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Impact of Market Gardening on Surface Water Reservoirs in Burkina Faso

Impacts of current agricultural practices around the reservoir of Toukoumtouré, Nariarlé basin, on natural phytoplankton communities.

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Preface

This master thesis was conducted on the behalf of French IRD, Institut de Recherche pour le Développement, in Ouagadougou, Burkina Faso, and for the Water Resources Department at the Faculty of Engineering in Lund, Sweden, by Stina Pernholm and Wille Hyrkäs. Mr Hyrkäs was awarded a Minor Field Study grant by the Swedish International Development Agency, SIDA to finance the work. The master thesis is the end of an education in Environmental Engineering during four years and a half. The thesis took five months to realize out of which three months were spent in Burkina Faso. The master thesis is part of the international program Small Reservoirs Project and initiates a two year project called IMPECA which is financed by the Danish International Development Agency, DANIDA and executed by the IRD compartment CyRoCo 167.

Summary

An evaluation of the ecological status of 23 small water reservoirs in Burkina Faso was made in 2004 by IRD (Institut de Recherche pour le Développement), Large dominance of cyanobacteria in some of the reservoirs was one of the signs of an imbalance in the ecology of the water (Cecchi et al. 2005). This led to a further investigation in 2005 and an assumption that the dominance of cyanobacteria was due to the high anthropogenic pressure, in particular the intense agriculture around the water bodies (Leboulanger et al. in prep). Further studies proved to be needed to find out the actual cause of the abundance of cyanobacteria and the mechanisms for water quality deterioration.

IMPECA is a project running for two years with the intention to collect information about agricultural practices around the reservoirs. Agricultural methods, added pesticides, water and fertilizers are going to be studied. In addition, the possible impact of added xenobiotics on plankton is going to be investigated.

This study is a pilot study for the project IMPECA, the first of this kind in Burkina Faso. The intention of the study is to try out a working procedure that will be used later in the project. Agricultural methods and added xenobiotics are investigated by a questionnaire survey, by visual investigation, and by GPS area measurements. Measurements of the impact of relevant xenobiotic application on the photosynthetic activity on phytoplankton communities are also made in the laboratory.

The working procedures were slightly modified during the study. Irrelevant questions were discarded and more appropriate questions were added. The cultures that were dominating the year 2006-2007 were scallion and eggplant. The cultures differed in the time it took for the plants to get ready. People chose what plants to cultivate according to the availability of land, the availability of money and experience. There was a big variation in the amount of pesticides and fertilizers added on the fields. The dominant pesticides were Lampride and Lambda Super. Lampride showed no measurable negative effect on the growth of phytoplankton. A possible method of deciding the LOEC on phytoplankton with the instrument phyto-PAM was suggested.

Summary in Swedish

År 2004 gjordes en studie av IRD i Burkina Faso med syfte att utvärdera den ekologiska statusen i 23 dammar. En hög koncentration av cyanobakterier i vissa dammar tydde på en obalans i vattnets ekologi. Detta ledde till ytterligare en studie år 2005 och ett antagande om att dominansen av cyanobakterier berodde på en hög mänsklig påverkan i området, i synnerhet den intensiva odlingen omkring dammarna. Ytterligare studier visade sig vara viktiga för att hitta

anledningen till den höga förekomsten av cyanobakterier och mekanismer som försämrar vattenkvaliteten.

IMPECA är ett projekt som kommer att pågå under två år med syfte att samla information om jordbruket som bedrivs omkring dammar i Burkina Faso. Jordbruksmetoder samt hur mycket, vatten, gödsel och bekämpningsmedel som används på grödorna kommer att undersökas. Dessutom kommer den eventuella inverkan av relevanta insekts- och ogräsgifter på plankton att mer genomgående studeras.

Denna studie är en förstudie till projektet IMPECA. Arbetsgången som kan komma att användas i det större projektet ska testas på en damm. Jordbruksmetoder samt användning av xenobiotika undersöks genom intervjuer, visuella undersökningar samt GPS-mätningar i fält. Mätningar av påverkan av viktiga tillsatser av xenobiotika på den fotosyntetiska aktiviteten hos fytoplankton undersöks i laboratorium.

Under arbetets gång modifierades bl.a. intervjufrågor. Vissa irrelevanta frågor togs bort och andra mer anpassade frågor lades till. Odlingar som dominerade år 2006-2007 var salladslök och aubergine. Grödorna skiljde sig åt i bl.a. tid det tog för att odla. Faktorer som bestämde vad bönderna odlade var tillgång på plats, tillgång till pengar att investera samt erfarenthet. Det visade sig vara en stor variation i mängden pesticider och gödsel som tillsattes till fälten. De dominerade pesticiderna var dock Lampride och Lambda Super. Lampride visade ingen negativ effekt på tillväxt av fytoplankton vid mätning i laboratoriet. En metod att bestämma LOEC av paraquat på pesticider på phytoplankton föreslogs.

Acknowledgements

A lot of people both in Burkina Faso and in Sweden have contributed throughout the work of this master thesis and have to be acknowledged accordingly. First of all Dr. Philippe Cecchi, supervisor and head of the IRD Research Unit n° 167 (CyRoCo) in Ouagadougou who invited us, took his time to help us, guided us and threw us out and into the unknown world of cyanobacteria-filled waters, phyto-PAM measurements and fieldwork. He also set us on the right path for carrying out the research and gave us lots of advices when editing and finalizing this report. Thank you!

Mr. Nicolas Moiroux, a GIS and computer specialist who helped us to draw maps, and Mr. Rémi Buchet who worked with us in the laboratory part of the theses have to be thanked. You have contributed with valuable knowledge that we could hardly have achieved without you. Mrs. Aude Meunier has to be thanked for her contribution and advices about how to carry out the questionnaire. Mr. Rigobert Banhoro and Mr. Bakary Sanou have to be acknowledged for their time and work shared in the office in Ouagadougou.

All the people helping us with the fieldwork have to be thanked. Frère Adrien for sharing his time, knowledge and taking us years back in time in his stories to make us understand what the life was like before the reservoirs were built. Mr. Christian Etongo Ilengo and Mrs. Lydia Yelemou are thanked for introducing us to the “Comité de barrage” and at the same time giving us a good start on the fieldwork. The head of the village, the farmers and the people in the village around Toukoumtouré have to be acknowledged. Without you, this thesis would not have been possible to carry out. Special thanks are given to the “Comité the barrage de Toukoumtouré” who kindly welcomed us and helped us to get in contact with the farmers. Mr. Issouf and Mr. Jossef Tapsoba made a big contribution in guiding us around the reservoir and the fields. Our interpreter and friend, Keoum (Mr. Djibril Zoegrana), was invaluable, thank you very much.

Dr. Ronny Berndtsson at Lund University is thanked for his continuous support and guidance when writing this report. Also SIDA, the Swedish International Development Agency, is thanked for the scholarship that financed a part of this study.

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Glossary (Acronyms and Abbreviations)

Cyanobacteria - Prokaryotic organisms (bacteria) that use photosynthesis to sustain their development. Cyanobacteria are also called blue green algae and constitute an important component of phytoplankton communities in tropical shallow freshwaters.

CyRoCo - Cyanobacteria, Roles and Controls, Research unit no 167 of IRD.

DANIDA - Danish International Development Agency.

EC50 - Effect concentration. EC50 is the concentration where effects are seen on 50% of the test organisms after short-lived exposure. Corresponds to a reduction of photosynthetic activity by 50% to phytoplankton.

GIS - Geographical information system.

IMPECA - “Impact du Maraîchage et des Pesticides sur l’Ecologie et les Communautés Aqutiques“, - Impact of Market Gardening and pesticides on the ecology of aquatic communities.

IRD - Institut de Recherche pour le Développement, French Institute of Research for Development.

LC50 – Lethal concentration. LC50 is the concentration that produces a specific measurable lethal effect in 50% of the test organisms within the stated study time.

LOEC - Lowest Observed Effect Level or Concentration at which adverse effects are observed.

Market gardeners - In this thesis, market gardeners are referred to as the farmers around Toukoumtouré that cultivate vegetables and fruits to sell on the market.

MATC - corresponds to the "Maximum Acceptable Toxicant Concentration" and is a hypothetical threshold concentration that is the geometric mean between the NOEC and LOEC concentration.

NOEC - No Observed Effect Concentration.

Pesticides - include all substances or chemical products that can kill or inhibit living organisms that are considered a nuisance. Includes herbicides (active against weeds), insecticides (active against insects) and fungicides (active against fungus).

Phyto-PAM - Pulse Amplitude Modulation fluorometer, instrument devoted to the measurement of the photosynthetic activity related to (natural or manipulated) phytoplankton samples.

Questionnaire survey - In this study the questionnaire survey is referred to as the part of the fieldwork where the farmers were asked questions about their farming methods and their household living standards. Their answers are also referred to as the questionnaire.

SIDA - Swedish International Development Agency.

Toukoumtouré - In this study Toukoumtouré is defined as being the reservoir which is delimited by its water volume. The water level is changing throughout the year.

Typology-study of types - In this study, Typology is referred to as classification of the cultures based on categories that can be used to measure the impact on the water ecology.

Water balance - The water balance is a budget-equation for all water entering and leaving a certain area. In this study the boundary for the area is defined as the Toukoumtouré reservoir.

WPI - Water poverty index, index based on information about water scarcity that enables a holistic measure of water poverty.

Xenobiotics - In this thesis, xenobiotics are referred to as chemical substances that are not naturally produced by organisms and that might act as pollutants in Toukoumtouré.

1 Introduction

The growing population leads to an intensification of agriculture all over the world. It is estimated that by 2030 the world population will increase to about 8 billions (United Nations 2004). A growing population means an increasing demand for food and probably less space for agricultural cultivation. The enhancement of water and soil productivity is a fundamental issue, which in turn often leads to the intensification of agriculture practices (see www.waterforfood.org).

Intensive agricultural practices strongly influence the fresh water cycle. Irrigation claims 70% of the world's total freshwater withdrawal (FAO 2006). An intensive water use in combination with water pollution contributes to the alteration of the ecology of fresh water (FAO 2006). With the intensification of agricultural practices and the world's increasing population a higher pressure is put on the world's freshwater. A high pressure on the freshwater leads to a change in the distribution of species and a possible impoverishment of biodiversity as a consequence. All goods and services associated to water resources are thus potentially but directly impacted by such alterations.

A changed water quality leads to changes in socio-economic conditions. Fresh water is used for numerous domestic and economic purposes e.g. drinking water for humans and herds, fishing, irrigation and for hygienic purposes. By an impoverishment of water quality, changes on social and economical but also sanitary levels are hence to be expected (UNDP 2006).

The Millennium declaration was adopted by 147 countries in September 2000. One of the goals is to "Ensure Environmental Sustainability" where the target is to integrate the principles of sustainable development into country policies and programs and thereby reverse the loss of environmental resources. Another target is to reduce half the proportion of people without sustainable access to safe drinking water and sanitation (Millennium development goals 2007). Logically, water is (explicitly or implicitly) central in most of the Millennium development goals. It appears thus fundamental to better assess the connection between the (obligatory) intensification of agricultural practices and the (necessary) preservation of water quality. This can then contribute to sound decisions regarding agronomical perspectives and orientations, from local to regional scales, about what agricultural methods to prioritize for a productive *and* sustainable use of fresh water resources.

1.1 Objective, scope and delimitations

The objective of this thesis is to investigate the influence of current agricultural practices on freshwater ecological properties in a tropical environment. Physiological response of phytoplankton is used as a proxy to assess these

influences. The overall intention is to study the general influences exerted by the intensification of irrigated gardening on algal communities in complexes of small reservoirs in Burkina Faso. Here, our specific goals are :
(1) to describe the different agricultural practices around the Toukoumtouré reservoir;
(2) to identify xenobiotics locally used by farmers;
(3) to evaluate the potential deleterious effects due to application of these xenobiotics on algal communities.

The study has a time limit of three months and has been conducted when the anthropogenic impacts on the reservoirs are supposed to be at a peak, i.e. by the end of the dry season when the water level is at its minimum. The system boundaries are defined according to the geographical limits in studies already performed (see IRD and IMPECA below) and are in our case limited to a study of the Toukoumtouré reservoir in the Nariarlé basin, south from the capital Ouagadougou.

When we limit our study to the culture nearby the water reservoirs and to the cash crops on a small scale, we thereby exclude the impacts from the great fields of rice, corn, peanuts and cotton that take place in the vast planes between the water reservoirs during the rain season. Those large scale cultures could be of importance when identifying the origin of toxic substances such as pesticides or other pollutants in the reservoir waters, and do indeed play a major role on a global scale. In Burkina Faso though, no chemical products are being added to enhance the growth and the protection against intruding insects (Cecchi 2007, pers. comm. 13 June 2007). The subject is not treated any further in our field study, and the run-off water that brings surface material to the water reservoir during the rain season is not being considered as a source of pollution to the ecosystem.

From background information on the large scale cultures, the following pattern is developing in the densely populated areas (Cecchi, pers. comm 13 June 2007): The tradition of fallow field and crop rotation is being neglected, and the soil undergoes increased erosion. The areas being used are also expanding to catch up with the yearly needs of food crops, and so the possibilities to respect the traditional cycles are reduced. The erosion of entire soil layers fills the water reservoirs with sediment (siltation) that reduces the capacity to store water. The scraping of the reservoir bottom is expensive as it demands bulldozers to be performed.

Three other potentially polluting factors that have been noticed in earlier studies are:

1. the increased concentration of bacteria due to high population density. There is no treatment plant, all used waters and human excrements in the catchment area are flushed down the basin during run-off which indeed

increases the presence of pathogens in the water reservoirs and may induce unhealthy conditions for some time;

2. the deforestation taking place, to set off more land for agriculture and to bring firewood, which in turn inhibits natural water treatment because the soil is no longer supported by vegetation that covers the ground. Vegetation gives shade, holds back water in the ground, and treat organic pollution;

3. other activities in and around the water reservoirs except from market gardening, for example brick making out of bottom sediment, which apparently turns the water turbid and lets less light through to the primary producers, and moreover set free pollutions that were potentially stocked in the sediments since long time.

These factors will be examined in detail the coming years to investigate their potential contribution to the anthropogenic stress on the ecosystem.

1.2 Method

Literature covering topics relevant for this study has been studied. A field work has been performed in Burkina Faso during two months: the first month was devoted to the description of agricultural practices in Toukoumtouré; the second month focused on experimental bioassays. In addition, maps have been studied along with existing databases covering different kinds of data (e.g. climate, etc.).

Agricultural practices have been assessed during field surveys (see chapter 2, phase 1). Market gardeners were selected and interviewed; field observations were conducted at the farms and information was collected by visual investigation and GPS-mapping. Retailers of pesticides were also visited and available pesticides collected.

The potential antagonist and/or synergetic impacts of xenobiotics applications (alone or in cocktail) on algal dynamics were performed in the CyRoCo laboratory. Pesticides and herbicides in different concentrations were added to samples of healthy natural phytoplankton communities and their physiological responses to these applications were measured with a Pulse Amplitude Modulation fluorometer (Phyto-PAM).

1.3 IRD

The entire study was performed in collaboration with IRD (Institut de Recherche pour le Développement, see www.ird.fr). IRD is a French institute involved in scientific activities conducted mainly in developing countries. IRD is composed of a series of Research Units, focusing on different thematic issues. Research unit n° 167, “Cyanobacteria, Roles and Controls” where this study has been performed, focus its studies on planktonic communities and the role cyanobacteria may play within planktonic food webs. Among other abiotic factors, xenobiotics are viewed as possible facilitators for the installation and dominance of cyanobacteria. The impacts of such biocides on microbial communities in tropical shallow waters constitute today an important research issue for the Research Unit 167 (see http://www.com.univ-mrs.fr/IRD/cyroco/).

1.3.1 IMPECA

An evaluation of the status of the water ecology of 23 reservoirs scattered all over the country was organized in 2004 by IRD (see http://www.ird.bf/activites/cyano_bf.pdf). The results highlighted the large and unexpected dominance of cyanobacteria, see Figure 1, particularly in the Nakambé basin, with also a significant reduction of both diversity and abundance of zooplankton communities at the same large scale. These results have in turn supported the organization of a second large field campaign, realized at the Nakambé Basin scale only, in 2005, with the sampling of more than 20 reservoirs again. The hypothesis was that, at this scale, there exist "anthropogenic factors", xenobiotics, able to control both zooplankton and cyanobacterial dynamics.

The possible toxicity (or deleterious impact) of dissolved materials embedded within water bodies of this cluster of reservoirs was thus assessed, in exposing natural planktonic communities to series of different concentrations of these dissolved materials (Leboulanger et al. in prep). Toxicity appeared elevated in certain water bodies, particularly those surrounded by intensely irrigated farmland. Although none of the suspected pesticides could be found from the analytical investigation of the water, the toxicity was regarded as being due to the intense agriculture around the water bodies. The lack of significant amount of toxic substances in the analytical samples was thought to be a misleading result. Either the right pesticides had not been tested or the method used was too rough for the detection of the pesticides (or their residues) involved.

As there was clearly a correlation between the high population density, the agricultural practice, particularly gardening, and both high cyanobacterial concentration and significant toxicity of water extracts, further studies proved to be needed to find out what caused the toxicity of the water. This was the start of the IMPECA project.

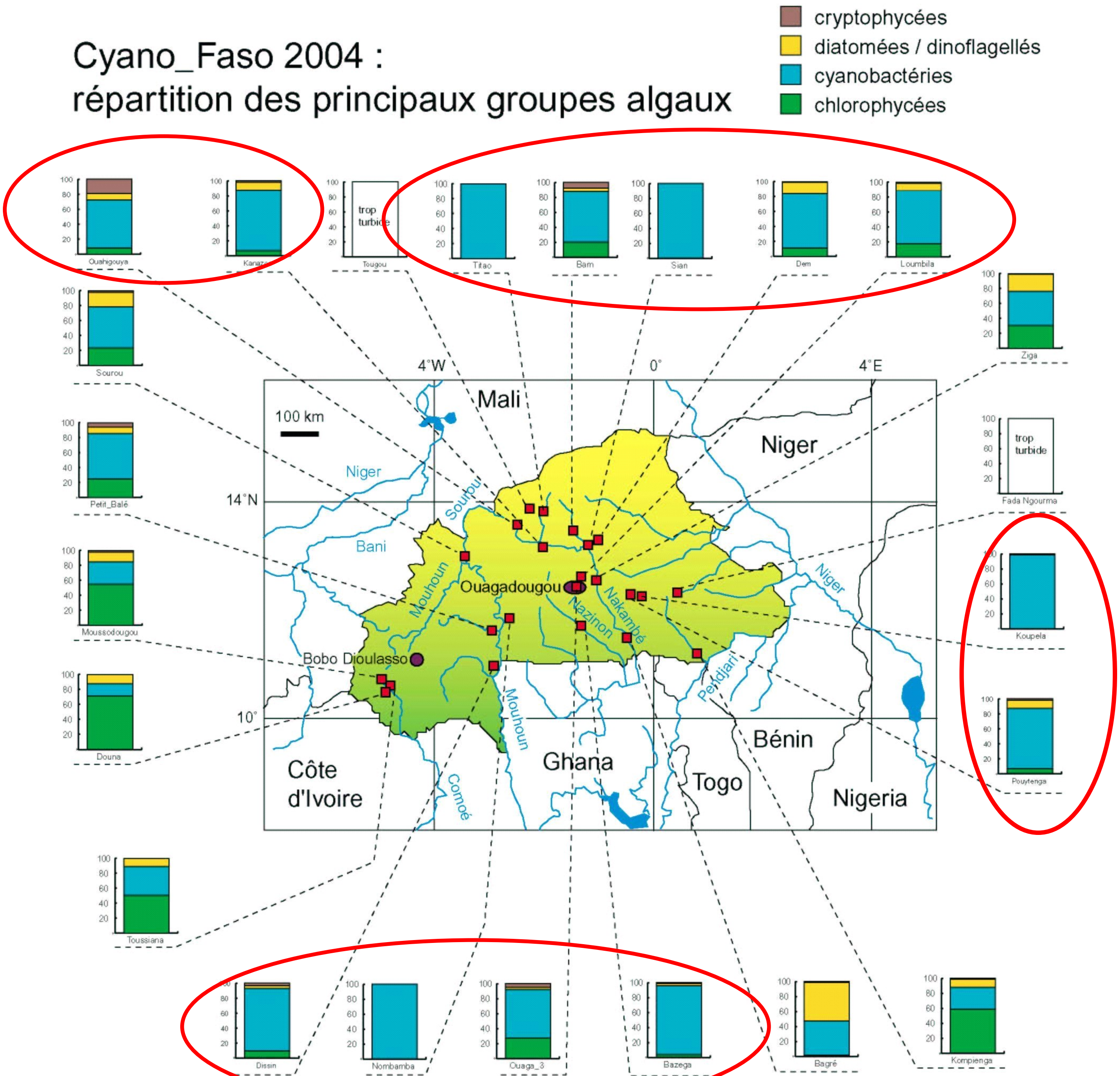

Figure 1 The composition of algae in reservoirs in Burkina Faso measured by IRD in 2004 (Source Cecchi 2005).

