Simulation modeling of management scenarios of livestock manure in urban and periurban zones of Mahajanga, Madagascar

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Abstract

This paper describes the use of a dynamical simulation model, called Magma, to evaluate the management scenarios of livestock manure in urban and periurban zones of Mahajanga, Madagascar. Three scenarios were tested: Scenario 1, corresponding to the current crop fertilization practices; Scenario 2, trying to maximize the use of livestock wastes on crops; and Scenario 3, testing the relocation of in-town animal farms to a rural area. By simulation, it has been showed that to manage more efficiently manures a better organization of transportation means is required. This may lead to avoid the lack of organic matter during the high season of market gardening. Environmental risk related to non-collected manures and to excess organic and chemical fertilizer application should be thoroughly considered.

Key words: Simulation, livestock, management, Mahajanga.

Introduction

Market gardening in the periurban zone of Mahajanga (N-W of Madagascar) is essentially composed of intensively-grown perishable leaf-vegetables with very short crop cycles (up to 12 cycles/year). Vegetable production demands high nitrogen inputs. Farming performances are very variable, depending strongly upon the availability of resources (namely fertilizers) and the farmers' know-how to master production intensification. In the current situation of farming practices, the important demand of farmers in low-cost fertilizers, like organic residues, cannot be satisfied due to the temporal or spatial unavailability of such materials. Paradoxically, 10 000 tons per year of manures are produced in town [3] and, as estimated by a survey, urban husbandry produces 87 tons nitrogen annually. In contrast, market-gardening in the area requires an estimated amount of 6 tons N per year only. As a matter of fact, starting eutrophication has been observed in lakes which edges are cultivated and rice verse problems appeared in paddies where market-gardening is part of annual crop rotations. Concurrently, in most animal farms, livestock wastes (table 1) are not used and, hence, constitute environmental leaks. Making these organic products available to market-gardening and taking benefit from livestock wastes is at stake in this area.

Table 1. Characteristics of manure available in Mahajanga

	Pig manure (g/kg de DM)	Cattle manure (g/kg de DM)	Chicken manure (g/kg de DM)	Sheep/goat manure (g/kg de DM)
Nitrogen	14.6	11.2	22.1	22,05
Phosphore	9.9	4.4	15.3	nd
Potassium	15.4	6.3	9.9	nd

Simulating the management of manures on the scale of the whole Mahajanga area with the dynamic simulation model Magma [1] allowed us to reason the mid- or long-term changes in crop fertilizing practices and the logistics required to improve as far as possible the recycling of those wastes.

Material and Methods

Magma, a dynamic flow-stock simulation model [1] has been used on the case of Mahajanga to simulate various management scenarios of livestock wastes at the whole territory level. Magma allows one to represent a farming territory as a set of production units (PU) and a set of consumption units (CU). For the sake of model simplification, the very little livestock and crop farms of the Mahajanga area were aggregated into approximately homogenous sets in terms of manure management. Hence, 17 PUs corresponding to the main manure production zones were obtained by aggregating actual livestock farms of same kind located in the same area out of a total of ≈2600. Similarly, 14 CUs corresponding to the main cultivated soles were obtained by aggregating little market-gardening farms located in the same district of Mahajanga periurban area out of ≈160. Additionally, 3 CUs were made out of 500 farms located in a remote rural zone in the east of Mahajanga (see Fig. 1).

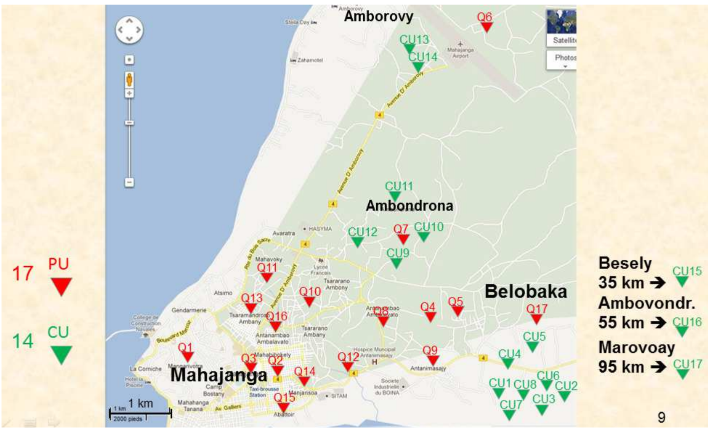


Figure 1: Localization of production units (PUs: Q_1,..,Q_{17} in red) and consumption units(CUs: U_1,…,CU_{17} in green)

