers and sellers. Nevertheless, these types of relationships between producers and the market are increasing, not only in our case study but also in other contexts. Indeed, we note a re-emergence of short supply chains in market-gardening products in many industrialized countries (Morgan et al., 2006) e.g. the growing movement of Locavores (Smith and Mc Kinnon, 2007) and in France the Amaps (Lamine, 2008). Such phenomena « confirmed the importance of better

Table 3
The rooms for manoeuvre in the three surveyed zones at farm and territorial level.

	Farm level	Territorial level	
		Land resources	Marketing system
Lowland 1	+	+ ^a	+
Lowland 2	+	++ ^b	++
Lakeside	–	–	–

^a Possibility to extend the cultivated surfaces areas by extending the cropping duration on tanety.

^b Availability of rice parcels uncultivated during dry season.

understanding the relationships between farming practices and marketing channels » (Navarrete, 2009).

Despite the low number of farmers surveyed, this study showed that the Mahajanga vegetables production faces simultaneously an increasing demand and high difficulties to access productive resources. We showed that farmers' intensity of land use is generally high. Thus, to increase the production, water and working forces resources of the city, as well as marketing systems, need to be addressed within a global land use policy.

The water resource in the UCM is a difficult subject: the only established point is that, nowadays, the farmers dig wells in superficial water reserves, between 2 and 4 m deep; the urban water needs are met by the local Water company "Jirama" though deeper water reserves (around 50–60 m) inside the calcareous subsoil. According to a confidential study made by Jirama, these deep reserves are so important that they could meet the growing city and the agricultural water needs for 60 to 100 years (Dumont, 2006). Nevertheless, the current problem for the farmers is the availability of the superficial water reserves: no study has been done on the matter, not even by the UCM or the Region, to estimate their hydraulic potentialities on the territory, despite of their major interest for local agriculture. A serious hydrologic study should be done to quantify the water reserves currently available to farmers: a possible use by farmers of the deep water reserves would imply high investments in mechanization, which does not seem to be up to date.

So far there has been no existing study regarding the agricultural working forces on the UCM, neither about its potential to increase. Nevertheless, our own data on 91 farms showed that in 2006, more than half of them have at least one member of the family (the farmer him/herself, his/her spouse) working partially or temporarily in the city, in factories, domestic work and/or informal economy. We then join the results obtained for the urban agriculture of Antananarivo, the capital of Madagascar (Aubry et al., 2008) regarding the importance of double activity for urban farmers. Nevertheless, in Mahajanga we did not note currently the dynamic of urban and periurban market-gardening that was observed in Antananarivo: around the Malagasy capital, young market-gardeners stay in or return to agricultural activity, with a strong movement of land extension for vegetables cultivation on the low fertile hills (*tanety* as they are also locally called) and technical adaptations to increase these new parcels' fertility and thus, to face the increasing urban demand (N'Dienor et al., 2006; N'Dienor and Aubry, in press.). With the worldwide alimentary and financial crisis, and for Madagascar, the additional political crisis in 2009, it is not impossible that such a movement of "return to agriculture" would occur in Mahajanga, as it was noted in Antananarivo during the last great political crisis of 2002 (N'Dienor and Aubry, 2004).

Regarding the marketing system, our results plead for a re-organisation of the market at the scale of the territory. For example, if urban planners better acknowledged the role of retailers by facilitating their access to marketplaces, this would ensure the flows of leafy vegetables throughout the season, thereby limiting the length of intercrop period (LICP). Indeed, the flow of leafy vegetables often takes place – via retailers – on spontaneous, informal markets set up on roadside or in neighbourhoods. But one question remains open: will farmers earn more or less by selling their products directly or via buyers? Indeed, farmers who sell their products directly on the markets have higher sale prices. But they are not really recognised as wholesalers/retailers and thus have more limited selling capacities. Furthermore it questions the economic valuation of time dedicated to the marketing in a context where the labour force for production activities is a limiting resource. It would also be interesting to carry out a study that would thoroughly investigate the subject from an economic point of view, and draw a comparison

between the various marketing strategies and their interest for farmers. In the same way, it would be very useful to have a more complete survey, of the technical and economic performances of the farms themselves, as well as their capacities for change, as studied by Parrot et al. (2008) in Cameroon.

A more precise design of what could be the future agricultural land uses in the UCM (the first estimation we have made is not sufficient to make political decisions) is also necessary: nowadays, no agricultural category of land is done on the urbanization Director Scheme. It could be particularly adapted for the UCM to make a global evaluation of land usable for agriculture, in its own and neighbouring district, as done by Thapa and Murayama (2008) in Hanoi, Vietnam or by Verburg et al. (2002).

At the present time, we can notice that urban agriculture in Mahajanga is not considered as illegal, as it was the case in other countries like Tanzania (Howorth et al., 2001), but it is totally ignored by local authorities, as it was non-existent in spatial and human occupation. With the increasing interest for this type of agriculture (Cissé et al., 2005; Van Veenhuizen, 2006), and especially for vegetable production (Kahane et al., 2005), this attitude could well change in the years to come. It was the case in other contexts with urban planners' increasing consideration for this agriculture (Dubbeling, 2009a). Urban planners are in need for methods and tools allowing them to reason with the place of the urban agriculture in the expanding cities.

Concepts and methods for studying urban agriculture were recently considered in particular in the geographical, economic or socio-political disciplines. The agronomic methodology used here, to understand the constitution of the cultivated surface areas inside farm territories in urban agriculture seems complementary to these methods. Its major interest is to help to (i) identify the factors limiting their potential increase, in terms of constitution of the cultivated surface areas, and to (ii) evaluate the rooms for manoeuvre on the farm and territory levels to raise these limiting factors. This can be a useful tool to define local public policies, which proved to be a determining factor for the promotion of the urban agriculture in other contexts.

Our study provides urban planners with insights on the respective parts played by farming systems, territorial resources and organization of marketing systems in the supply of the cities by urban agriculture. The results obtained show that the room for manoeuvre to increase the cultivated surface areas lies mainly in a modification of the productive resources (land, water and labour). These factors come within the definition of a strategic planning of the part played by this agriculture in the urban development. Although the room for manoeuvre at the farm level to extend cultivated surfaces remains limited, it nevertheless exists, which is not obvious in an urban context. Explicitly introducing the farm level in urban policies is paramount to understand farmers' constraints and opportunities and ensure they adopt proposals at their level. It is also necessary to take into account the farmers capacities in the urban policies. The analyses of farming system management and therefore of stakeholders' room for manoeuvre are compulsory, not only to estimate the potential of extending the production, but also to identify the constraints and the levers to tackle them. Thus, defining the place of agriculture in urban development seems to be beyond the sole expertise of urban planners. Understanding the roles such agriculture plays or could play in a sustainable city also relates to agronomic research.

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