IMPECA ("Impact du Maraîchage et des Pesticides sur l'Ecologie et les Communautés Aquatiques", Impact of market gardening and pesticides on the ecology of aquatic communities) is a project that will gather information about agricultural practices in vicinity of the small reservoirs, and their actual impact on planktonic organisms. The project is financed by DANIDA (Danish International Development Agency) and is scheduled for two years from the start in March

2007. The intention is to study the different market gardening activities around the reservoirs. Information about the use of xenobiotics connected to different agricultural activities (types of cultures and practices) will be collected and quantified. The impact of the possibly toxic xenobiotics on target aquatic communities (bacteria, phytoplankton and zooplankton) is thereafter going to be investigated in the laboratory. The gathered information might result in a further understanding of the different interactions between people and reservoirs, and might explain what causes the observed toxicity of the water.

The project will include researchers from different disciplines (hydrologists, ecologists, and social scientists) and two contrasting sites are going to be studied. One site is the catchment area of Massili, north from Ouagadougou where the water in the largest reservoir, Loumbila is used for the provision of drinking water to the capital. The other site is the catchment area of Nariarlé consisting of about 50 small reservoirs south from Ouagadougou where there has been a massive increase in agriculture during the last years (Cecchi 2006). The comparison of these two contrasting situations is expected to provide valuable indications in terms of IWRM (Integrated Water Resources Management), which includes some part of flexibility regarding on one hand the socio-economic context of water resources (e.g. provide drinking water and sustain agriculture, respectively), and on the other hand the strategies and tools to be implemented to protect these water resources.

The variability in agricultural management among the farmers (typology of practices) at the sites selected is going to be evaluated with Geographical Information System (GIS). Axes of variability that are going to be evaluated are seasonal variability, site variability, agricultural method variability and crop variability. To enhance a good practice of the use of pesticides, if needed, consciousness rising will later be performed among the farmers to practice sound farming when it comes to pesticide use (Cecchi 2006).

In this thesis, Wille Hyrkäs and Stina Pernholm will work according to the method suggested in the project description of IMPECA. First, during the fieldwork (Chapter 2), data regarding the agricultural practices will be collected. Later in the laboratory (Chapter 3) the toxicity of the pesticides will be tested on natural phytoplankton communities.

2 PHASE 1 fieldwork: assessment of agricultural practices and intensification issues around the Toukoumtouré reservoir.

Agriculture is the predominant occupation for the 80% rural population in Burkina Faso. More than 1 500 reservoirs all over Burkina Faso store water that otherwise would run off and join major stream systems: Niger, Comoé, but principally Volta through the Nakambé (White Volta), the Nazinon (Red Volta) and the Mouhoun (Dark Volta) that all converge to fill the Akosombo Dam in Ghana (GIRE 2001). The anthropogenic pressure on the ecosystem is said to be particularly intense in the Nakambé basin, since most of the people in Burkina Faso live there, including all the people in the capital Ouagadougou (Cecchi 2006). The pressure is particularly severe during the dry season when the water level is low. During this time irrigated gardening develops on the shore sides of the reservoirs as nutritious bottom sediment becomes progressively available after water in the reservoirs has evaporated (Cecchi 2006, pers. comm. 21 Feb 2006). This intense agriculture is occurring in close vicinity of the reservoirs and often involves many people in the countryside villages. The increasing population has led to an increasing demand of vegetables which has resulted in even more stakeholders investing in such "cash crop" agriculture. It has resulted in more money transferred to the countryside and a possibility for people to ameliorate their living standard. However, the intensive agriculture might also have reverse consequences for the environment and particularly the water quality in the small reservoirs involved.

2.1 Objective

The main objective of the fieldwork is to do a *pilot study* of one reservoir selected for the study IMPECA. This pilot study will serve as a base for classification and method to be used later in the IMPECA project. A part of the study is to try to create a typology for the different crops grown, indicating the different intensity and possible impact on the water in the reservoir. The fieldwork involves also the collection of xenobiotics used by peasants and collection of WPI data to be used later in a database to classify the economic capacity of the market gardeners. The economic capacity is said to be a proxy, among others, of their "intensification potential". See table 1 for an overview of objectives mentioned in the project description of IMPECA (Cecchi 2007).

Table 1 Overview of the fieldwork.

	Objectives	Hypothesis	Variables studied	Method	Presentation
I	*Describe the different agricultural practices around the Toukoumtouré reservoir	-Different crops cultures have different impact on the ecology of the water	-size of sites of different exploitations -practices in the cultivation of different crops -qualitative and quantitative data from the field	- Questionnaire surveys - GPS mapping of surfaces -visual investigation -literature study	-Description of agricultural practices -GIS map
II	* identify xenobiotics locally used by farmers	-the xenobiotics that are used influences the ecological properties of the reservoir	-qualitative and quantitative information about pesticides and manure used.	-Questionnaire survey -visual investigation -visit to the local market	-Presentation of the xenobiotics used -Presentation of the active substances
IIi	*Classify the different crops grown based on differences in : water, fertilizers, and pesticides investment	-The higher grade of exploitation the greater risk of an impact on the ecology of the water	-added xenobiotics -cultivated area -water use -location of the fields -investments	-literature study - Questionnaire surveys -visual investigation	-typology of crops comparison of the different crops with regard to water, fertilizers, pesticides and investment
IV	*Quantitative estimations of the exploitations at the site Toukoumtouré.	-The market gardening have an impact on the water in Toukoumtouré	-qualitative data from the field.	-Questionnaire survey. -Literature study	-water balance -yearly water use -yearly pesticide use -yearly fertilizer use
IV	*Classify the economic capacity of the peasants	-A higher economic capacity is correlated with a more intense agriculture, hence a higher impact on the ecology of the reservoir.	-Ownership and land tenure -family structure -distance to the water -size of exploitation -water use per day	- Questionnaire surveys	-Towards a Water Poverty Index

2.2 Study site

The Toukoumtouré reservoir, situated in the Nariarlé basin south from Ouagadougou, was selected for the pilot study (see Figure 2). The reservoir is situated about 20 km southeast of Ouagadougou at -1° 20’ degrees longitude and 12°15’degrees latitude. The reservoir which was built in 1984, covers an area of 23.7 ha when it is filled, and it is partly surrounded by fields managed by market gardeners, see Figure 3.

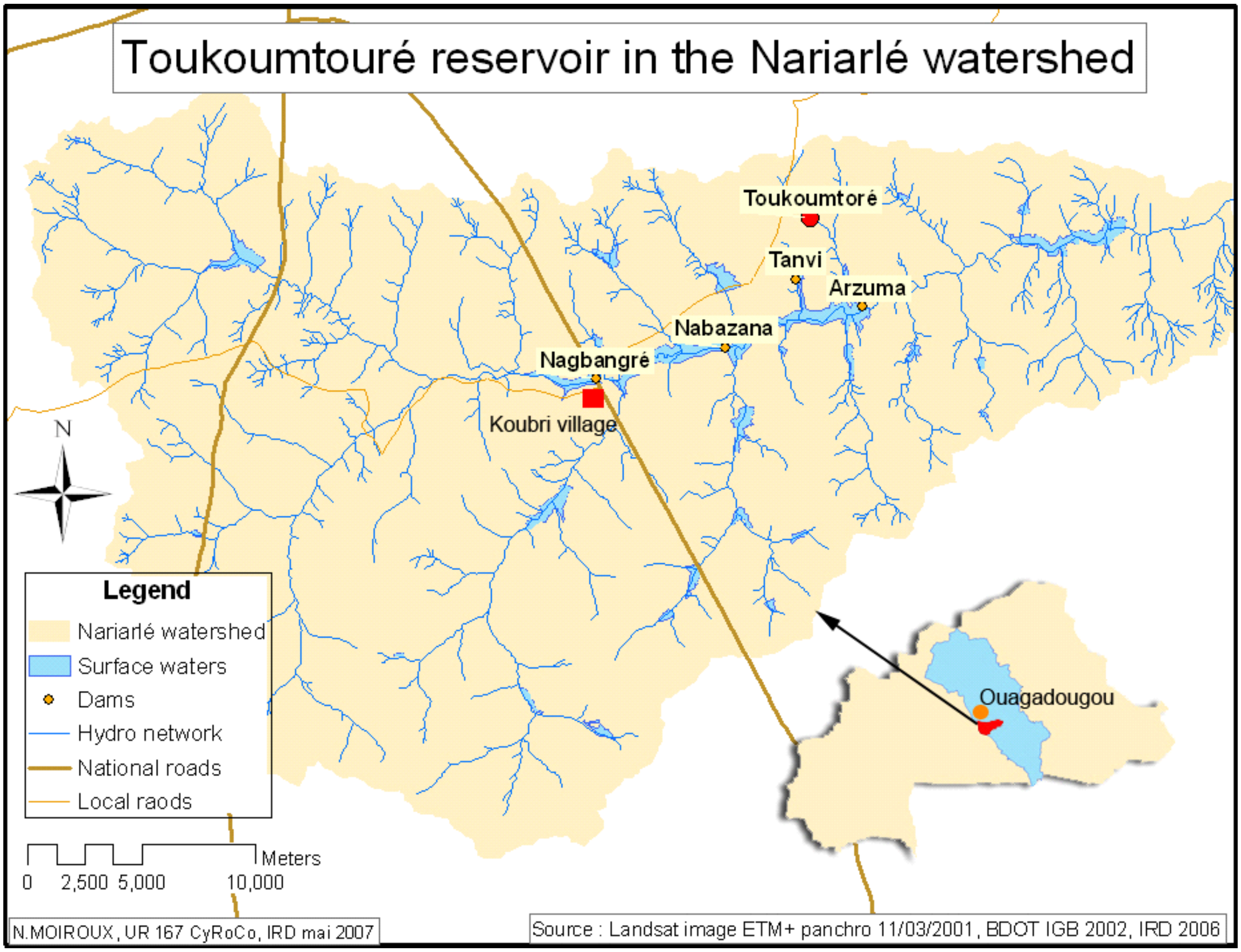

Figure 2 Toukoumtouré reservoir in the Nariarlé watershed.

The reservoir is situated in the Sudano-Sahelian climate zone and the average rainfall is 600-900 mm per year. It is one of many reservoirs in the area built under the supervision of “Frère Adrien”. The history section in Appendix 1 is a description of the first years of reservoir building in the Nariarlé basin.

Figure 3 The reservoir and surrounding fields.
(Source Google earth, quickbird image, Jan 25 2003)

2.3 Methodology

The questionnaire survey, the visual investigation, and the GPS measurements were done by the authors during a two weeks fieldwork in Toukoumtouré. The field work started on March 21, some days after the inception meeting of the IMPECA project, and ended ten days later. See Appendix 2 for an agenda of the fieldwork and Appendix 3 for a hazard assessment of the fieldwork. Below is a detailed description of the fieldwork in Toukoumtouré that might be useful for future field trips. Small gifts are mentioned since they are an important part of the common code of honor.

2.3.1 The first day of the fieldwork

The first day of the fieldwork started with a visit to the local market in Koubri. All different pesticides and manures found were bought and later used as a part in the Questionnaire survey. Later during the day the “Comité de barrage” was encountered in Toukoumtouré together with two representatives from the Belgian NGO “Broderlijken delen” and our interpreter Djibril Zoegrana. An explanation and presentation of our work was done in Mòoré (the local language) by Lydia Yelemou. Ten kola nuts were offered to the head of the “Comité de barrage” as a friendly gift. Before the actual survey started, the village chief was also visited and our work introduced. As no kola nuts could be found to buy that morning, 1000 CFA was offered instead.

2.3.2 The Questionnaire survey

The questionnaire survey was carried out among the market gardeners. The questionnaire included enquiries both about current agricultural practices and about water and the household (water poverty index). See Appendix 3 for the full questionnaire including some modifications of the questions used during this study. The farmers were chosen out of the “cahier de recensement” (census booklet) provided by the “Comité de barrage”. As it appeared that only 17 farmers were declared as market gardeners “jardiniers”, we decided to encounter all the farmers. Later it was found that not all cash crop farmers were registered in the “cahier de recensement” and with the help of the "Comité de barrage" we could find another 6 farmers that worked around Toukoumtouré on fields larger than 0.25 ha. In total 23 farmers were thus encountered.

After each interview the farmers’ field was visited for a visual investigation of the agricultural practices. The questions during the interview and the visual investigation were asked in French by Wille and then translated into Mòoré by Djibril. The answers were translated from Mòoré to French by Djibril. The answers were written down by Stina and as a back-up the interviews were recorded with an MP3 player. All available pesticides and fertilizers in the Koubri market were shown to the farmers so as to find out which products they were using. Four to six farmers were interviewed each day and a small gift, two packages of green tea and 1 kg of sugar, was offered to the last farmer each day to share with the other farmers that had been encountered during the day.

2.3.3 The mapping of surfaces

The surface extension of the water was measured by walking around the reservoir with a GPS (Garmin GPSMAP 76CSX). Data was collected each 20 m. The limit of the highest water level was shown to us by one person from the “Comité de Barrage” and one farmer. These persons were also helping us in giving information about abandoned fields and finding the way through fences and bushes to be able to map all the fields cultivated during the actual growing season. After three days of work the two people were offered 4 kg of rice and some oil.

The fields were also mapped with a GPS. The crops cultivated on each mapped field were recorded. Different crops were grouped together according to similar demands of pesticides, water, and manure. If many fields with the same crop were situated close to each other they were all recorded as one big field. The fields were divided into abandoned and managed fields and we limited our recording to the fields that had been managed since the last rain season. Different methods were used to calculate how large area that was cultivated during the year and to find out the applications of water and xenobiotics on the different crops.

2.4 Results

The areas used by different farmers for different crops were calculated from the GPS data except for the scallion (*Allium fistulosum*) field where each parcel was estimated being an area of about 3.9 m^2. This made the calculations possible from the GPS measurements where all the small scallion fields had been bunched together as one big field.

2.4.1 Description of agricultural practices

See for a summary of the answers from the questionnaire survey.
The market gardening starts in the end of the rain season (October to November in our area). During the rain season (from June to November), the farmers are normally working in other fields for food crop cultures (corn, sorghum, millet, and rice). There is traditionally no financial compensation for work devoted to these food crop cultures, but during "normal" hydrological years, the whole village is provided with basic food supplies. When the rain season is over, some stakeholders who have access to money (for seeds, fertilizers, and pesticides) and to fields progressively made available by the seasonal runoff decrease, invest in irrigated vegetable farming. This commercial activity may generate money but is time limited by the storage capacity of the reservoirs: when the reservoirs dry out again, market gardeners return to prepare their large crop fields for the next rain season. This situation may in some place be counterbalanced by the presence of another category of stakeholders, namely urban people strictly concerned by the potential benefits attached to irrigated cash crop cultures. For these people, gardening appears as a seasonal but speculative activity.

Crops cultivated

There were 11 different crops cultivated around Toukoumtouré during the dry season 2006-2007 (see Table 2). There were some common agricultural methods for different crops used by all the farmers around Toukoumtouré. The scallion was cultivated by dividing the lot into small parcels, see Figure 4. The number of parcels varied between 19 and 306. The zucchini *(Cucurbita pepo),* see Figure 5, was cultivated one by one, described as being cultivated in holes, banana *(Musa sp.), see Figure 6,* and papaya *(Carica papaya)* were also described as being cultivated one by one. The eggplants *(Solanum melongena, Solanum aethiopicum),* tomatoes *(Lycopersicon esculentum),* see Figure 7, cucumber *(Cucumis sativus)* and red pepper *(Capsicum annuum)* were cultivated in rows.

Figure 4 Parcels of scallions.

Figure 5 A zucchini field.

Table 2 Crops cultivated around the reservoir Toukoumtouré during the dry season 2006-2007. (Source: *questionnaire survey and Mansfeld's World Database 2003)

Plant fr.=**French**	Time from seed to the first harvest *	Harvest*
Papaya *(Carica papaya)* fr. papaye	6 months	The fruits continuously during 5 years
Banana *(Musa sp.)* fr. banane	6 months	The fruits one time. The whole plant is at the same time removed.
Scallion *(Allium fistulosum)* fr. Oignon vert	2 months	The whole plant
Eggplant *(Solanum melongena)* fr. Aubergine	3 months	The fruits every three to six days during the cultivating season
Onion violet de Galmi *(Allium cepa)* fr. oignon violet de Galmy	3 months	The whole plant
Tomato *(Lycopersicon esculentum)* fr. tomate	3 months	The fruits every three to six days during the cultivating season
Zucchini *(Cucurbita pepo)* fr. courgette	3 months	The fruits every three to six days during the cultivating season
Cucumber(*Cucumis sativus)* fr. concombre	3 months	The fruits every three to six days during the cultivating season
Cabbage(*Brassica oleracea L*) fr. choux	3 months	The whole plant
Wild African Eggplant *(Solanum aethiopicum)* fr. Aubergine sauvage	3 months	The fruits every three to six days during the cultivating season
Red pepper *(Capsicum annuum)* fr. poivre de Cayenne	3 months	The fruits continuously during the cultivating season

Figure 6 Banana in a papaya/banana field.

Figure 7 Rows of tomatoes

Irrigation

The parcels were irrigated either with a pump or manually with buckets. If the field was irrigated manually every parcel was added 4 to 6 buckets of water every three days, see Figure 8. If the field was irrigated with a pump, a network of small channels was built along the parcels and the irrigation was regulated by closing off the channels. See Figure 9. First the channel was closed of near the uppermost parcels and the water was led into those parcels. When the parcels had got enough water, the channel was again opened to lead the water to the next parcel. Big channels were built to get the water as close as possible to the fields, see Figure 10 for an illustration of a channel. These channels got deeper and longer when the water in the reservoir diminished. All water for the irrigation was taken from the reservoir.

Figure 8 Farmer irrigating their fields with buckets of water.

Figure 9 Farmer using a motor pump for the irrigation of the field.

Figure 10 Channel for irrigation.

Figure 11 Grasshoppers eating the scallion.

There was neither regulation nor restrictions concerning the water use. Farmers who did not own a pump was often borrowing a pump from another farmer and there was no obvious conflicts in the sharing of the water and the pumps. Instead the farmers seemed to be used to work together when digging the channels and moving the pipes to the motor pumps.

Pesticides

The pesticides were sprayed if there was an attack of insects, see Figure 11, often both morning and evening for a couple of days. If there was no attack the pesticides were preventively sprayed once a week. If the farmer could not afford a tank with a nozzle, a brush was used to spread the pesticides from a bucket. There was no common idea of where to put the used bottles of pesticides. Some are thrown away, some are buried in the soil and some are burnt.

Fertilizers

Fertilizers were bought on the market and, depending on the crops that were grown, added in different amount to the fields. Natural fertilizers, cow manure and compost were not added to the irrigated fields around the Toukoumtouré reservoir. In contrast, cow manure was frequently used on the big cereal fields during the rain season. Compost making was starting up but was also intended to be used on the big fields during the rain season.

GIS-map

The result from the GPS-mapping is shown in Appendix 9. Bananas were always grown together with the papaya on the fields. They were hence grouped together in our analysis. The red pepper, wild African eggplant and cucumber were put in the same group as eggplant as they got almost the same treatment as the eggplants. The cabbage field found was already abandoned and no information could be found about how the cultivation of cabbage was done. Cabbage is hence excluded from the analyses. The rice field was small compared to the other fields and as this field probably was cultivated for household purposes, thus it was also excluded from the analyses.

2.4.2 Identification of the xenobiotics locally used by the farmers

The pesticides used in Toukoumtouré in year 2007 are listed in Table 4 together with their active substance. Also a picture from the Koubri market is shown in Figure 12. Some of the pesticides were meant to be used on cotton fields, see Table 3. The recommended doses given on the bottles were in $l.ha^{-1}$. No information was given about the recommended frequency of application. Is it once per month, once per day or once per hour? A further description of the pesticides used is found in Table 3.