These PUs and CUs were linked by the possibilities of manure transfers that may be achieved from the former to the latter by various transportation means (of which man-hauled carts are the most popular). Taking as input parameters the characteristics of the PUs (herd size, manure flow, storage capacity,…), the CUs (cropping areas,…), the transportation means (number, payload, velocity,..) and management rules (fertilization schedules and doses,…), Magma allowed us to simulate the time evolution of PUs and CUs stocks, the manure transportation and application activities, as well as indicators of agronomical (amount of manures applied on crops, fertilization indices), logistical (working time, distances travelled…) or environmental (manure stock overflow, crop over fertilization,…) natures. In spite of the fact green leaf-vegetable monoculture constituted their main source of income; farmers have only a small plot of land and practice intensive crop rotation to maximize its use. Market gardens produce green vegetables for 3 to 12 cycles per year depending on the location of the plots. Acreage annually for all lakes and lowlands of Mahajanga is about 56ha.

Similar situation were found for livestock farms: most of them were small family farms with a herd reduced in size (pig≤3, cattle≈2, poultry≤250).

Three main scenarios were tested. Scenario (1) was aimed at understanding why farmers complained about a supposed low availability of manure by simulating the current observed situation. Scenario (2) aimed at improving the use of livestock wastes in the current PU-CU configuration network, and scenario (3) at testing the relocation of production units out of town (a trade-of officially envisaged by the municipal authorities) while applying their wastes on crop farms in remote territories (nearly 100 km away). In Scenario 3 we wanted to see what would happen if herds from the city centre (PU $_{1\text{-}3;\,11\text{-}15}$ and non-collected manure in PU $_{4\text{-}10)}$ were relocated in rural areas. 54.81t-nitrogen is envisaged to be transferred because of urbanization, low availability of land and sanitary problems. This relocation would allow solving both the problem of leakage of manure to the environment in the city and the lack of organic matter in rural areas. All simulations were assessed with respect to two main criteria corresponding to manure management objectives to achieve: no stock overflow at livestock farms' (PUs) and regular supply of market gardening areas (CUs) with manures.The simulation assessment and comparison criteria we used are mainly environmental: fertilization index, manure stock overflow in production units resulting in environmental leaks and excess nitrogen in consumption units causing pollution to groundwater and lakes. $NB = N_{soil} + N_{min}\ x\ UAC_{min} + N_{pro}\ x\ UAC_{pro} - N_{abss}$ with NB, nitrogen budget, N_{soil}, mineralized nitrogen from the soil, N_{min}, nitrogen from mineral fertilizers, N_{pro}, nitrogen from PRO fertilizers, UAC_{min} use apparent coefficient of mineral fertilizers (equal 0.6), UAC_{pro} use apparent coefficient of PRO fertilizers, N_{abs}, absorbed nitrogen by the plants .

Results and discussions

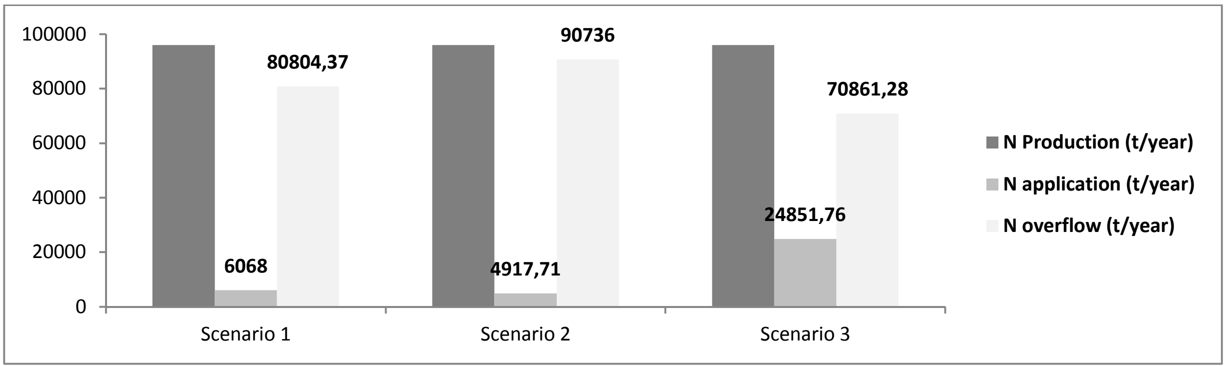
In the context of imbalance between manure production and consumption, important nutrient losses are obviously witnessed. The annual production of manure in the city of Mahajanga is important: 10 220 t of fresh manure per year. However a significant proportion composed of pig manure essentially (≤50t/year) of that production is released into the environment and accumulates in the shantytowns barely urbanized where it threatens public health. It is thus a loss for agriculture and a cause of pollution to the environment. Immediate environmental risks are actually due to substantial loss recorded in production units ('stock overflow'): 63% of the manure production cannot be collected because of the tiny size of animal farms considered as a waste of time by the carters who collect principally livestock farms with important herds. There is also a large release of organic fertilizer in the environment especially from production units due to the absence of manure collection during the rainy season. Stables or barns have no rooftop for most, so the rains of the wet season carry a lot of manure left on the ground. Arable land where manure application is needed is also too little, located only on the upper slopes thus reducing the manure requirements and consumption.