Most common pesticide used this growing season was Lampride. (It had been used by 65 % of the enquired farmers since July 2006). The next most common pesticide used was Lambda Super. (It had been used by 48% of the investigated farmers since July 2006). An interesting remark is that no herbicides seemed to be used among the farmers around Toukoumtouré. About 26% of the investigated farmers also mentioned using the fermented liquid made from the fruits of the Neem tree ("margousier", *Azadirachta indica*) as a (natural) pesticide alone, or in a mixture with other pesticides.

Three main products were found to cover all the needs of fertilizers, used in the market gardening activities. The urea at 46% N, the Yara NPK 15.15.15, and the Yara NPK 23.10.05 enriched with MgO, S and Zn, see Table 3 and Figure 12. The urea was described as having a rapidly resulting short term boosting effect, while the NPK was described as a long lasting fertilizer. The boosting effect of the urea is probably the reason why most farmers used the urea initially or at every fertilizing event, mixed with the NPK 15.15.15. As mentioned by the farmers, urea has to be added together with a lot of water as it dries out the field. The Yara NPK 23.10.05 was more expensive and hence it was used by less people.

Table 3 The xenobiotics used by farmers around Toukoumtouré during the dry season 2006-2007.

Commercial name	**Description**	**presentation**	**Active substances**	**Recommended dose**	**Company P=producer D=distributor**
Lampride	Insecticide	Emulsion concentrate 0,5l bottle	30g.l^{-1} Lambda Cyhalothrin 16g Acetamipride	1 l.ha^{-1} cotton(eqv to 30 g.ha^{-1} Lambda Cyhalothrin and 16 g.ha^{-1} Acetamipride)	P:Senchian, Senegal Sofitex, BF, D:campagne cotonnière 2005-2006
Lambda super	Incecticide	Emulsion concentrate 250 ml bottle	25g.l^{-1} Lambda Cyhalothrin	0,4-0,8 l.ha^{-1} vegetables(eqv to 10 – 20 g.ha^{-1} Lambda Cyhalothrin	P:Shenzhen Baocheng, china D:Kumark trading Ltd
Décis	Insecticide	Emulsion concentrate 100 ml bottle	12,5g.l^{-1} Deltaméthrin	1 l.ha^{-1} vegetables(eqv to 12,5 g.ha^{-1} Deltaméthrin)	P, D:Bayer Crop science, Abidjan
Rocky	Insecticide	Emulsion concentrate 500 ml bottle	350 g.l^{-1} Endosufan 36 g.l^{-1} Cypermethrine	1l.ha^{-1} cotton(eqv to 350 g.ha^{-1} Endosufan and 36 g.ha^{-1} Cypermethrine)	P: Saphito BF
Cypercal	Insecticide	Emulsion concentrate l l bottle	36 g.l^{-1} Cyperméthrine, 250 g.l^{-1} Monochrotophos	l l.ha^{-1} cotton(eqv to 36 g.ha^{-1} Cypermethrine and 250 g.ha^{-1} Monochrotophos)	P:SPIA Senegal; D:MDC Bamako Mali
Capt	Insecticide	Emulsion concentrate l l bottle	72 g.l^{-1} Acétamiprid 16g.l^{-1} Cyperméthrine	1l.ha^{-1} cotton(eqv to 72 g.ha^{-1} Acétamiprid and 16 g.ha^{-1} Cyperméthrine)	P :ALM internat. France, D :Sofitex BF, campagne cotonnier 2006-2007
Furadan	Insecticide nematicide	Granules l kg	3% Carbofuran	25g.m^{-2}(eqv to 7500 g.ha^{-1} Carbofuran)	P: FMC cooperation, USA. D:Chemico Ltd Ghana
Caiman Rouge	Insecticide/ Fungicide	Powder 90 g	25 % Endosulfan 25 % Thirame	90g for 30 kg cotton grains	P: CCAB BF D:Sofitex cmpagne 2006-2007
Neem*(Azadirachta indica)*	Insecticide	Fermented liquid of the seeds from the Neem tree.	Azadirachtine		Made locally by the farmers

Figure 12 Pesticides and seeds on the market.

Figure 13 Sacks of manure on the market.

Table 4 An overview of the active substances in the pesticides used by farmers around Toukoumtouré.

Pesticides → / Active substances ↓	Décis	Rocky	Cypercal	Capt	Lampride	Lambda super	Furadan	Caïman Rouge	Neem *(Azadirachta indica)*
Acétamiprid				X	X				
Azadirachtine									X
Cypermethrin		X	X	X					
Deltaméthrin	X								
Endosulfan		X						X	
Lambda Cyhalothrin					X	X			
Monochrotophos			X						
Carbofuran							X		
Thirame								X	

2.4.3 Classification of the different crops

The crops can be classified in more than one way. Differences in added xenobiotics, water use, location of the field and investments are studied in this chapter. The classification of the crops can be used in the future to make a typology and a scale where the different crops can be listed according to the different (potential) impacts their culture may induce on the water in the reservoir. To create a typology of crops one has to evaluate whether the cultivation of one certain crop has a more severe impact on the water than the cultivation of other crops.

The cultivated plants have different needs regarding water, pesticides, and fertilization. These needs can be evaluated by asking the farmers the amount of water, pesticides, and fertilizers that are added on the crops. The impact of the xenobiotics eventually reaching the water is more difficult to evaluate. In this study the classification of the crops will be based on differences in agricultural practices. Differences in agricultural practices are e.g. time of cultivation and surface area, water use, pesticide use, fertilizer use and investments.

Area calculations

Because of the bunching together of the scallion fields, we did not get the different areas for the scallion fields from the GPS-measurements. Instead we used the information about each farmer's number of parcels on his field. We assumed a size of 3.9 m^2 for each parcel. 3.9 m^2 is the average value of the size of the parcels from two fields that were measured separately. We could then easily calculate the area of each farmer's scallion field.

E.g. farmer no 1 had 100 parcels of scallion: 100 parcels*3.9 m^2.parcel^{-1}= 390 m^2.

As we knew the area of each currently managed field and the active months during the year, a monthly value of all the currently managed fields could easily be calculated.

We knew the finishing date of all abandoned fields from information collected during the GPS measurements. We assumed that the area above HWL (high water level) started to get cultivated in September. That gave sufficient time for the plants to grow before harvest. The area below the HWL was assumed to start to get cultivated in December.

There are some areas were we did not have any information about added water, pesticides and fertilizers, see Table 5. We assumed that the fields we had no information about were spread out equally on the surface. We calculated a missing percentage relative to the managed fields. From that information we could extend the area of different crops and months with this percentage to get a more precise value of the actual cultivated area. This area including the area of the fields that were abandoned during the questionnaire but managed during that certain month will be added together to result in the total area. See Figure 17.

E.g. the total area of scallion cultivated in October:
1218 parcels*3,9 m^2.parcel^{-1}=4750,2 m^2.
Extended area=4750,2*1,8404=8742 m^2. Area of abandoned scallion fields that were managed in October =2362,70 m^2. Total area of scallion fields managed in October: 8742+2362,70=11105 m^3.

These calculations were repeated for all months and all crops. The result is shown in Table 8.

Table 5 Total areas measured during the fieldwork and areas used as a base for calculations.

	Banana Papaya	Scallion	Eggplant	Onion	Tomato	Zucchini	Cabbage	Rice	Total
Total area GIS	9978	26788	21278	3461	3981	557	1137	70	67249
Currently managed fields*	9570	11423	18486	3461	3172	557	0	0	46669
Area abandoned **	409	5764	1734	0	129	0	1137	70	9242
Area without information ***	0	9600	1058	0	680	0	0	0	11338
Fields without information about area (percentage of currently managed fields)	0	84,0	5,7	0	21,4	0	0	0	24,3

Water use

The irrigation techniques are described in Chapter 2.4.1, description of agricultural practices and the precision in estimating the water use during separate months showed to be very low. The ones who irrigated with buckets and used the parcel system are accurate, but the ones using motor pumps and cultivating rows were more difficult to predict, e.g. the flow of the water from the pump was never measured and had to be estimated theoretically.

Because all of the six farmers who used the motor pump for irrigation, cultivated scallion and used the pump to irrigate the scallion. We made the assumption that they put the motor pump at the same effect when irrigating all other plants as when irrigating scallion. We assumed that the motor pump users put the same amount of water on their scallion fields as the people who used buckets for the irrigation, i.e.~75 l per parcel which would correspond to five buckets. The total amount of water needed for a field was divided with the time that the motor pump was used for the irrigation of the same field, (information from the questionnaire survey). This results in a certain pump flow for each farmer and an average value of 8,44 $m^3.h^{-1}$ for all six farmers. The standard deviation was large, 2,86 $m^3.h^{-1}$. This indicates that the pump flow varies a lot between the farmers, or that the farmers used different pump flows for different fields. Another probable explanation is the difficulties among the farmers to estimate the exact time in hours of irrigation without having measured it with a watch. The water use for the different crops is calculated as follow:

- the zucchini fields are well described in the interviews. The area for each zucchini field is measured with GPS. The water use divided by the area is calculated for each farmer and the average value for all the farmers growing zucchini is 162 mm.m^{-2}.month^{-1} ,see Figure 14;

- the water consumption of scallion is also calculated through the known number of parcels and the information about the number of buckets of water added. The parcel size has been determined by dividing known areas of two scallion fields by the number of parcels on it. The average parcel size is then 3.9 m^{2}. The average of the water consumption of scallion around Toukoumtouré is thus167 mm.m-^{2}.month^{-1}, see Figure 14;

- The tomato, onion and aubergine water demands are determined by using the calculated pump flow for each farmer individually. The calculations give us the following water demands: tomato 138 mm.m-^{2}.month^{-1}, onion 201 mm.m-^{2}.month^{-1}, aubergine 231 mm.m-^{2}.month^{-1} and papaya/banana 160. The literature value of water need is 150-200 mm.m-^{2}.month^{-1} on a papaya field and 125-150 mm.m-^{2}.month^{-1} on a banana field (CIRAD-GRET 2002). This seems to correspond to our average value for the banana/papaya field of 160 mm.m-^{2}.month^{-1}.

- The abandoned cabbage field and the rice field are left out in the calculus as we do not have enough data for these fields.

Pesticides

The amount of pesticides applied on the fields was given in litres per month. By dividing this number with the area, the amount of pesticide applied on the fields was calculated. An average amount for all farmers could then be calculated (see Figure 15). There seemed to be a big variation among the different farmers, hence all the farmers fields were treated individually when calculated the total amount of pesticides used around Toukoumtouré. The total amount pesticides used around Toukoumtouré the year 2005-2007 was calculated by multiplying the each farmer's individual pesticide use per month and field with the area of the field and the number of months it is managed.

E.g. farmer no 1 total pesticide use on his scallion field: 6,4l Lampride.month^{-1}.ha^{-1} * 0.039 ha * 5 months=1,28l Lampride.

Every farmers total pesticide use was multiplied by a percentage to include the areas without information that are found in Table 5.

As we did not have any information on the pesticide use on the abandoned fields, we used average pesticide values for the different crops, see Figure 15. The total pesticide use (see Figure 19) includes the managed and the abandoned fields. This was then converted into grams of the active substance per hectare, in the diagram as it is the way that one might continue using in e.g. the Prompt model, (Whelan et al. 2007).

As Lambda Super and Lampride were almost the only two other pesticides used, these were also the only two included in the calculations, Only one person was using Roxy and two people told us they had been using Décis before, but that they could not find it on the market any more. One person had used Caiman Rouge in a mixture with Lampride and one person had used Furadan mixed with Caiman Rouge one time around the plants to prevent termite attack.

Fertilizers

The amount of fertilizers was calculated from the information on the numbers of sacks of fertilizers added per month, knowing that 1 sack corresponds to 50 kg. The calculation follows the same procedure as for pesticides. The fertilizers were divided into NPK, urea and NPK+MgO etc. and the variation was large between the different farmers, see Figure 16. The total amount of fertilizers used in the year 2006-2007 can be seen in Figure 20.

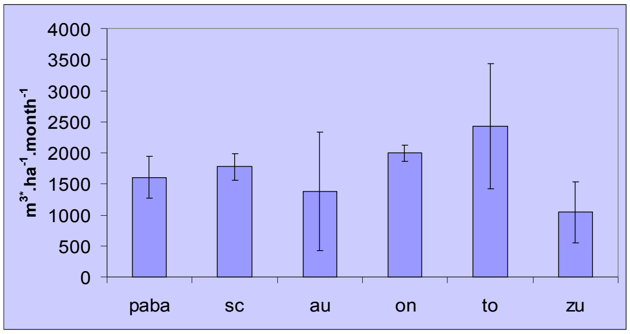

Figure 14 Average amount of water added to the different crops per month.
The variations are large and the farmers are clearly using different amounts of water on their fields which shows on the high variation of the individual data. The difference could be explained from the different irrigation techniques where a motor pump easily can pump more water than what is needed by the plants.
paba=papaya,banana, sc=scallion, au=eggplant, to=tomato and zu=zucchini

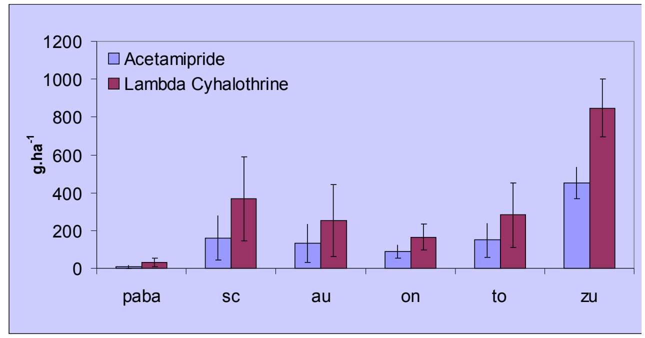

Figure 15 Pesticide use per month.
The banana/papaya seems to demand less pesticide per month although the variations between the applications by the different farmers are large.
paba=papaya,banana, sc=scallion, au=eggplant, to=tomato and zu=zucchini

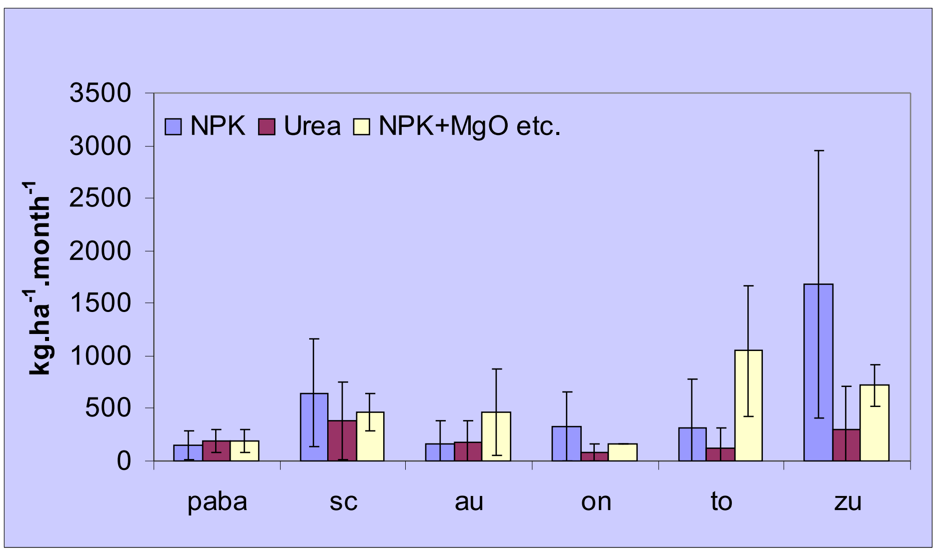

Figure 16 Fertilizer use per month.
Also the use of fertilizers shows a big variation. The fact that fertilizers are expensive might be one reason for the variation as some farmers can afford more fertilizers than other farmers. paba=papaya,banana, sc=scallion, au=eggplant, to=tomato and zu=zucchini

The unit in the diagram above is kg per ha per month and growing period. As papaya for example grows permanently for one year whereas scallion needs two months before harvest, some weighting of the data is required. This means that even though the papaya seems to need less fertilizer, the accumulated amount of fertilizers during one year for a papaya field can highly exceed the fertilizers used one year on a scallion field.

Location of the fields

Crop selection by farmers also depends on the location of available fields and their distance to the reservoir. Papaya must be grown above the highest water level as it is a perennial plant. The eggplant, tomato, and zucchini are preferably planted early during the growing season as they can be harvested continuously from the first harvest. Hence, they are located nearer to the upper water limit. They do not have to be planted above the highest water limit as these vegetables are replanted every year. The scallion is the choice when the water level is low. It grows quickly and can be grown in the short time span which lasts between the exposure of new land around the reservoir and the total disappearance of water in the reservoir by the end of the season.

Where the people are allowed to grow their crops, the question regarding ownership of the land, reveals the Moose people's system of land tenure, which is a strictly traditional matter. The Teng Naba, the land chief (fr. chef de terre), is born to decide over the land use, and is always going to approve anyone a piece of land where it is not yet occupied if he offers for example a chicken to the piece of land in question. The people who have been approved land from the Teng Naba call themselves owners of the land. If the land that has been approved to the farmer from the Teng Naba is too large, the land is either taken back or the farmer distributes it to other people that can farm the land. Those farmers say that they borrow or rent the land. According to the answers from the questionnaire they are never obliged to pay anything, but they often give symbolic presents such as some of the harvest, small money or an animal.

Investments

The investment that has to be made to get an outcome is different for different plants. It is also an important factor in the decision of which plants to grow. The investment made on one field can be divided into money that has to be invested before the first harvest and money that is needed per month for the maintenance of the cultivation. In the case of onion, the money does not return immediately after the harvest as the onion often is stored several months before being sold.

The questions concerning the sell-off of the harvest gives a picture of how the business goes. The farmers sell the crops by sacks at a varying price due to the market. Prices are low when the crop is abundant, and you can have a high outcome if the demand is great while the crop is rare. Therefore it can be very profitable to store the onions for maybe six months, and let them dry before to sell them. Most vegetables cannot be stored though, but need to be sold quickly after harvesting. The buyers are women that work in the market places of mostly Ouagadougou and Koubri, and they sell the vegetables by pieces or by volume (number of standard bowls). The sacks are turned over to these ladies either in the village where they have been grown, somewhere on the road to town, or in town at the market place where the lady is selling. The price is higher the closer to town you transport your harvest.

The fertilizers and the pesticides differ in price, fertilizers seem to be the most expensive xenobiotics used by the farmers, see Table 6.

Table 6 Prices at Koubri market.

Product	Size	Price CFA
Lampride	500 ml	3000
Lambda Super	250 ml	3000
NPK	50kg	15000
Urea	50kg	15000
NPK+MgO etc	50kg	15000

Below is an example of the calculation of the profits from a typical scallion field of 0,2 ha, see Table 7.

Table 7 profits from the cultivation of scallion.

	Month 1	**Month 2**	**Selling**	**Total**	**Comment**
seeds	--	--		--	No cost for the seeds as the plants are taken from already exciting fields
water	--	--		--	No cost for the water as we assume that the field is irrigated with buckets and not with a motor pump.
pesticides	-1886	-1886		-3773	Lampride:0,02ha*10,48 $l.ha^{-1}$*6000 $CFA.l^{-1}$=1258 Lambda Super:0,2 ha *2,62 $l.ha^{-1}$*12000 $CFA.l^{-1}$=629 CFA
manure	-8916	-8916		-17832	0,02ha*(643+379+464) $kg.ha^{-1}$/ 50 $kg.sack^{-1}$ *15000$CFA.sack^{-1}$=8916CFA
			+51300	+51300	51,3 parcels/1.5 parcel* $sacks^{-1}$*1500 $CFA.sack^{-1}$=51300
		Profit		+29695	

2.4.4 Quantitative estimations of the exploitations around Toukoumtouré

A further evaluation of the impact of water, pesticides and manure on the aquatic ecology of the reservoir has to be done to establish which crop has the highest impact in the long run. The amount of a certain pesticide applied on the surface might for example not reflect the impact it might have on the water ecology. In a study on different pesticides in Costa Rica and their effect on water ecology it was found that 5 out of 30 active substances used contributed to more than 75 % of the aquatic toxicity (Humpbert et al. 2007). The five substances yet represented less than 40 % of the total amount of substances used. The study takes into account different parameters such as residence time of the substance in water, amount of pesticide transferred from the fields to the water and impact on species based on LC50 values. Although the model used in the study is adapted to Costa Rican climate conditions, it indicates generally that dose/hectare is not enough if you want to describe the toxic impacts of a pesticide on the water ecology. The recommendation in the study was to change the toxic herbicide Paraquat and use Glyphosate instead. Also Cypermethrin was considered an interesting substance to use as it had a very low aquatic ecotoxicity. Cypermethrin is one of the substances used by the farmers around Toukoumtouré.

Table 8 Areas of the crops grown 2006-2007 around Toukoumtouré. Average water use average pesticide use and average fertilizer use.

		Papaya/ banana	Scallion	Eggplant	Onion	Tomato	Zucchini
Area grown (ha)	**Jan**	0,9978	2,0617	2,1226	0,3461	0,3979	0,0319
	Feb	0,9978	2,1433	1,8812	0,3461	0,3979	0,0557
	Mar	0,9569	2,1023	1,7780	0,3461	0,3850	0,0557
	Apr	0,9569	2,1023	1,2117	0,3461	0,0000	0,0557
	May	0,9569	1,7176	0,9129	0,1545	0,0000	0,0557
	Jun	0,9978	2,0617	2,1226	0,3461	0,3979	0,0319
	Jul	0,9569	0,0000	0,4222	0,0000	0,0000	0,0000
	Aug	0,9569	0,0000	0,4222	0,0000	0,0000	0,0000
	Sep	0,9978	0,2542	0,8134	0,0000	0,1961	0,0000
	Oct	0,9978	1,1105	1,6764	0,0000	0,3363	0,0000
	Nov	0,9978	1,2444	1,9405	0,0000	0,3363	0,0180
	Dec	0,9978	2,0741	2,1226	0,3461	0,3979	0,0319
Average water use (m^3. $month^{-1}$. ha^{-1})		1603	1774	1385	1993	2422	1045
Average pesticides added (l. $month^{-1}$. ha^{-1})	**Lampride**	0,45	10,08	8,35	5,53	9,40	28,25
	Lambda super	0,77	2,62	0,07	0,00	0,00	0,00
Average fertilizer use (kg. $month^{-1}$. ha^{-1})	**NPK**	148	643	160	326	313	1682
	Urea	193	379	172	81	123	307
	NPK+ MgO etc.	193	464	462	162	1048	724

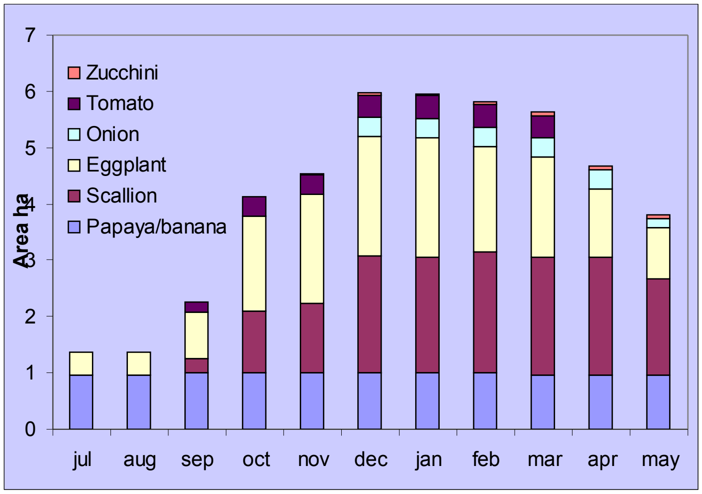

Figure 17 Cultivating pressure around Toukoumtouré. December and January are the months with the highest cultivating pressure around Toukoumtouré. Most of the cultivation starts in October and ends when the raining season starts in the end of May.

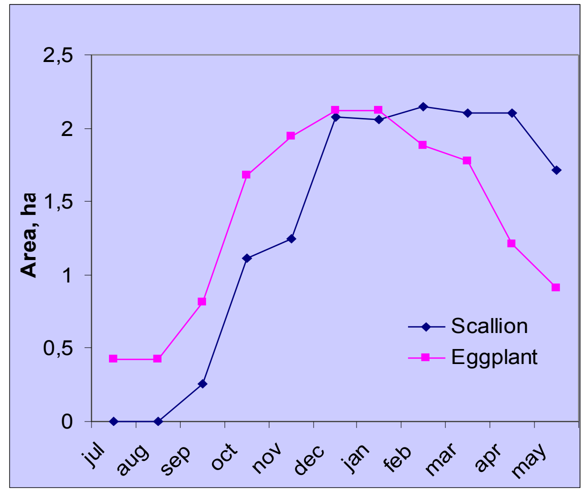

Figure 18 Differences in cultivating pressure between scallion and eggplant.
While eggplant has its peak in December and January, scallion has its peak in March. The fact that the eggplant fields are abandoned earlier could indicate that it is harder to irrigate the eggplant fields later in the season as they are no longer situated close to the water.

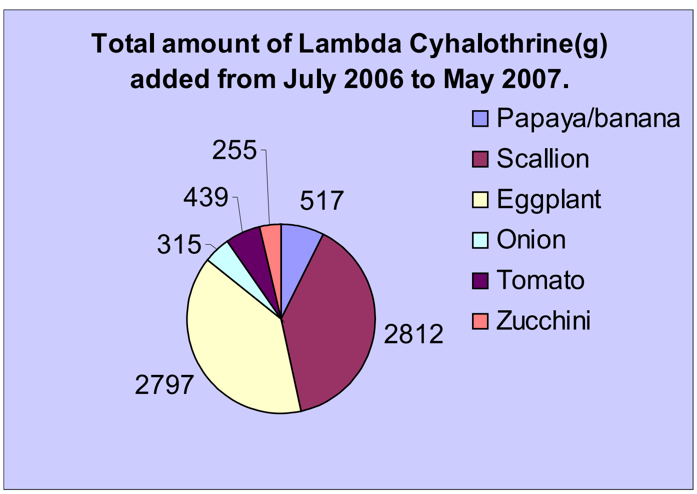

Figure 19 Lambda Cyhalothrin use in 2006-2007 around Toukoumtouré.
The scallion and tomato fields are covering a high percentage of the cultivated area around Toukoumtouré. They are hence also using most pesticides in total.

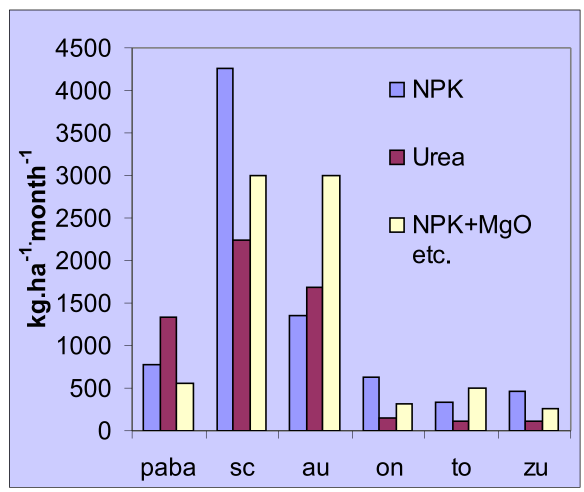

Figure 20 Fertilizer use in 2006-2007 around Toukoumtouré.
Eggplant and Scallion fields are also using the most fertilizers in total due to their large areas.
paba=papaya,banana, sc=scallion, au=eggplant, to=tomato and zu=zucchini

Water Balance Modeling

To determine the consumption of reservoir water in a useful way every inflow and outflow must be considered when setting up a water balance equation. The reservoir is filled during the rain season from June to October and we assume that the reservoir system is saturated, completely full. The water level starts sinking in November and the lake looses continuously water until it eventually may dry out around May or June. The amount of water by November is calculated through the reservoir volume estimation. The different major losses are the evaporation, E_{ret}, the irrigation of the market gardening, I, the watering of herds (mainly beef cattle), W, and the household consumption, H, all active during the draining period, November to May.

One major uncertainty may be losses from the reservoir water to the surrounding groundwater aquifer, which could as well be of opposite effect and rather refill the reservoir.

The GLOWA Volta project has also been studying “sustainable water resource management in the Volta basin [which encompasses the Nariarlé basin]” (www.glowa-volta.de) since 2000. Recently it sponsored a study on the groundwater development potential within the Volta basin (Martin and van de Geisen 2004) and has supported other studies on recharge and groundwater modeling at small basins in Ghana (Martin 2006). Although none of these studies have specifically addressed recharge through reservoirs, stable isotope testing has shown water from surface bodies to be present in the groundwater (Martin 2006).

The actual exchange is left out in this discussion being far too difficult to estimate, which unfortunately makes the whole water balance equation as presented here not the least reliable. The effects of different water losses due to human pressure on the reservoir and their relative proportions are still of interest, and indeed the aim of this water balance. Nevertheless we made a rough estimation for all contributing terms in the balance resulting in the following formula:

$$V = V_{\max} - \left(E_{ret} + I + W + H\right) \qquad \text{Eq. 1}$$

where

V = the volume of the reservoir, m^3
Vmax= the maximum volume of the reservoir, m^3
E_{ret}= water losses due to evaporation, m^3
I=water losses due to Irrigation, m^3
W= water losses due to watering of animals, m^3
H= water losses due to household consumption, m^3

Reservoir volume estimation, V_{max}

We simplified the model by Jens Liebe (Liebe 2005), who determined the volume of a reservoir in northern Ghana by 120 depth measurements and 504 GPS-points. In our model only one depth measurement was used.

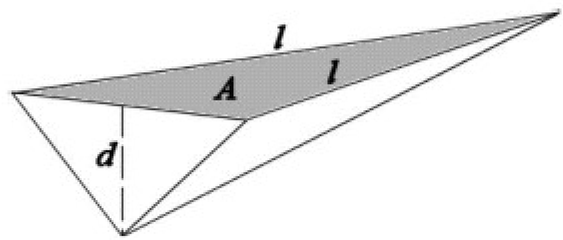

Figure 21 A top-down pyramid describes the volume of the reservoir.
The top down pyramid model describes the shape of a reservoir. A-Area, l-length of one side. D= depth. (Source Liebe 2005)

The model of a top down pyramid describes very well the shape of such reservoirs; see Figure 21, created through damming a stream on a flat land like in this part of Burkina (Liebe et al. 2005). The GPS gives us the exact surface area and the length of the reservoir dike. The deepest depth has been measured with a measure tape from the water front to the spillway of the reservoir wall and the estimation by a wading fisherman, to 3.7 meters. Even though the original stream meanders two times throughout the reservoir (when filled), the curved shape of the surface area can be approximated straight and precisely calculated by the enclosed area of the high water level being pointed out with the GPS. The surface area is 23.7 ha, and the reservoir wall is 330 meters long. Using these values to calculate the length of the reservoir as the height of a triangle with this reservoir wall length for base, and the same surface area, it turns out to be 1400 meters. When measuring the distance between the reservoir wall and the most far away point on the high water level contour in the satellite picture, you obtain 1100 meters. The difference may correspond to the curvature of the reservoir which would measure 1400 meters if stretched out. Using the above model to obtain the volume is really easy taking the area multiplied by the depth and dividing by four, since the depth is triangular in two dimensions.
This gives 220 000 m^3.

$$V = \frac{1}{4} A \cdot d = 0.25 \cdot 237000 \cdot 3.7 \approx 220000 \qquad \text{Eq. 2}$$

The volume found is confirmed to be true by Frère Adrien, who built the reservoir, it, was originally dimensioned to hold back between 200 000 and 300 000 m^3 of water.

Due to the relationship depth-volume found for small reservoirs in different countries of the region (Burkina Faso, Ghana and Côte d'Ivoire), the depth of 3.7 m would rather correspond to a volume of 600 000 m^3,194 000 m^3 and 301 000 m^3, respectively (Gourdin et al. in press). Discrepancies observed between these estimations are primarily linked to the heterogeneity of lake samples used for the establishment of the relationship used. For Burkina Faso, the relationship is thus largely influenced by relative large lakes whose hydrological behaviour may significantly differ from those of small reservoirs. In that way, estimations provided by the relationships elaborated for Ghana and Côte d'Ivoire give a valuable approximation compatible with the volume calculated.

$$V = 39871 \cdot H^{2.08} = 606000 \qquad \text{Eq. 3}$$

Table 9 Volume calculations for reservoirs with a depth of 3.7 m.

LnV = Ln(a)+bLn(H)						
	a	b	H	bLn(H)	Ln(a) + Ln(b)	V
Côte d'Ivoire	5799	3.02	3.7	4.0	12.6	301 524
Ghana	2618	3.29	3.7	4.3	12.2	193 800
Burkina Faso	39871	2.08	3.7	2.7	13.3	606 062
Sertão	3049	2.7	3.7	3.5	11.6	104 304

This estimated volume of 220 000 m^3 will be considered as the correct one.

Market gardening irrigation estimation, I

From the above calculations (see Chapter 2.4.2, classification of the different crops, water use) the average amount of water added to the different crops and the total amount of irrigation water used per month are estimated. See Table 10 and Table 11.

Table 10 Average amount of water added to the different crops around Toukoumtouré (mm.m^{-2}.month^{-1}).

Papaya and Banana	Scallion	Aubergine	Onion	Zucchini	Tomato
160	177	139	199	242	105

The fields are managed either all around the year or only during certain months when irrigating is made easy enough, the water moving away from the field as the water level sinks. The same farmer may for example abandon one field situated above the highest water level for a another field closer to the water front, and within the inundation zone that is submerged by the reservoir during one part of the year. Since we know which fields are managed during what time of the year, we can estimate the irrigation water consumption monthly. One can clearly see that short term scallion fields are dominating by the end of the dry season, situated low down in the reservoir basin which is covered with water until the end of February. Among the abandoned fields outside the high water level, aubergine is dominating. This means a general change of production from November to May, see Figure 18.

Table 11 The total water consumption of the year 2006-2007
is about 56 900 m^3, found by summing up all crops' water needs, and 44 800 m^3 during the drain period. To be compared with the 220 000 m^3 of the reservoir when full.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Year tot
Pap. and ban.	1476	1476	1476	1476	1411	1411	1411	10136
Scallion	1354	2444	2415	2337	2037	2037	1658	14282
Aubergine	1901	2248	2248	2127	1985	1352	1127	12989
Onion	0	695	695	695	695	695	287	3761
Tomato	483	708	708	708	677	0	0	3286
Zucchini	22	44	44	52	52	52	52	316
Total	5237	7615	7586	7395	6856	5546	4534	*44770*

Animal watering estimation, W

Cattle herds drink by far the most water per day among the animals depending on the reservoir. Other animals are sheep, goats and donkeys, but they are outnumbered by the beef cattle. That's why we decided to count only the number of cows during one day, knowing that a cow drinks about 30 litres per day (NDSU 1999) and visits a water point three times per day. The number being counted was then multiplied by 10 litres to have the daily animal watering. By the time that we performed the counting, the 13 of April 2007, the water was already very low, filled with mud and green from a high concentration of algae. The people around the reservoir told us that the water now had a bad effect on the animals, their stomachs swell and they go tired. Many herds then choose to walk to another water point with better water, and we did count a lot less cows than normally takes water from Toukoumtouré, only 527.

For a year around estimation we were told that in a period of filled water reservoirs in the area, from June to January, only about 400 cows take water in Toukoumtouré, which would yield 1200 daily visits, and later in the season, February and March, the smaller reservoirs are already empty and about 1000 cows take their water from Toukoumtouré, i.e. 3000 daily visits. By the time that we counted the cows a small rain had fell recently that filled some small reservoirs nearby, that may have watered many cows who normally come to Toukoumtouré, and hence reduced the number even more.

- The maximal consumption would then be 30 000 litres per day, 30 m^3, and at the occasion of counting cows 5 270 litres, 5 m^3.
- During the dried out season and just before, by the end of April and May, the consumption is zero.
- The rest of the year, June to January, during normal conditions, the consumption is 12 000 litres per day, or 12 m^3, see Table 12.

Table 12 The amount of water loss due to watering of cattle.
The total amount is 4830 m^3 per year. 3030 m^3 is used during the draining season. In February and March the water loss due to cattle watering has its peak, 900 m^3.This is due to the drying out of nearby reservoirs hence more cattle arriving to drink in Toukoumtouré. In April and May, other reservoirs are preferred as the water quality in Toukoumtouré is getting worse.

June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	total
360	360	360	360	360	360	360	360	900	900	150	0	4830
Only dry season (m^3)					360	360	360	900	900	150	0	3030

Household consumption, H

Certain primary household needs are satisfied by water from the reservoir, such as cleaning clothes, washing and watering small animals like chicken. Some people collect water in one or two 200 litre barrels, pulled on a chariot by a donkey. They are estimated to be about 20 per day. Assuming that they come every day and always take two barrels of water, the total volume of water will be 8 m^3 per day, and 240 m^3 per month. When counting chariots the 13 of April 2007, only three were spotted. The water was by then already of so bad quality that people started taking water for household needs elsewhere. This contribution to the total water consumption was really small, and may be mentioned only during the months November to March, and then left out when water use start to decline, see Table 13.

Leaking water through the reservoir dike constitutes an alternative source to the normal well. The water is naturally purified when passing through the gravel and sand deep under the bottom of the reservoir. See Figure 22

Figure 22 A leak in the reservoir dike provides people with clean water.

Table 13 Water losses due to household consumption

month	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot

m^3	240	240	240	240	240	0	0	1200

Evaporation estimation, E_{ret}

The evaporation is due to the surface area, and changes during the draining period as the surface goes smaller. The evaporation can be calculated with help from the formula

$$E_{ret} = 122,94 \cdot Lat + 619,36$$

where Lat is the latitude in degrees north. This formula has been elaborated for small reservoirs of a couple to 40 ha surface in Burkina Faso, when performing statistics on the Loumbila reservoir just north of Ouagadougou by Bunel and Bouron 1992. Our reservoir is situated 12°15' N, wich gives Lat = 12,25 and thus evaporation is estimated as E_{ret}= 2125 mm per year.

$$E_{ret} = 122.94 \cdot 12.25 + 619.36 = 2125 \qquad \text{Eq. 4}$$

For a monthly estimation we use the model recommended by Bunel and Bouron 1992. Receiving the monthly potential evaporation as a mean value since thirty years of measurements from the airport of Ouagadougou, ET_o, (see Appendix 7) allows us to apply the given ratio k = E_{ret}/ ET_o for small reservoirs in Sahelian climate to estimate the monthly evaporation during the drain period of the reservoir:

Table 14 Water losses due to evaporation (mm.month^{-1})

	Nov	Dec	Jan	Feb	Mar	Apr	May	Tot
ET_o	171.1	178.0	183.7	182.7	201.6	188.6	184.4	1290
k	1.35	1.35	1.35	1.35	1.25	1.25	1.25	
E_{ret}	231	240	248	247	252	236	230	1684

The evaporation is given in mm.month^{-1} To convert the evaporation into volume, the surface of the reservoir every month, A, is needed. We have only three exact measured surfaces;

- in November (the highest water level) 237 000 m^2,
- in February 28 , 41 100 m^2,
- and in March 29, 23 800 m^2.

The surfaces are indicated in bold letters in Table 15. The volume is depending on the rate of water consumption, not only the evaporation part, and would be represented by a differential equation relationship on the form:

$$dV = -A\left(E_{ret} + \frac{I + W + H}{A}\right)$$ Eq. 5

where the time step is one month. The new volume, area and depth is being calculated at every time step, and the water balance is presented in Table 15.

Water Balances

Table 15 Water balances
The water taken from the reservoir exceeds en the month of April the total amount of water stored in the reservoir. As there is still water in the reservoir might be explained by the interaction with the groundwater table that is not included in the equation.

	Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Tot**
V, m^3	220 000	159 500	103 300	55 700	20 000	2 000	-9 300	
I, m^3	5237	7615	7586	7395	6856	5546	4534	44770
W, m^3	360	360	360	900	900	150	0	3030
H, m^3	240	240	240	240	240	0	0	1200
E_{ret}, m	0.231	0.240	0.248	0.247	0.252	0.236	0.230	1.684
A, m^2	**237 000**	200 000	159 000	**110 000**	**41 100**	23 800		
E, m^3	54 700	48 000	39 400	27 200	10 000	5 600		
-dV,m^3	60 500	56 200	47 600	35 700	18 000	11 300		
d, m	3.7	3.1	2.5	1.7	0.64	0.37	?	

$$V = V_{\max} + \int_{nov}^{may} dV$$ Eq. 6

The presumed top down pyramid model of the reservoir fix the area and the depth fraction A/d at 237 000/ 3.7 = 64 050. This implies the new area and depth of the reservoir at every step from Nov to Feb for the new volume found by withdrawing the volume loss dV from the total volume 220 000 m^3 in the case of Nov, the new volume noted in the top row and for the following month in Table 15. The depth is also noted, in the bottom row.

$$\begin{cases} V = \frac{1}{4} A \cdot d \\ A/d = 64050 \end{cases} \Rightarrow \begin{cases} \frac{1}{4} d^2 \cdot 64050 = V \\ \dfrac{\frac{1}{4} A^2}{64050} = V \end{cases} \Rightarrow \begin{cases} d = \sqrt{\dfrac{4V}{64050}} \\ A = \sqrt{4V \cdot 64050} \end{cases}$$ Eq. 7

To compare the found volume for March, 20 000 m^3, with the measured area 41 100 m^2, which by the top down pyramid model corresponds to a volume of only 6 600 m^3, was indeed the way to check the mathematic model. The calculus can be considered successful, even though nothing could be said about the following months of May. The calculated volume in May turned out to be negative. The consumption exceeded by far the volume of the reservoir during April and May, which may be explained by the interaction with the ground water aquifer that has been left out in the model, but possibly provide the reservoir with water when it reaches levels below the ground water table. The area measured in April, 23 800 m^2 corresponds to a volume of 2 200 m^3 and a depth of 1.2 meters.