In addition, there is also an environmental leak due to overfertilization of the consumption units. Model simulations revealed that, whereas farmers complain about the scarcity and high cost of organic matter in town and its periphery, they are actually already in a situation of excess with one application of manure and two of urea made for each cycle of 21 days; which is the double of the recommended doses for leaf-vegetables for european standards [2]. Repeated applications of both animal manures and chemical fertilizers clearly indicate excess nitrogen applications brought both by manures and chemical fertilizers. This situation constitutes a risk of environmental pollution. The lack of organic matter for market-gardening during the high season (June to August) can be rather explained by the lack of adapted logistics to carry manures from the PUs to the CUs and carters were not numerous enough for collecting all production areas. It had been simulated with the model that farmers' needs of organic fertilizer can actually be satisfied with a minimal logistics by only 27% of the manure available in the town of Mahajanga. According to scenario 1, the allocation of a man (capacity: $0.087m^3$, working 8 hours a day) for a couple of CU-PU is sufficient for the transport of manure. Therefore this confirms that the problem of manure supply to market-gardeners was due to a lack of transportation means. With more cartmen and better logistical organization there should not be any disruption.

By simulating Scenario 2, optimizing the use of livestock wastes in the current PU-CU configuration network, it has been found that if the application of manure was halved on the C_1-C_{14} the losses of nutrients and environmental risks while the crop requirements are still fulfilled (the resulting amount actually corresponds to the recommended dose for leafy vegetables in Europe). The adjustment of mineral and organic fertilizer applications in urban market-gardening has thus been found essential to reduce the nutrient losses of these farms and their potentially negative impacts on the environment.

We thus considered a rural zone in the East of Mahajanga producing rice, jatropha, medicinal herbs, onion and pepper for export (cf. consumption units C_{15}-C_{17} Fig. 1). 42t-Nyear was needed in these

CUs which suffered from the lack of fertilizers. Animal farms there are essentially extensive: animals remain in pastures during the day, resulting in the unavailability of their manure for market-gardening. As shown by simulating Scenario 3, relocating animal farms and transporting their effluents to remote locations is a good strategy, provided the transportation means and the PU-CU configuration is more adequately set. This would allow the environmental impacts due to effluent discharge in town to be reduced (Graph 1). This logistic improvement must be reasoned jointly with exporting animal manures out of the Mahajanga territory, to places where fertilization needs are currently not satisfied.



Graph 1: Nitrogen production, application and overflow for Mahajanga territory

Conclusion and perspectives

In Mahajanga, both livestock and periurban agriculture are sources of pollution because of substantial losses of manures in livestock farms and over fertilization in market-gardening units. The modalities (quantity and temporality) of fertilizer application must be well thought-out to prevent environmental problems. As shown by simulating the logistics of manure at the territory level, managing more efficiently the effluents of animal farms produced in Mahajanga is possible. It requires transportation means to be better organized and more effective than the current ones (truck instead of cart because the distance PU-CU is more important), in order to take benefit of all the organic materials produced. Further, adjusting organic and chemical fertilizer application rates should also be jointly considered to reduce the risks of environmental leaks towards groundwater due to periurban market gardening.

References

[1]Guerrin F., 2001. Magma: A model to help manage animal wastes at the farm level. Computers and Electronics in Agriculture, 33(1): 35-54.

[2] Foury C., 1994, Productions légumières: Légumes feuilles, tiges, fleurs, racines, bulbes, volume 3, Agriculture d'aujourd'hui, Productions légumières: Légumes feuilles, tiges, fleurs, racines, bulbes. Lavoisier-Tec et Doc. 639p

[3] Ramahefarison H., 2011, Déterminants agronomiques des pratiques de fertilisation dans les systèmes de culture maraichers en zone périurbaine : fertilisation des cultures de légumes feuille à Mahajanga. Thèse de doctorat, Université de Mahajanga, 210 p.

[4] United Nations, 2008. World urbanization Prospects – The 2008 Revision.United Nations Population Division, Department of Economic and Social Affairs, New-York.

[4] Van Veenhuizen R., Danso G., 2006. Profitability and sustainability of urban and periurban agriculture. FAO, Rome, 95p.

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