Vulnerability: the rain risk

Gardeners are sure to never be inundated if they keep their fields above the highest water level all year. But the ones who plant scallion down by the water front in March risk loosing the whole field at one single rainfall. That is what happened to a number of farmers in year 2007, early rainfall already in April submerged plenty of fields of scallion in the dam bed of Toukoumtouré. All of the gardeners had answered that the dam would for sure dry out this year, 2007, but big surprise to everyone, the rain came early. Other gardeners were happy about the rain since they didn't need to irrigate for a couple of days.

The question-"Is the reservoir normally drying out during the dry season, do you think the reservoir is going to dry out this year?" was always answered by a yes, but deeper investigation of the matter let us know that former years it was not the case. Still ten years ago, the reservoir never dried out. The sedimentation of run-off sludge fills up the bottom and the dam becomes more and more shallow every year. Some scraping by bulldozers is needed, but too expensive. There is a leak in the dike of the dam, deep under the piled stones and the cement block, which let water pass downstream. The water is lost from the reservoir, but is instead undergoing some successful filtration through the sand and gravel, and is used as drinking water by some village citizens, see Figure 22. Even Adrien who built the reservoir considers the leak very hard to repair.

2.4.5 Water poverty index

The Water Poverty Index is a proxy used to evaluate the impact of water scarcity on people's well-being (Sullivan et al. 2003).

It can be used to measure how amelioration in the water sector would benefit the water poor people. The main idea is to collect data and to quantify the overall water use in different fields to create a synthetic index. The different components measured are:

- Resources;
- Access
- Capacity
- Use

It is further explained in Appendix 8.

WPI investigation in Toukoumtouré

All WPI questions in the questionnaire for the farmers at Toukoumtouré are falling under the access component.

-Access to clean water as a percentage of households having a piped water supply.
-Reports of conflicts over water use
-Time spent in water collection, including waiting.

None of the enquired farmers had piped water supply. The water used for cooking and drinking was taken from either a well, a drilled well or a drained well, a “puisard”, just beside the reservoir. The water used for washing and watering of the animals was almost entirely taken from the reservoir.

The question about conflicts around the reservoir, is supposed to reveal competition between farmers to access land pieces or between fishers, breeders, families household needs, and farmers who use the same water. Most people answer no, as if there were never any discussions, they all just use the water without slowing down until the last drop, and when the water finishes for the year everybody share the same need to walk the way to the deep drilled well. The farming stops by then, until the rain makes it possible again. The only threat is the intruding animals, sheep, goats, cows, donkeys and others may break down the surrounding fence made up of branches of thorny bushes, and graze on the cultivated plants, see Figure 23 and Figure 24.

Figure 23 Fence made from thorny bushes

Figure 24 Animals eating from the fields.

Therefore most farmers are sleeping next to the field and staying close by the whole day to prevent this kind of disaster to take place. The very little conflicts around this reservoir is soon explained by the fact that it dries out almost every year, which makes it less attractive compared to neighbouring reservoirs who never dries out. In their case it is far more difficult to have a piece of land, and there are more than intuitions regarding conflicts between water users.

The time spent for water collection was a difficult question to answer for the farmers as they were not the ones collecting water. Mostly it was the job for women and children and those men who do not work with market gardening.

Even though no valid Water Poverty Index could be established from the questionnaire survey answers, the answers were giving information about the small scale farmers' actual economic status and family constitutions and their contribution to the family economy. Normally the farmers are part of families that share the same compound constituted by a circle of huts, of between 15 and 80 family members. They share the food, and support the needs of the family members. In the old times money were not even used. This is still being remembered by the elders and involuntarily practiced by many family members. The possibility to sell crops in town changed life considerably. The small money that the gardeners make is used for medicines and other unavoidable costs, matter of survival to the family members. Most children do not go to school as the fee is too expensive. The gardeners learn gardening from each other and their level of education is very poor. Most of them do not speak French and in general they do not know to read and write.

2.5 Discussion

The number of farmers encountered during our survey remains small and the results have to be interpreted with precaution due to high individual variations. Probably some of these variations could have been avoided by asking the questions differently in the interviews. Answers might be biased due to “demand characteristics” (Dobbin and Gatowski 1999) i.e. the farmers answer what they think we might expect them to answer. This became evident when we asked the question: “How many hectares do you farm?” Even though a hectare is a unit far too big to use for the small fields around Toukoumtouré, the farmers gave us answers anyway. Nobody told us that the question was difficult to understand. Other examples where demand characteristics might have biased the data are the questions about pesticides. E.g. A “bottle” of pesticide might be a too large unit. It might be better to ask how much is used during one treatment and then how many treatments there are per month. A “quasi-filter question” (Dobbin and Gatowski 1999) providing a 'don't know' response alternative might also be a way of reducing the farmers' guessing.

All people say that the water is going to disappear in April and May. When it rains, it fills up the reservoir during the month of June. The rain came extraordinary early though, and submerged many scallion fields in April. Even if everyone answered the same, the weather proved the opposite.

There seems to be some limitations and conditions that decide what crops the farmers grow. The papaya and banana fields are limited by the fact that they have to be placed above HWL. This means both that the farmers need a motor pump to ensure the survival of the plants all year around *and* that land has to be available and free to use for many years, which touches the question of traditions and ownership of the land (see for example Ouédraogo 2006). Scallion seems to be the first choice for the people that start a market garden, even if they know that for example onion would give more money in the long run. Scallions generate money straight away and can be cultivated late in the season on areas that earlier were inundated by the reservoir water. Onions as a contrast does not generate money straight away as it is often stored a long time after the harvest. Fertilizers are many times more expensive than the pesticides, and so it might be the economically limiting factor. It was difficult to see which crop needed the most fertilizers due to high variation. The time and experience seems also to decide what kinds of crops are grown. The farmers with the largest fields seem to have been farming for a longer time. The farmers with the large fields started up with a small field many years ago, where they at a low cost grew for example scallion and they earned money to invest in more expensive crops.

It is not sure that the pesticide products always contain the same active substances from year to year. Lampride for example contains Acetamiprid, but that pesticide was invented only a couple of years ago, and put on the market in 2003. It had a label with the text “campagne 2005” and our guess is that when the stock from the year 2005 is finished, the pesticide must be replaced by another pesticide.

The transports of chemicals from the fields to the water are difficult to predict although different models could be used, e.g. prompts model (Whelan et al. 2007) or LCA (Humbert et al*.* 2007). The most probable way of transport except from rain and run-off should be the irrigation water that bring with it the soil dust and run down the slope towards the water front. Groundwater transport may also occur or aerial dispersion. The transport of chemicals and impact of chemicals on the water has not yet been studied.

2.5.1 Error estimation

The depth used for the calculation of the reservoir volume for the water balance was estimated with less precision, even though a single decimetre changes the volume markedly. The importance of the depth measurements have been mentioned by Jens Liebe, (Liebe 2005) due to the implication of the depth for all further geometrical and mathematical evaluation. The importance of the depth measurement is obvious in the volume estimations of the Toukoumtouré reservoir, where 1 dm change in height when the reservoir is full would roughly correspond to

$0{,}1*237000=23700m^3$

which is more than half of all of the water used for irrigation! A suggestion for future studies is to measure the depth more carefully.

An assumption has also been made that all people withdraw the same amount of water with a pump or when using the buckets. This might be erroneous. A further study on the flow of the water in the channels would be a better measure. Also it would probably have been better not to bunch the fields together but measure all the fields as different fields due to big variations. It remains however that such a survey is largely original.

Another suggestion is to interview fewer people in a random sample. In that way their abandoned and active fields could be measured carefully with the GPS and statistical data could be drawn from this random sample. Later, the whole managed surface and abandoned surface could be easily measure by bunching together similar crops to large fields.

Some assumptions have been made when calculating the area of the cultivated fields. Information was lacking for some of the fields. See Table 5. These fields correspond in April 2007 to 24,3 % of the currently managed fields. To assume that these fields are similar to the managed fields might be erroneous and contribute to the unreliability of the result. Data of added water, pesticides and fertilizers was also lacking for some of the abandoned fields. One field to be mentioned of the abandoned fields is the cabbage field that according to the farmers need most pesticides of all plants because you can not see on the outside if there is a pest on the inside. The cabbage has to be sprayed even as a precaution.

How a WPI could be used

A database with information on the water poverty index could be used to reveal information about how people are influenced by an change of the situation around the reservoir. It is a help to elaborate a succession of typologies: typology of exploitations, of agricultural practices, of environmental threats, and, through experimental approaches, of toxicity risks. Approaching a typology of exploitation via WPI is supposed to be an efficient proxy, because of the assumption that intensification of agricultural practices is linked to the capacity of stakeholders to mobilise money for their investment.

Hypothesis 1: poorer people, as identified by WPI, are less efficient than richer to intensify their practices.

Hypothesis 2: richer people, due to their intensified agricultural practices contribute more than poorer to the degradation of aquatic ecosystems.

A value on the WPI cannot be fixed for the people of Toukoumtouré without further investigation, only a small part of the complete background information needed is revealed through our questionnaire survey. Probably a WPI survey has to be conducted at home at the house hold scale to include all different water users and thereby prevent the bias of using only individuals with the same employment.

3 PHASE 2 laboratory work- impact of xenobiotic application on natural phytoplankton communities.

The CyRoCo division of IRD has already made clear that the health state in the water reservoirs in the Nakambé catchment area is degraded, especially around Ouagadougou where the reservoir density and the market gardening take their greatest proportions. The primary production of an ecosystem reveals clearly the effect of abnormal abiotic factors such as chemical pollution. Cyanobacteria are visible to the eye in many water reservoirs, see Figure 25. This is one indication of a deranged ecosystem.

Figure 25 Algae in the reservoir Toukoumtouré

3.1 Objective

The laboratory part is supposed to repeat under controlled circumstances what happens in nature when a poison is being spread to the surface water. The algal community in each sample is studied for four days and its sensitivity to toxic xenobiotics is determined.

3.1.1 Hypothesis

As previously indicated (see chapter 2.4.1, pesticides), the two most popular pesticides, used by farmers around Toukoumtouré were Lampride EC 46, (30g.l^{-1}) Lambda Cyhalothrin and 16 g.l^{-1}Acetamipride) and Lambda super EC 25, (25g.l^{-1} Lambda Cyhalothrin). Both Lampride and Lambda Super contain Lambda Cyhalothrin and our hypothesis is that Lambda Cyhalothrin has a negative impact on the photosynthetic activity of the natural phytoplankton communities in the reservoir water. No herbicides were found being used around Toukoumtouré although some herbicides were found on the market. Calloxone Super is one of the herbicides found on the market and it is assumed that it is used for the market gardening in the area. Calloxone super contains Paraquat which is highly toxic for phytoplankton. A possible, synergetic effect could occur when Lampride and Calloxone Super are applied together and this will also be tested. The presence of pesticide combinations with different modes of toxic actions, herbicides with insecticides for an example, so-called across-class mixtures, has resulted in varying toxic responses, which challenge their predictability (Lydy et al. 2004) and justify such experiments.

Experiments to understand the real effects of pesticides on a broad range of taxa seem to be the best way to get information about patterns of diversity and productivity in aquatic systems subjected to pesticides. Among the aquatic biota, micro organisms are generally highly sensitive to and seriously affected by environmental perturbation. Bacteria, phytoplankton and zooplankton have fast growth rates and can provide meaningful and quantifiable indicators of ecological change on short timescales (Paerl et al. 2003). On the other hand, these organisms can exhibit major stresses when exposed to low levels of pollutants such as pesticides, which constitute a major anthropogenic stress on natural communities (Relyea 2005). Here, we select natural phytoplankton as target community.

Natural phytoplankton collected in a medium size reservoir located near Toukoumtouré has been used to perform bioassays. It appeared that in the Toukoumtouré reservoir, turbidity was too elevated when time came for laboratory work, and was not suitable to perform efficient bioassays. This excessive turbidity was a simple consequence of the concentration of lake waters (end of the dry season), with a dramatic reduction of the depth (max as mean): resuspension of settled particles as frequentation by riverine people and herds induce this classically observed elevation of turbidity at this period of the year.
Optic properties of water masses are considerably altered by suspended materials. In our case, the use of a fluorometer (phyto-PAM) to perform our tests will have been considerably complicated by the presence of such particles, which exert strong influences on absorbance and fluorescence of water. It was thus decided to work with natural phytoplankton collected in another lake, exhibiting a "normal" profile. The Arzouma reservoir was selected, due to its close proximity to Toukoumtouré and previous knowledge relative to its composition.

The reservoir water being used in the experiments is collected around six in the morning and brought to the air conditioned laboratory within two hours, before the outdoor temperature exceeds 35 degrees. The important volume of the can of five litres prevent from such severe alteration of abiotic factors that would endanger the health of the communities of aquatic microorganisms. This mode of procedure is employed since many years by the same personnel, and is proved to be safe.

3.2 State of Art, literature summary

A lake is a predictable and isolated environment, restricted by the terrestrial/aquatic border (ecotone) even though exchange of water may take place between groundwater aquifer and lake. We assume that a small reservoir can be considered a very small lake with a residence time depending on the duration of the dry season: there is each year a complete re-initialisation of both biological and metabolic processes during the flooding period (Arfi et al. 2001). Abiotic factors in lakes and their seasonality are thus relatively predictable; small temperature variations, for example 2°C while air temperature differs sometimes daily for more than 30°C. Transient stratifications of water masses are however regular, with during the driest and hottest periods, a daily pattern induced both by the nyctohemeral periodicity of light and temperature on one hand, and of meteorological (wind) regime on the other hand (Talling and Lemoalle 1998). Day-to-day variations in primary production, decomposition, oxygen rate and other parameters integrate such short-term variations and are also generally smoothed on longer periods of several days during which environmental conditions exhibit a relative homogeneity. Hydrological and climatic disturbances constitute however major events at different scale. Storms contribute to the enrichment of the water column, thus enhancing irregularly but significantly the primary production (Arfi et al. 2001). Droughts or excessive floods may inversely affect the global metabolism of ecosystems (Thomas et al. 2000). Due to the importance of allochtonous materials inputs within such lakes, eutrophication constitutes a real threat, maybe facilitated by poorly efficient trophic transfers within the planktonic food web (Aka et al. 2000). Light and nutrients remain the most important limiting factors for phytoplankton in small reservoirs, where autotrophy remains the most important metabolic process (Bouvy et al. 1998).

3.2.1 Blue-green Algae and Phytoplankton

Once flooding period is finished, a small reservoir becomes an isolated water mass where both biotic and abiotic factors will contribute together to the organization of aquatic communities. Resilient communities (e.g. fish) encompass seasonal and drastic fluctuations, whereas for planktonic communities there is each year a massive and annual reintroduction of organisms. Foundation effects are probably essential, as could be also the meta population functioning of most of them. For phytoplankton, massive blooms of one species of algae one year may not occur the next year as there can be a completely different set-up of algal species (Lampert and Sommer 1997).

Phytoplankton

Phytoplankton is the assemblage of all photosynthetic organisms living in surface waters. Blue-green algae (or cyanobacteria) constitute one subdivision. Large fractions of tropical phytoplankton communities currently exhibit also mixotrophic behaviours. Phytoplankton species are interacting mainly by sharing the sun-light and the nutrients in the water column. Phytoplankton is also in permanent interaction (competition but also mutualism) with pelagic bacteria. Both are grazed by flagellates and zooplankton, which regulate their population and canalize matter and energy transfers along the planktonic food web. Chlorophyll a, involved in the capture of sun-light energy for photosynthesis, is a pigment shared by all phytoplankton species. Phytoplankton biomass is thus classically estimated in measuring chlorophyll a in samples with the help of a spectrophotometer, or a fluorometer (as a Phyto-PAM, Ruser et al. 1999). From now on in this text, the phytoplankton refers to all other phytoplankton but the cyanobacteria, composed mostly by different algae species, (Canter-Lund and Lund 1995).

Blue green algae / Cyanobacteria

Blue green algae are prokaryotic (no nucleus in the cell), and are actually bacteria, known as cyanobacteria. They have the nature of a plant since they are photosynthetically active. They are said to be the first organisms producing oxygen on Earth. Diazotrophy is shared by some genera (ability of N_2 atmospheric assimilation) and gives a real advantage to these organisms in nutrient's limited situations. Their tolerance and adaptability to a large spectrum of conditions, even extremes, justify their broad distribution. Cyanobacterial blooms are more and more widespread, at the planet scale, and are often attributed to both a general alteration of water quality in aquatic ecosystems and the efficiency of these organisms to encompass adverse situations (Whitton and Potts 2000). The production of potentially harmful secondary metabolites, namely cyanotoxins, constitutes today an important issue due to their major and adverse health consequences (Chorus and Bartram 1999). The understanding of the occurrence of cyanobacterial blooms remain surrounded by basic questions: Where and when? Which taxa? Which toxins?

Cyanobacteria need 16 elements to grow, P may be the limiting factor in Europe, but N seems to be the major element controlling growth in the tropics. The use of fertilizers may potentially cause eutrophication, either through direct enrichment or because of stoechiometric disequilibrium. In strongly disturbed environment, and particularly in case of pollution, cyanobacteria may dominate the planktonic communities, either because they exhibit a lower sensibility to pollutants than other phytoplankters, or because the pollution stimulates their dynamics in inhibiting some of their competitors.

Interaction among algae or Sensibility to pesticides

The occurrence of blooms is determined by several environmental factors such as nutrients, temperature, pH, irradiance, grazing by zooplankton and competition with other photoautotrophs. However, virtually lacking from these reviews on the pathway to noxious cyanobacterial blooms is the role photosynthesis-inhibiting pesticides might play. The indiscriminate use of herbicides for chemical control of pests may strongly aggravate dysfunctions in aquatic systems (Relyea 2005). These herbicides are deliberately released into the environment by agricultural activities and may affect non-target aquatic plants after runoff to nearby surface waters during the spraying season and periods of high precipitation, through leaching and/or accidental spills. It is therefore not surprising that such herbicides have been detected in numerous surface waters in Northern America and Europe (Steen et al. 1999; Scribner et al. 2000). Even if the situation is far less well documented in West Africa, there are also some signals of such pollutions of aquatic ecosystems (Ntow 2005).
The response of phytoplankton to photosynthesis-inhibiting herbicides depends on the sensitivity of species and in general, green algae and diatoms are more sensitive than cyanobacteria (Bérard et al. 1999a). Because of the different sensitivity, competitive interactions could lead to replacement of the susceptible algae by more resistant ones, thereby affecting algal community structure (Bérard et al. 1999b). Hence, exposure of algal assemblages consisting of mainly green algae and cyanobacteria to typical concentrations of herbicides could alter the species composition in favour of the cyanobacteria.

Lambda Cyhalothrin

The two most used pesticides found during the field study contain the active substance Lambda Cyhalothrin. In the case of Lampride 46 EC it is combined with Acetamiprid. Lambda Cyhalothrin is known to be harmful to mammals and bees (CDC 2006), but many tests have been carried out on water living organisms such as fish, invertebrates, algae and water living plants, always showing a high toxicity. One could doubt about its efficiency in eliminating plants when it is designed to kill insects, but the different tests show that the dose needed to stop growth of one specie, EC_{50}, for example green algae, is not very different from the dose needed for fish or invertebrates (Wendt 2007, pers. comm. 15 Apr. 2007). Furthermore it is present as a widely reputated common pesticide all over the world in products such as Karate 5 EC, Karate MAX 2,5 WG, Engeo 247 EC, Lambda cal 100 EC, Pacha 25 EC, Pilori 15 EC and Tyson 150 EC. (Ministry of Agriculture and Rural Development Cameroon 2006)

Chemical

The compound is a synthetic pyrethroid ester, Lambda Cyhalothrin [(RS)-a-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimenthylcyclopropanecarboxylate] existing in two isomers at equal concentrations before being resolved, the Lambda form being the efficient and commercialised one, see Figure 26. Once it is being used, the molecule slowly changes shape so that the ratio of the Lambda form may diminish from 1:4 to 1:1.3 in three weeks. (Wendt 2007, pers. comm. 15 Apr. 2007). Associated physical and chemical properties of synthetic pyrethroids (see Table 16) result in perceived low environmental exposure potential due to relatively short residence time in surface waters (Hand et al. 2001). Exceptional hydrophobicity results in rapid partitioning from the water column, low mammalian and avian toxicity, and relatively short environmental half-lives.

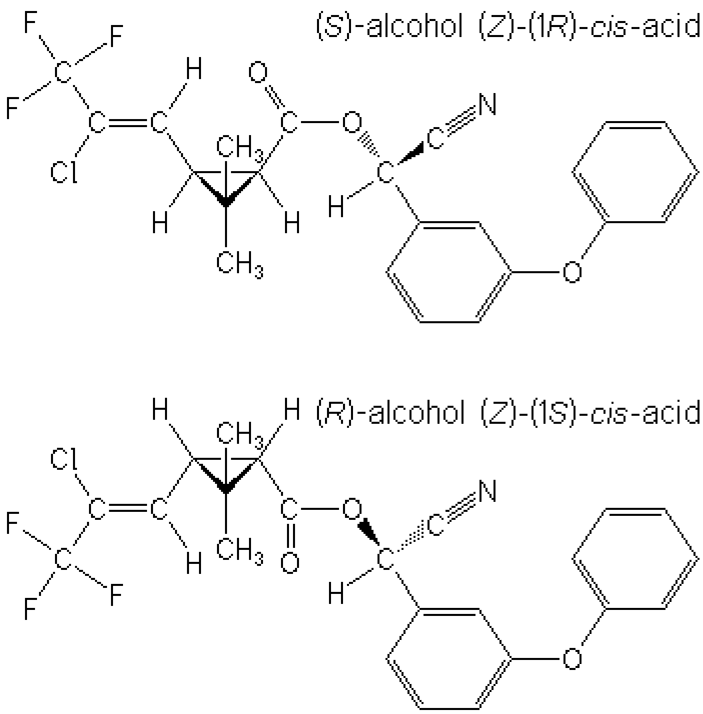

Figure 26 Cyhalothrin.
Source (Wood 2005)

This early decomposition step may be the explanation to the disappearing of the substance in all experiments where the concentration has been measured continuously. (Wendt 2007, pers. comm. 15 Apr. 2007) Another factor might be the very low water solubility, only 5 µg.l^{-1}, which causes the substance to rapid partitioning from the water column with a relatively short environmental half-life. Such compounds accumulate in the sediments of streams and reservoirs, to be resolved when stirred up by flooding or other mechanical interaction.

Table 16 Chemical properties of Lambda Cyhalothrin
(Source Bouldin et al. 2006)

Chemical property	Lambda Cyhalothrin
Water Solubility ($mg.l^{-1}$)	0.005
Adsorption coefficient (log K_{OC})	3.37
Partition coefficient (log K_{OW})	7.00
Hydrolysis half-life (days)	233
Aerobic soil half-life (days)	62
Anaerobic soil half-life (days)	128
Henry's law constant ($M.atm^{-1}$)	$5.629*10^{3}$
Vapour pressure (mPa)	$2.0*10^{-4}$

Concentrations

The low solubility in water means that the water is saturated with Lambda Cyhalothrin at only 5 $\mu g.l^{-1}$. The EC50 found for different water living organisms is in the range of 0.3 to 5 $\mu g.l^{-1}$ when the times of incubation were a matter of days: Lambda Cyhalothrin toxicity measured with aquatic invertebrates in laboratory conditions (PAN 2007) has led to a number of complex ecological risk assessments. The lowest concentration which shows any toxicity was about 0.05 $\mu g.l^{-1}$. (Wendt 2007, pers. comm. 15 Apr. 2007))

After combining these different elements, we decide to test a concentration serie as follow:

0.01 0.05 0.1 0.5 1.0 5.0 [$\mu g.l^{-1}$]

This seems to be the reasonable dilutions to examine in the laboratory.

Acetamiprid

Acetamiprid, see Figure 27, is a substance, from the Chloro-nicotinyl family, that is not yet completely known in detail.

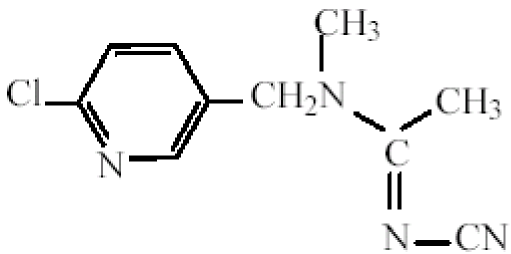

Figure 27 Acetamiprid

The solubility in water depends on the pH, but at pH 7 it takes its lowest value, 2.95 $g.l^{-1}$. Its hydrolytic stability DT50 is stable for pH 7 and lower, at pH 9 it starts to decompose. EC50 for Daphnia and fish range from 43 to 98 $mg.l^{-1}$. That means more than 10 000 times less toxic than Lambda Cyhalothrin. There is no specific concentration series for this compound as it has been tested simultaneously with Lambda Cyhalothrin (included in the same commercial formulation). The different concentrations applied were:

Lambda Cyhalotrin	0.01	0.05	0.1	0.5	1.0	5.0	[$\mu g.l^{-1}$]
Acetamiprid	0.005	0.027	0.053	0.27	0,53	2,67	[$\mu g.l^{-1}$]

Paraquat

General

The highly toxic herbicide active substance Paraquat [1,1'-dimethyl-4,4'-bipyridinium] is common all over the world, and in Burkina Faso, it is the active substance in for example the commercial product, Calloxone Super. Its high toxicity to humans is being discussed, as many accidents happens, and even deaths. In Europe it has become a common way to commit suicide among farmers, while in the developing countries unsafe handling not respecting the necessary precautions to be taken cause accidents in homes and when spraying. Skin burns may develop even many hours after contact, and one single gulp swallowed by mistake leads directly to a painful death, there is no antidote. (PAN 2007)

Chemical

The water solubility is very high, 700 $mg.l^{-1}$, alcohol is also a good solvent. But other organic solvents cannot solve Paraquat. It is a quaternary ammonium herbicide active as an ion but sold as a salt, and the tail methyl groups in the Figure 28 are often chloride ions.

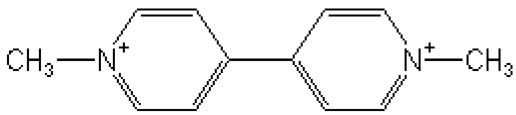

Figure 28 Paraquat

Toxicity of Paraquat

Many tests have been carried out showing the toxicity of Paraquat on aquatic organisms.Narrative descriptions of acute toxicity of paraquat were assigned based on LC50, (Kamrin 1997).

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Table 17 Toxicity categories
(Source: Kamrin 1997)

Toxicity Category	**LC50 (ug.l^{-1})**
Very high toxicity	<100
Highly toxic	100-1,000
Moderately toxic	1,000-10,000
Slightly toxic	10,000-100,000
Practically nontoxic	>100,000

Data was taken from "pesticideinfo.org". After that, references were isolated by taxonomic groups and ranged following the type of toxicological indicator used to characterize toxicity, see Table 17 and Table 18.

The database used as reference originally present 541 data on toxicity, but a number of data entries were discarded to compare the analysis to the case of the Paraquat experiment.

Table 18 Chosen data for Toxicity Analysis.
Total corresponds to the initial number of references with µg.l^{-1} as units.

	selected	**total**
phytoplankton	76	111
fishes	123	188
zooplankton	56	62
amphibians	38	55
fungi	9	28
crustaceans	9	14
insects	7	11
macrophytes	2	26
mollusces	9	14
nematodes	0	2
	329	**511**

In Table 18 the kept data are presented for each taxonomic group, 30 data were already discarded because they were presented in irrelevant units other than $\mu g.l^{-1}$. Other data were discarded because they considered incubation times exceeding 120 hours, or they were based on the fixation of atmospheric nitrogen.

One can see in the resulting figures: Figure 29, Figure 30 and Figure 31, that very small concentrations have effect on phytoplankton. The values presented also gives an idea on the series of concentrations to be chosen when performing an experiment on phytoplankton with Paraquat.

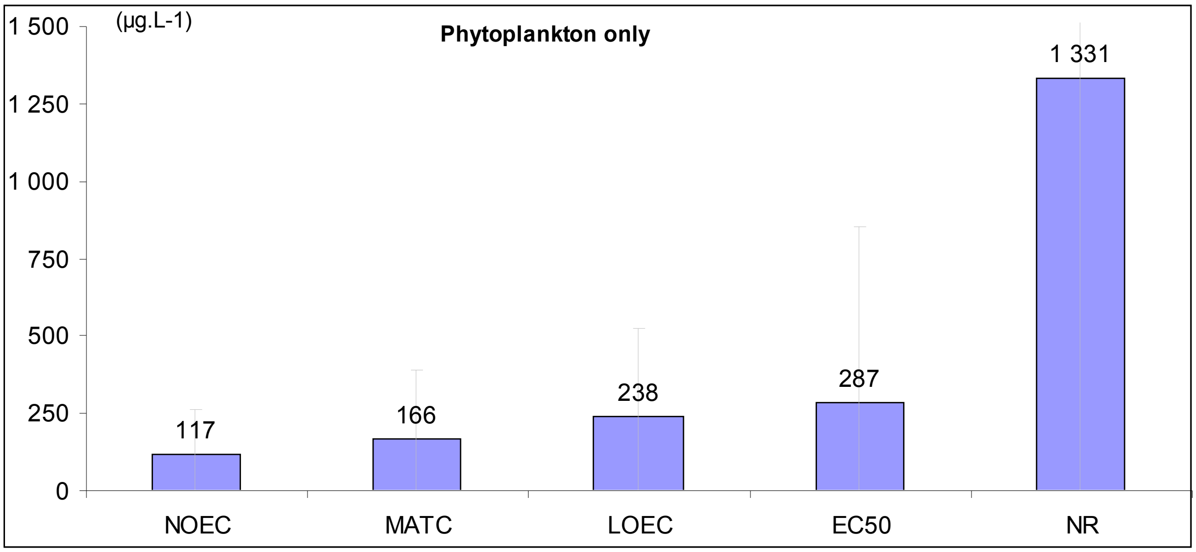


Figure 29 Toxicity parameters for Paraquat on phytoplankton.
NOEC= No Observed Effect Concentration, MATC= Maximum Acceptable Toxicant Concentration, LOEC= Lowest Observed Effect Level or Concentration at which adverse effects are observed, EC50= Concentration where effects are seen on 50% of the test organisms after short-lived exposure, NR= Non reported information/Induced effects but no toxicity endpoint.

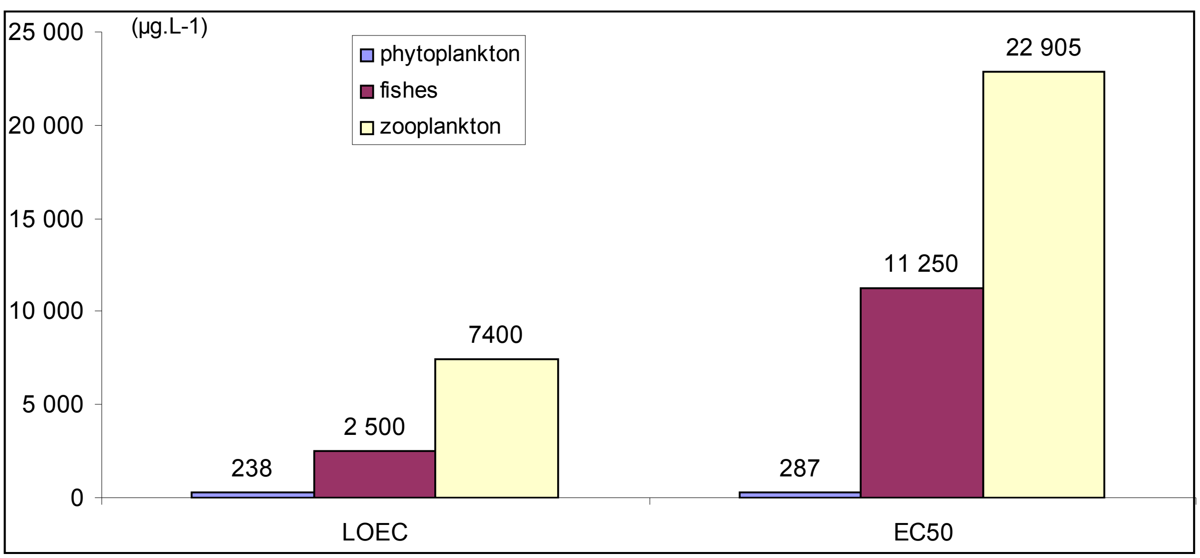


Figure 30 LOEC and EC50 Paraquat, comparison phytoplankton, zooplankton and fishes.

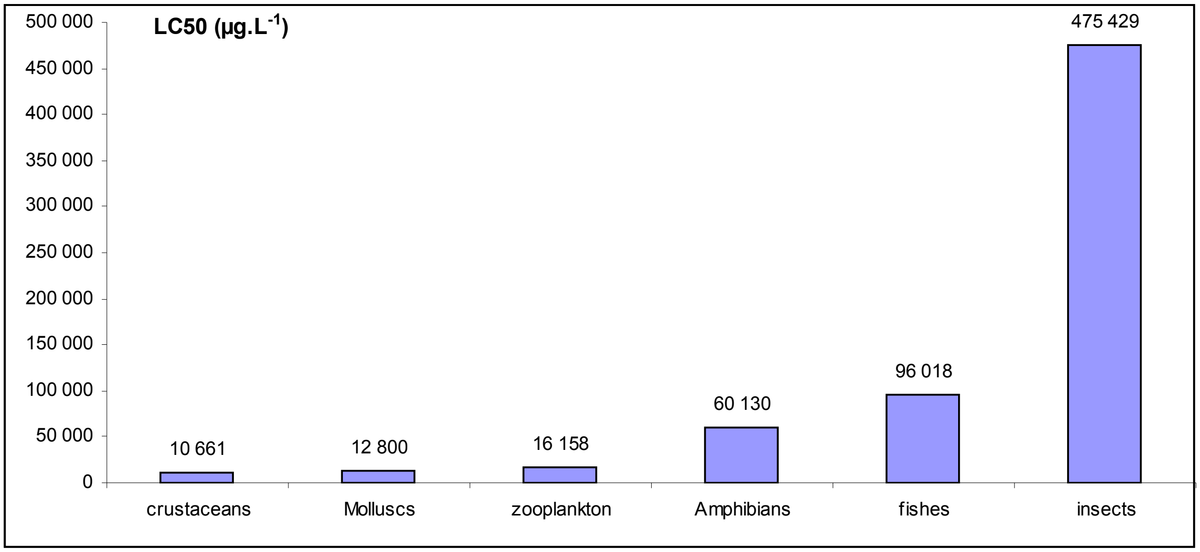


Figure 31 LC50 Paraquat for different aquatic organisms except from phytoplankton

Concentrations

Lethal concentrations to fish are around 10 mg.l^{-1}, see Figure 31, but as it is an herbicide, algae are endangered at a lot lower concentrations. Earlier tests realized by the CyRoCo team help to choose convenient values. Adequate concentrations to be applied in the experiment given for a dimethyl compound of Paraquat are the following:

5 20 50 170 350 550 [µg.l^{-1}]

Calloxone Super is a dichloride compound though, and has to be recalculated with help of the molar weight of methyl and chloride. The concentration of the simple ion in the bottle is given, 200 g.l^{-1}. The new series of concentrations is

4 17 43 146 302 474 [µg.l^{-1}]

The serie of concentrations is validated by Figure 29 where the NOEC, LOEC and EC50 is included in the range.

3.2.2 Phyto-PAM

The Phyto-PAM (Pulse Amplitude Modulation fluorometer) is an instrument used to study the photosynthetic properties of phytoplankton that allows estimations of chlorophyll concentration and descriptions of the photosynthetic efficiency of algae. Three main algal groups, green (chlorophyceae), blue-green (cyanobacteria) and brown (diatoms/dinoflagellates), can also be separated in a sample after proper calibration of the instrument. The photosynthetic efficiency can be used as a proxy to measure the “health” of a sample.

Principle

The fluorescence measured with the PAM technique is emitted from the pigments of Photosystem II (PS II) reflecting the efficiency of photochemical energy conversion of PS II reaction centres (Krause and Weis 1991). Chlorophyll a is the principal pigment involved in energy transfers towards chloroplasts, where light energy is converted into chemical energy. When light is absorbed by chlorophyll, three main ways of relaxation (energy dissipation) act concurrently (see Figure 32):

1) heat dissipation,
2) fluorescence emission,
3) photochemical transfers (photosynthesis mainly), with oxidation of reaction centres followed by electron transport for the ultimate production of glucose.

Under strong light the system can be saturated as the electron acceptors become fully saturated: chlorophyll a won't be able to absorb any more light and assuming that no energy is given off as heat, all the excess light will be given off as fluorescence.

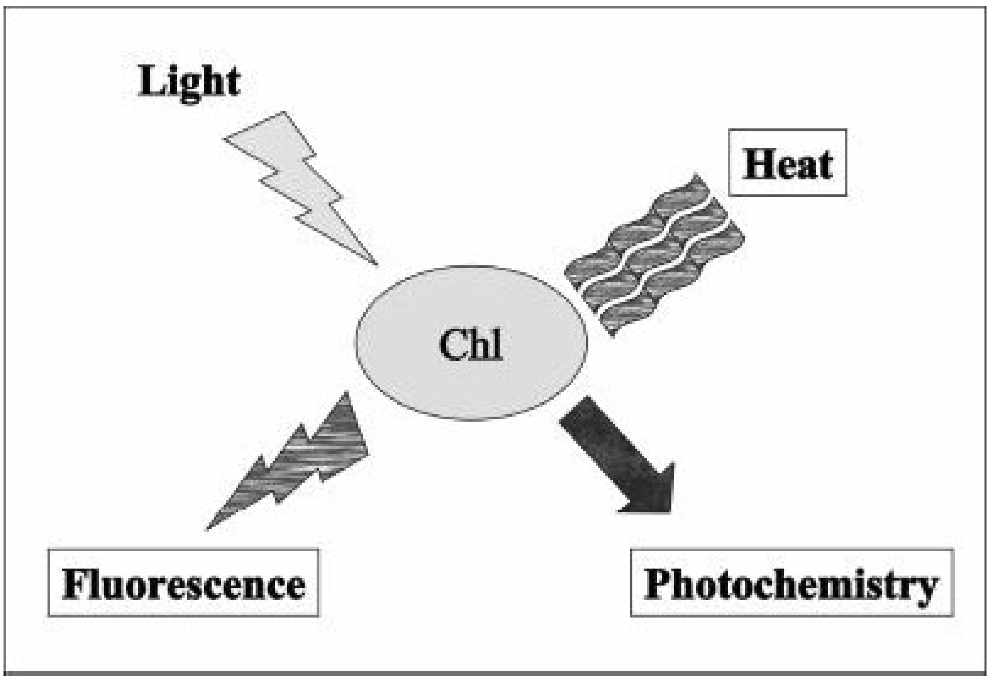


Figure 32 Competitive mechanisms involved in energy transfers following a light flash.

These mechanisms are competing, and, in normal conditions, heat represents indeed only a very small part of energy transfers. Fluorescence is thus considered as the unique veritable process in competition with photochemical used of energy. Chlorophyll fluorescence can consequently be used as a tool to estimate the efficiency of electron fluxes along the photosystem (Clayton 1980; Maxwell and Johnson 2000). It has been experimentally shown that the fluorescence variability is a property of photosystem II (PS II) that could be used to estimate the photosynthetic activity (Schreiber et al. 1986). And during the past 15 years, such measurements of chlorophyll fluorescence have proved their utility for photosynthetic properties studies, in laboratory as in natural conditions (Schreiber 2004). These results were partly linked to the development of fluorometric methods based on PAM (Pulse Amplitude Modulation) and saturation flash methods.

The Phyto-PAM uses three different light sources to stimulate phytoplankton pigments, which react by fluorescence emissions (See Figure 33):

1 – a slight light (MB, 1 µmol photons m-2 s-1, Figure 33 is firstly used to induce fluorescence but without activation of photosynthesis. For dark-adapted samples, this fluorescence is quite exclusively produced by PS II antenna (Fo, see Figure 33). Without actinic light, the amount of energy received by algae is insufficient to oxidise reaction centres that remain "open": there is no electron transfer. This fluorescence is measured just before the application of a saturation flash (Sat. Pulse). Fo has sometimes been used as a proxy for biomass estimations (Jesus et al. 2005).

2 – the second light source used is provided by a saturation flash (red, 655 nm), short but intense (8 000 to > 10 000 µmol photons m-2 s-1 ; duration: 0,2 s), used to "close" all the reaction centres of PS II. This saturation flash (S.Fl., Figure 33) induces a significant rise of fluorescence because, in such conditions, QA, the first electron receptor of PSII becomes completely reduced. The resulting fluorescence, Fm, corresponds to the maximal fluorescence (Krause and Weis 1991). Fv/Fm = (Fm-Fo)/Fm represents the maximal fluorescence yield of PS II: it corresponds to the maximal fraction of absorbed electrons involved in electron transfers and further chemical reactions. For healthy superior plants, this value could be around 0,8, whatever the species considered but lower values (Fv/Fm > 0,6) are generally expected for phytoplankton (McMinn and Hegseth 2004). Lower values indicate an alteration of reaction centers in PSII. This is a frequently observed situation for natural composite communities. Values < 0,4 are associated to damaged samples (Strutton et al. 2000).

3 – the third light source, using actinic light (AL, > 2 000 µmol photons $m^{-2}.s^{-1}$), is used to stimulate the photosynthetic apparatus and induce photosynthesis. Actinic light could also be used to adapt samples to strong light, before a novel saturation flash application and the consecutive measurement of yield. For light-adapted samples, fluorescence (previously Fo and Fm for dark-adapted samples) are now Ft et Fm’ respectively. After a saturation pulse, the observed fluorescence (Fm') is lower than fluorescence observed for a dark-adapted sample: QA is again completely reduced. The difference between Fm' and Ft represents the photochemical quenching whereas the difference between Fm' and Fm represents the non photochemical part of quenching. The effective fluorescence yield of PSII is then deduced as follow, PSII = (Fm’-Ft)/Fm’ = F/Fm' (Genty et al. 1989). This last parameter represents the photonic fraction effectively used for chemical reactions, and can thus be used as an indicator of the photosynthetic efficiency of organisms.

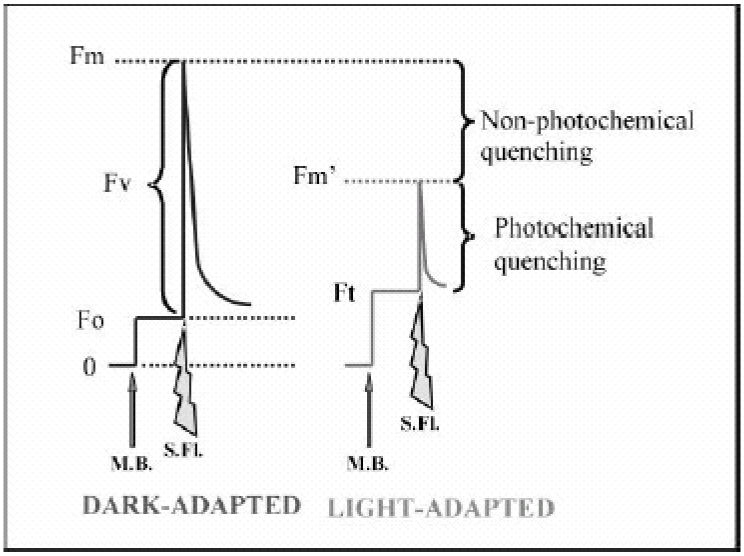


Figure 33 The theory behind the fluorescence in a dark-adapted and a light-adapted sample. (Source Varotto 2002)

The Phyto-PAM uses Light Emitting Diodes (LED) to stimulate pigments and induce their fluorescence when light flashes (10 µs) are applied. Four different wavelengths (470, 520, 645 and 665 nm) are used alternatively at very high frequency, allowing instantaneous specific fluorescence measurements. These fluorometric responses are thus used to discriminate the different taxonomic groups that constitute the studied community. For green algae, fluorescence is elevated for excitation wavelengths in the blue and in the red part of the PAR (Photosynthetically Active Radiation) spectrum (470, 645 and 665 nm), but remains low when green light (520 nm) is used. For cyanobacteria, there is quite no fluorescence with blue light (470 nm), whereas the response is particularly important with red light (645 nm), due to phycocyanin and allophycocyanin pigments. Inversely, for the last group (diatoms / dinoflagellates), excitation within the blue (470 nm) and green (520 nm) parts of the PAR spectrum are relatively elevated because of the presence of fucoxanthin, chlorophyll c and carotenoids. Here, due to the lack of proper and specific calibration of the instrument, such deconvolution of the fluorescence signals are not suitable: we'll further use global responses of the samples studied, without re-allocation of the measured fluorescence to taxonomic groups.

One powerful function in the phyto-PAM fluorometer is the light curve analysis. It demands six minutes to be executed, so the time to do the 16 samples is then largely extended. We choose to do it on the three blank samples at time zero, and on the whole setup at the time 72 h, at every test series.

After the yield 1 and the chlorophyll at dark adapted mode, the light curve analysis examines the changing phase from dark to light adapted mode step by step, before to continue with the yield 2 and the efficient chlorophyll to be tested when light adapted. This is done by sending brief light pulses at increasing intensity and/or duration, PAR, every 20 seconds, and then continuously store the data obtained. The successively changing yield, y, and the active electron transport, i.e. the light energy used for photosynthetic activity, ETR, make up a great deal of data for every sample. The diagram that results from PAR on the x-axis and y and ETR on the y-axis respectively may then be interpreted to reveal more about the health state among the algae in the sample. For example the photosynthetic efficiency, α as the tangential initial slope in the ETR(PAR) diagram which corresponds to the ignition of the chlorophyll, the response to light. The ETR reach its maximum value ETR_{max} for the light impulse Ek [PAR]. If the light impulses would have continued to increase beyond the capacity of the Phyto-PAM, a decline in ETR would be the result- the photo inhibition of the chlorophyll.

3.2.3 Turner Fluorometer

The Phyto-PAM is a low cost and non invasive method, particularly efficient for the comparison of samples during experiments involving series of treatments (relative responses against a blank). Classical methods, as the fluorometric quantification of chlorophyll a after its extraction with a solvent, allow the determination of absolute concentrations and so, of algal biomass. Phyto-PAM treatments have been thus enforced by a complementary fluorometric measurement of the chlorophyll a of samples following a classical method, (Yentsch and Mentzel 1963). A known volume of each water sample is filtered through a Whatman GF/F glass fiber filter (0.7 µm porosity) placed on a vacuum pump. After filtration, filters are enrolled in small plastic tubes and kept in a freezer for less than two weeks. Pure methanol is added to perform the pigment's extraction during 45 minutes in a refrigerator. This extracted alcohol solution is pored into the test vessel and the fluorescence is measured in the Turner fluorometer, f_0. The operation is repeated after addition of 30 µl of HCl (0.5 M) to be able to take into account the amount of degraded chlorophyll, f_a.

With respect to the degraded chlorophyll the concentration is found by using the formula:

$$[Chloro] = p \cdot (f_0 - f_a) \frac{\tau}{\tau - 1} \cdot \frac{v}{V} \cdot \frac{1}{D} \qquad \text{Eq. 8}$$

It can be just enough to only consider the total chlorophyll without using the data after acidification, the formula is then:

$$[Chloro] = p \cdot f_0 \cdot \frac{v}{V} \cdot \frac{1}{D} \qquad \text{Eq. 9}$$

with:
p = constant of calibration (with help from different known chlorophyll samples)
τ = acidification ratio
v = volume added of extract, 7 ml
V = volume of filtered water, 10 ml
D = Dilution

3.2.4 Site selection

The reservoir water is collected in Arzouma, a neighboring reservoir of Toukoumtouré near Koubri, about 30 km south of Ouagadougou (see Figure 2), at 5.50 a.m. the 24 of April 2007. It has a composition of algae species often dominated by cyanobacteria, and such water samples are examined regularly by the staff at IRD. Two times a week a number of reservoirs around Ouagadougou are tested in the lab, since June 2003. The reservoir we choose to take our water from is often of good quality in the test results, with healthy concentrations of algae. It has been tested regularly since March 2005. The water of the Toukoumtouré reservoir where we executed the field work is of too bad quality to be tested. Only the amount of suspended soil particles makes it impossible to run in a Phyto-PAM fluorometer, which functions with light.

3.3 Experimental procedures

The laboratory part of the study succeeded the field study. After the interviews, the GIS and the visit to the water reservoir of Toukoumtouré which gave a meaningful insight in the water situation and the water use, the bioassays are realized in the IRD office. For all the bioassays realized, water is first filtered with a plankton net with a mesh size of 60 µm to eliminate all zooplankton organisms grazing on algae. After that, we assume that the observed responses are only associated to phytoplankton and that they are not attributed to cascading effects.

Lampride 46 EC

Dilution of the pesticide product Lampride 46 EC is done in two steps with acetone, to achieve the order of magnitude of concentration that serve for further mixing. The active substance λ-Cyhalothrin has an extremely low water solubility, which makes it necessary to use another solvent than water. The actual concentrations to be tested are of the order of single µg, and the product is concentrated to 30 $g.l^{-1}$, which expressed in µg corresponds to 30 000 000 $µg.l^{-1}$.

- The liquid from the commercial bottle was measured with a pipette to 100 µl and added to 0.100 liter of acetone, the mother solution, [30 000 $\mu g.l^{-1}$].
- The mother solution was in turn measured with a pipette to 1000 µl and again added to 0.100 liter of acetone, the daughter solution DS, [300 $\mu g.l^{-1}$].

The complete range of treatments to be tested is constituted by a double series of conical flasks at six different concentrations, and two blanks with (5 cc) and without acetone, i.e. 16 beakers in all. See Table 19. Their volume is 250 ml of reservoir water, and the DS is added with a pipette with up to 5 ml.

Table 19 Dilution of Lampride.

Flask nr.	**1, 2**	**3, 4**	**5, 6**	**7, 8**	**9, 10**	**11, 12**	**13, 14**	**15, 16**
Conc. wanted $\mu g.l^{-1}$	0	0.01	0.05	0.1	0.5	1.0	5.0	0 acetone
Amount DS µl	0	10	50	100	500	1000	5000	0 acetone

Samples are kept in a thermostatic (25 °C) culture chamber, with white lamps miming nyctohemeral cycles (14 hours day – 10 hours night), to keep up the photosynthetic activity of the algae, standing on turning turntables for the flasks to receive the same amount of light. The incubation time will be 24 h, 48 h and 72 h from the moment of mixing, 10.30.

Three tubes of reservoir water are tested in the Phyto-PAM right after the mixing above, to have the blank at time zero. The water is in good state, the amount of algae present in the samples show to be normal. The three dam water samples are also passed through the fluorometer at time zero to measure the initial concentration of living algae.

25 April, incubation 24 h
First complete Phyto-PAM treatment were performed on all 16 solutions. A significant decrease in biomass and photosynthesis capability was noted at the highest concentration samples, flasks nr 13 and 14.

26 April, incubation 48 h
Same as yesterday, we suspect that the acetone as solvent is more deleterious for algae than the small Lampride concentrations themselves, because the blank with acetone showed a decrease in biomass and photosynthesis activity.

27 April, incubation 72 h
The last Phyto-PAM treatment doses not surprise, it is the same as yesterday. The chlorophyll a concentrations within each samples was finally measured in the Turner fluorometer .

Calloxone Super

Being extremely toxic, the active substance Paraquat must be handled with much care. The fume cupboard, the plastic gloves and the protection glasses turned out to be of use this time. The solvent would be water, since paraquat is soluble only in water and methanol and methanol might give the same effect as acetone did in the preceding experiment, to kill off the algae. The Paraquat was diluted in two steps, one mother solution of 10 ml Calloxone Super and 90 ml water which made up 1 dl, and a daughter solution 2 ml MS and 998 ml water to make up 1 liter with the concentration of 40 000 µg Paraquat ions/liter. In Table 20, the final dilutions are shown.

Table 20 Dilution of Calloxone Super.

Flask no.	**1,2**	**3,4**	**5,6**	**7,8**	**9,10**	**11,12**	**13,14**
DS µl	0	30	100	300	1000	2000	3500
Paraquat $\mu g.l^{-1}$	0	4.8	16.0	47.9	159.4	317.5	552.3

The experiment was performed exactly as the preceding one, exactly one week later.

Calloxone Super and Lampride 46 EC

To avoid the effect of acetone at high concentrations in the first experiment, the concentration at 1 ml acetone dilution was setting the limit for the Lampride dose. Two different concentrations of Lampride and three concentrations of Calloxone Super would be mixed in six solutions to verify the possibly synergetic effects when combined. We picked the concentrations of interest that clearly differ in the two preceding test results. The acetone blank, flasks 15 and 16, contains 1 ml of acetone. See Table 21.

Table 21 Dilutionserie of Calloxone Super and Lampride.

Flask no.	**1,2**	**3,4**	**5,6**	**7,8**	**9,10**	**11,12**	**13,14**	**15,16**
Paraquat $\mu g.l^{-1}$	0	4.8	317.5	552.3	4.8	317.5	552.3	0, a
DS µl	0	30	2000	3500	30	2000	3500	0, a
Conc. λCM $\mu g.l^{-1}$	0	0.1	0.1	0.1	1.0	1.0	1.0	0, a
Amount DS µl	0	100	100	100	1000	1000	1000	0, a

Thus the third week of laboratory treatment was performed exactly as the two weeks before.

3.4 Results

Much data were created when performing the experiment at IRD in Ouagadougou between 24 April and 11 May 2007. The parameters and dimension of the experiment are shown in Table 22 and Table 23.

Table 22 The phyto-PAM parameters and the Turner Fluorometer parameters.

Measuring device	**Parameter**	
Phyto-PAM	Yield at dark adapted mode	Y1
	Chlorophyll fluorescence	Chl
	Light curve yield	Y
	The photosynthetic efficiency	α
	The photosynthetic activity as functions of PAR, the light flash intensity and duration	ETR
	Effective Yield- Yield when light adapted	Al + Y
	Active chlorophyll	dF
Turner fluorometer	Chlorophyll a, corresponding to the living biomass	Chl
	the pheopigment including all other pigments than chlorophyll a, corresponding to the living biomass	Pheo

Table 23 The test series' dimensions.

Dimension	**Number**
Concentrations	6 + 1 or 2 blanks
Times	4 (0h, 24h, 48h and 72h)
Duplicates	2
Pesticide compositions	3 (Lampride, Paraquat, Both mixed)

3.4.1 Graphical interpretations, Lampride

Solvent effect

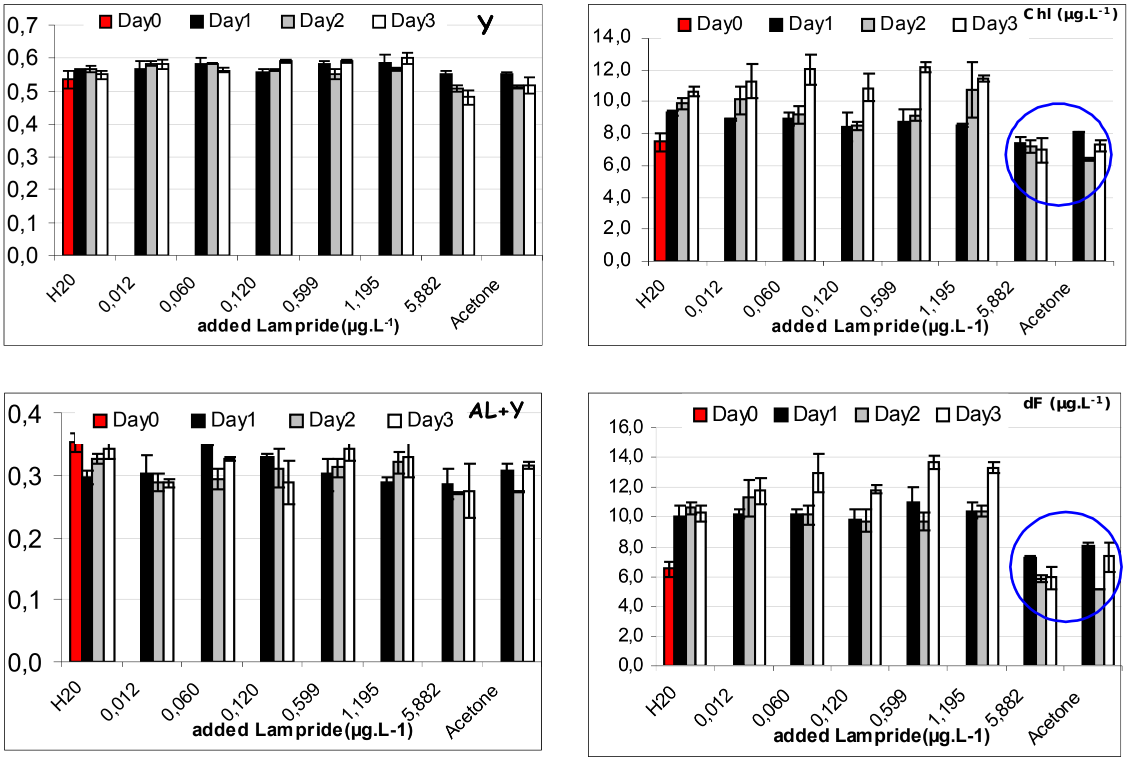


Figure 34 Phyto-PAM parameters variations with time and concentration for Lampride.

When comparing Chl measurements during the bioassay to initial values (in red in Figure 34), a lot of information is available:

First, whatever the concentration of Lampride, there is a global augmentation of measured biomass. This evolution is apparent from the first day to the last. It is particularly significant with the H_20 blank, indicating that the algal population tested doesn't experiment any kind of limitation: algae were growing during the bioassay in the absence of contaminant. This same observation is available with dF. In the absence of enrichment (e.g. with nutrients to sustain the population during the assay), this observation could be a result of both the absence of zooplankton (alleviation of predation) and of the favourable experimental conditions (absence of thermal or light stress and absence of brutal water motions, as naturally experimented by algae).

However, bases on these coarse data, this visual interpretation shows also and without ambiguity the impact of solvent on algal properties. There isn't noticeable effect when considering yields, but significant impacts appear clearly with both

Chl and dF. As shown on Figure 34, for the highest treatment (i.e. [Lampride] = 5.9 µg.L^{-1}), Chl and dF are in the same order of magnitude as for the blank made with 5 cc of Acetone, and remain significantly lower than values obtained with other treatments, whatever their concentration (i.e. black with H_2O included). This should be associated to the influence exerted by Acetone on organisms, more than the possible impact of Lampride in the highest treatment.

T_0-T_3 comparisons

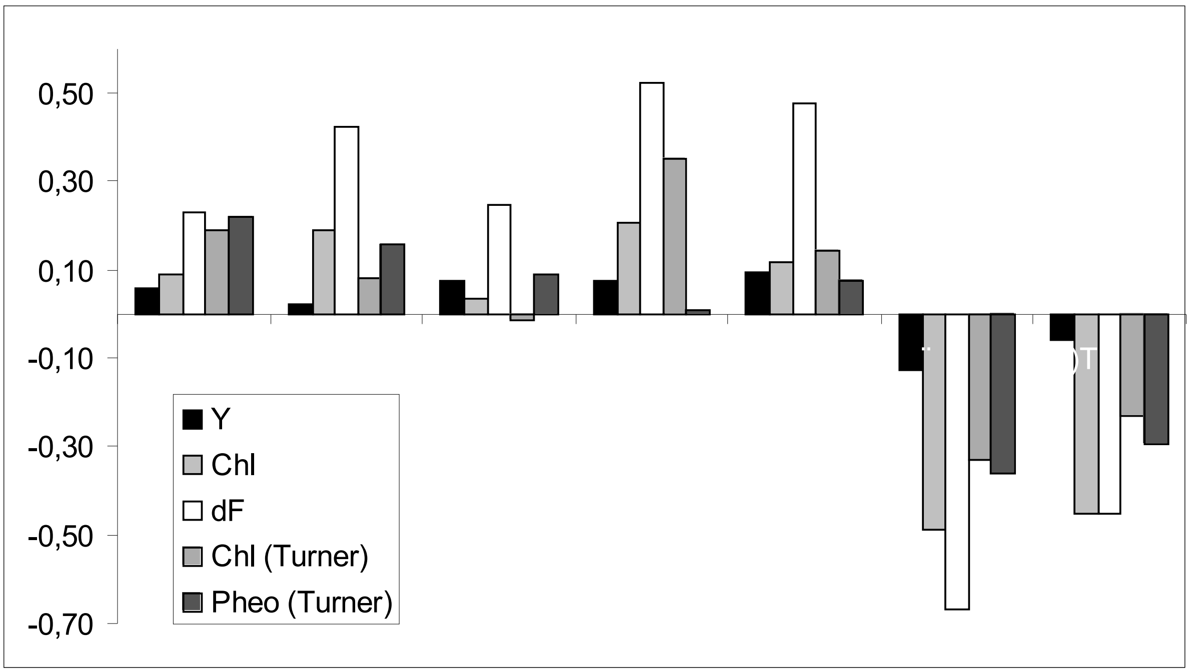


Figure 35 Relative comparison of all indicators to the water blank on day 0.

For the construction of Figure 35, data of day 3 relative to the blank constituted of water only (without acetone) were compared to the values obtained on day 0: this gives the baseline of the blank evolution for the different indicators from day 0 to day 3. The same procedure was thus applied for the different concentrations of contaminant, and also for the Acetone blank (e.g. Chl turner for the conc. "x" on day 3 – Chl turner for the H_20 blank on day 0). These differences were then homogenized by subtracting for each of them the value obtained for the blank H_20: we obtained thus the evolution of the different indicators for the different treatments, in relative values (e.g. comparatively to the blank evolution).

Two points have to be noticed:
- the behaviours of the highest treatment and of the Acetone blank are similar;
- there is no evident tendency relative to the concentration of contaminant for the first concentrations.

Again, we conclude that the observed evolutions for the highest concentration are to be attributed to the impact of Acetone and that Lampride does not exert any significant deleterious influence for the lowest concentrations of contaminant. Inversely, the augmentation of both dF and Chl turner seems to indicate a tendency towards a positive effect.

The effect of Acetone was re-evaluated again:

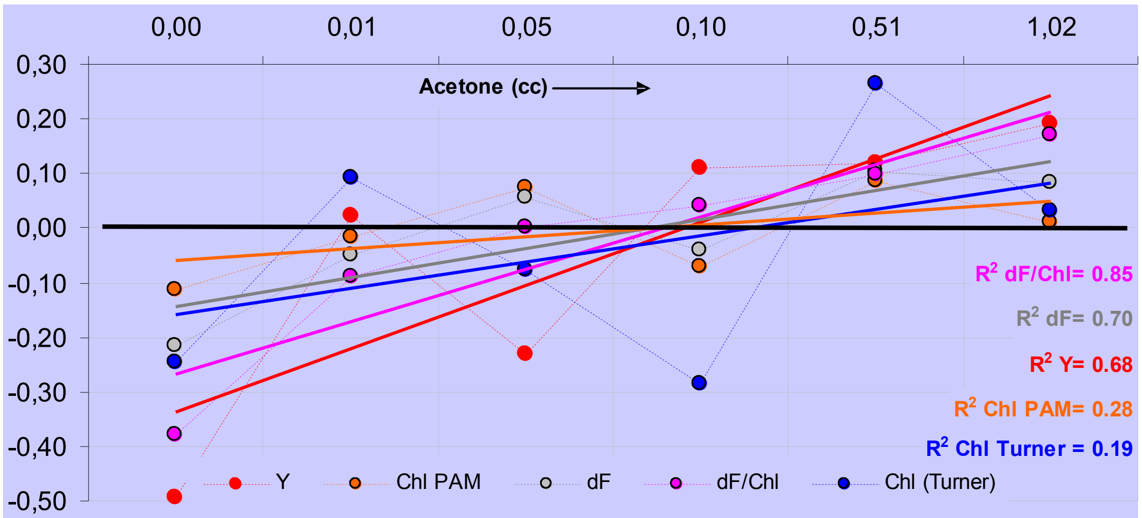


Figure 36 Comparison of ratios (indexes) from Day 3 for the different treatments of Lampride to the value of the blank without acetone on Day0.

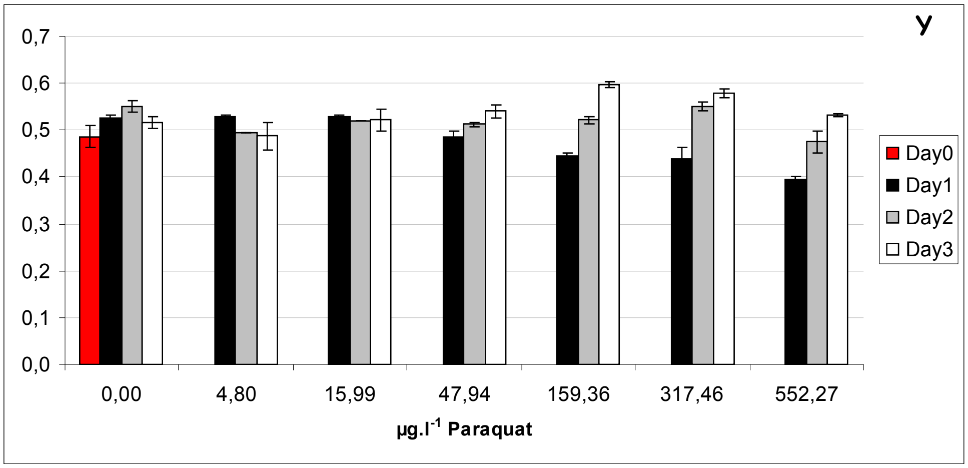
Here we compared ratios of values obtained on Day 3 for the different treatments of Lampride (so the different concentrations of acetone involved) to the value of the blank without acetone obtained on Day 0. This ratio is thus homogenized by the calculation of a variation index. The mean of the ratios for the different treatments is subtracted (numerator) and added (denominator) and the index is then calculated. If there isn't any toxicity associated to Lampride, then the observed variations could be attributed only to acetone.

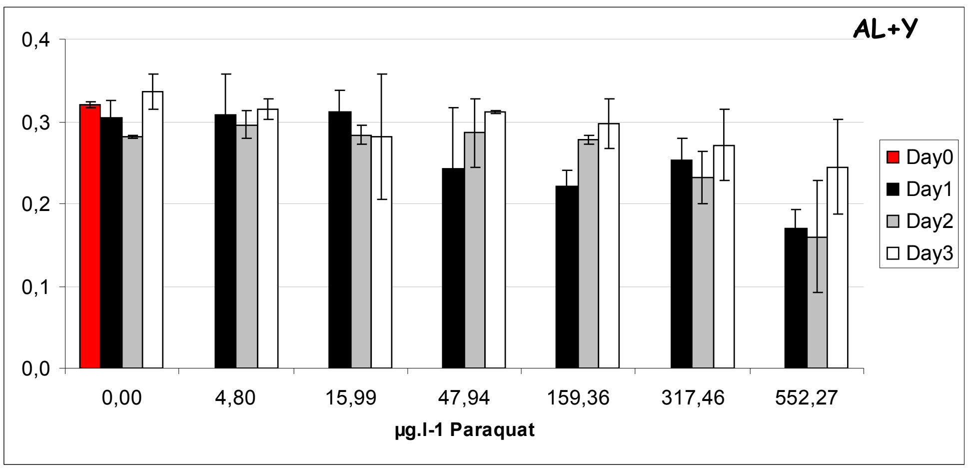
Depending on indicator, tendencies are more or less apparent. There is no significant tendency for the effective yield (AL+Y, not shown), and tendencies remain slight for both estimations of biomass (with the Phyto PAM and with the Turner Fluorometer). There are inversely important effects for the maximal yield (Y) and for the active biomass (dF).

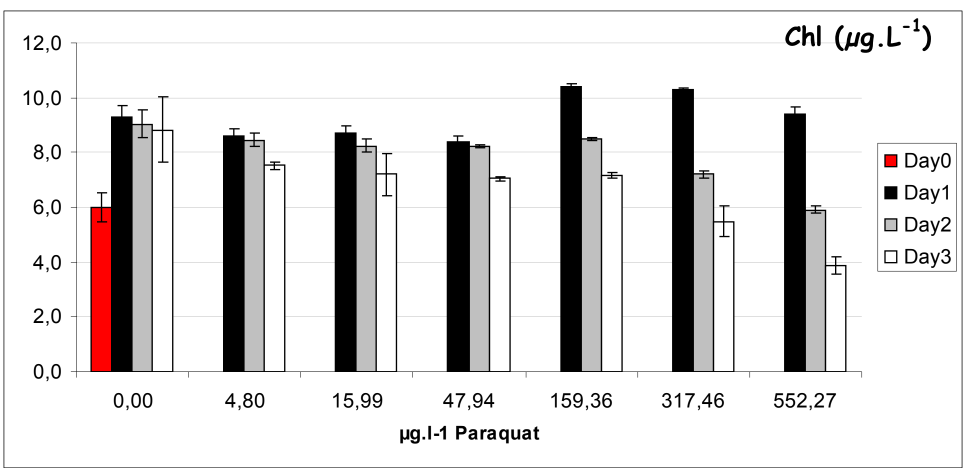
These results are to be considered with precaution. First we assume that Lampride is not toxic for algae: it was however our first hypothesis! Second, we didn't proceed to blank preparations involving each of the quantities added of Acetone. It's thus only an approximation, useful in indicating a potential deleterious effect of the solvent when its concentration is increasing.

This also confirms the necessity for further comparisons to consider separately blanks with and without acetone depending on the concentration of Lampride added during the cocktail bioassays.

3.4.2 Graphical interpretations Calloxone Super







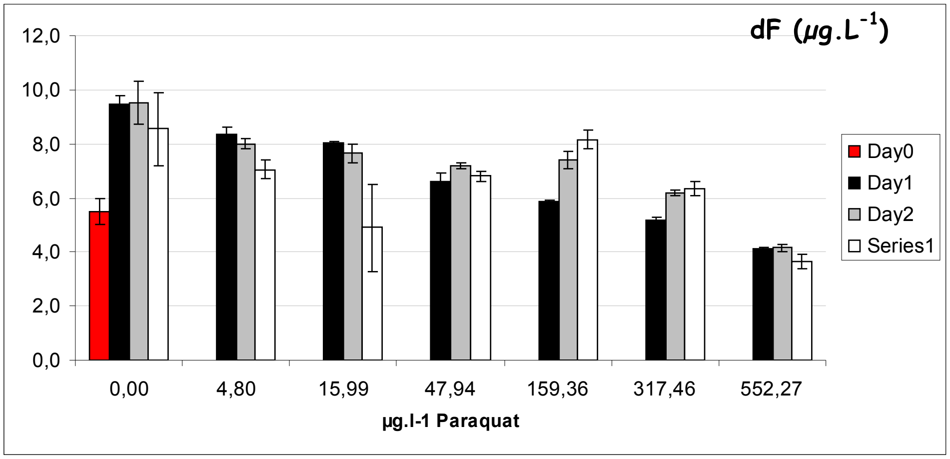
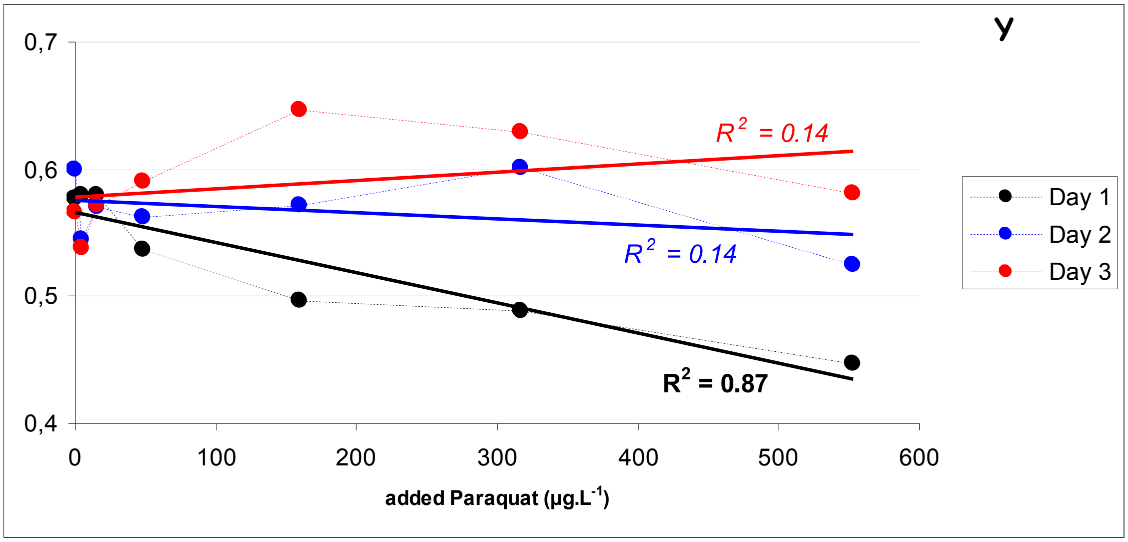


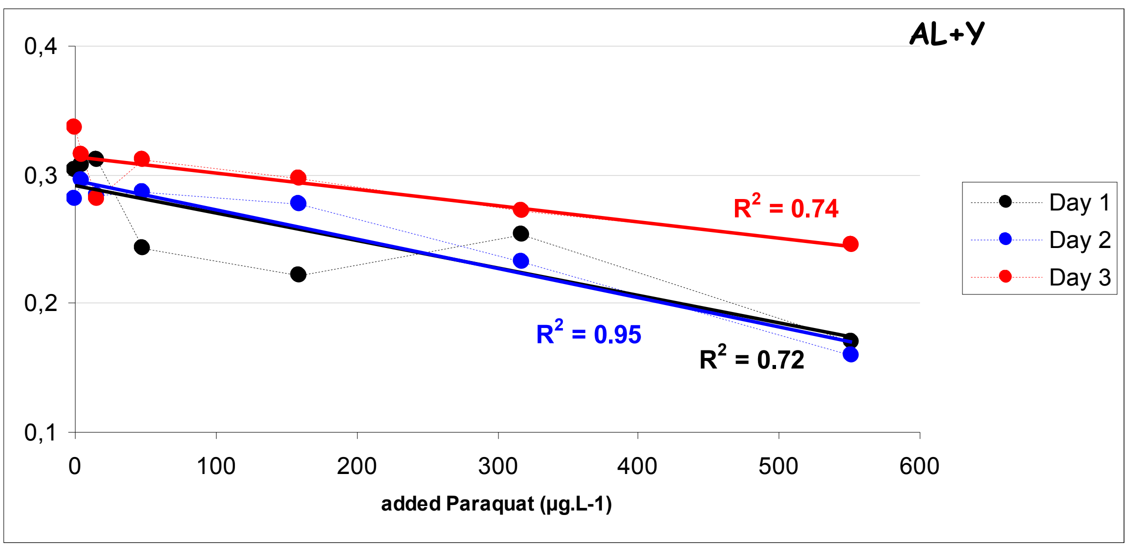
Figure 37 Phyto-PAM parameters variations with time and concentration for Paraquat.

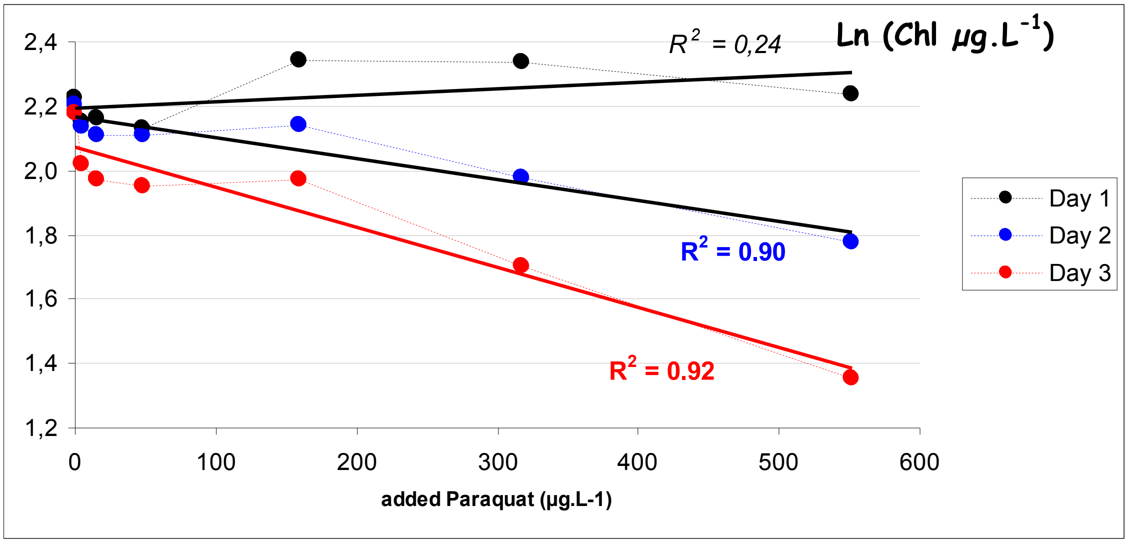
As for Lampride, the first observation is related to the health status of phytoplankton during the bioassay. Compared to measurements at the beginning of the experiment (in red), it appears clearly that algae remain in good health in the blanks (concentration = 0) for the duration of the assay: there is a significant increase of biomass (Chl as dF) the first day. However, whereas this growth was also noticeable during the following days with Lampride, Chl and dF in the blanks remain stable the following days during this experimentation.

It appears clearly that Paraquat influences the phytoplankton community with, as a consequence, after three days, a significant inhibition of its photosynthetic properties. A good correlation appears also with the contaminant concentrations involved, even if the temporal evolution during the three days of experiments reveals intriguing effects, :
- There is a sharp decline of dF with increasing concentration, every day from day0 to day3;
- there is a similar global trend for the effective yield (AL+Y);
- the situation is less evident for Chl due to significant differences from day to day;
- similar lack of trend for the maximal (theoretical) yield (Y).

Temporal perspective







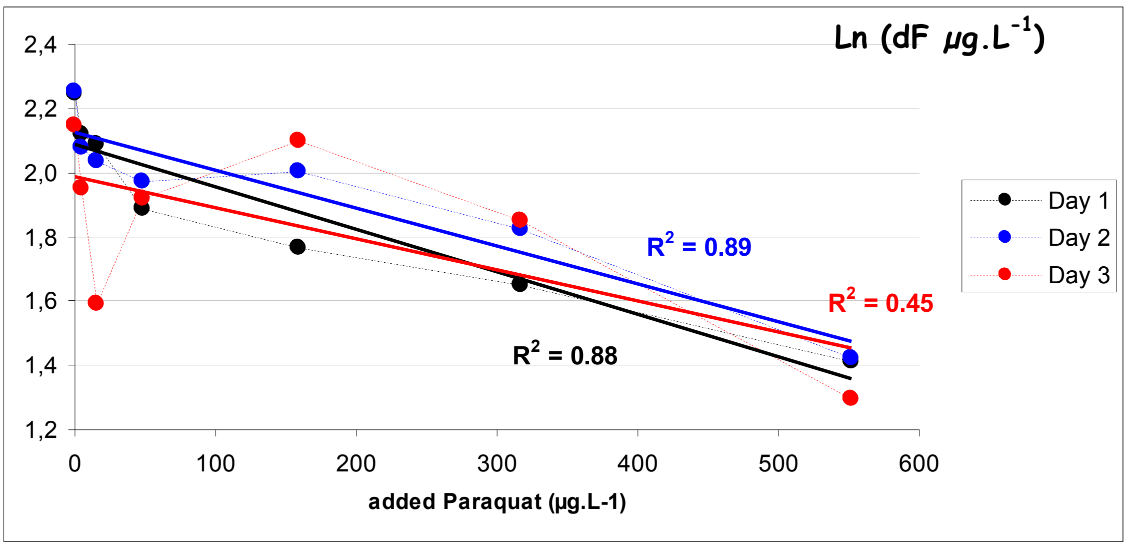


Figure 38 Phyto-PAM parameters with correlation coefficients and logarithmic Chl and dF.

There maximum yield (Y) is significantly influenced the first day, but there is not any clear tendency the following days.
Inversely, the estimated biomass (Chl) seems not influenced by the contaminant concentration the first day whereas there is a clear and redundant negative effect the days later.
The maximal yield (AL+Y) and the active biomass (dF) appear the most strongly influenced parameters by the presence of contaminant, even if this effect seems attenuated on the last day, (see Figure 38)

For the T0 – T3 comparison, Y will be discarded due to its poor response on day 3.

T_0-T_3 comparisons

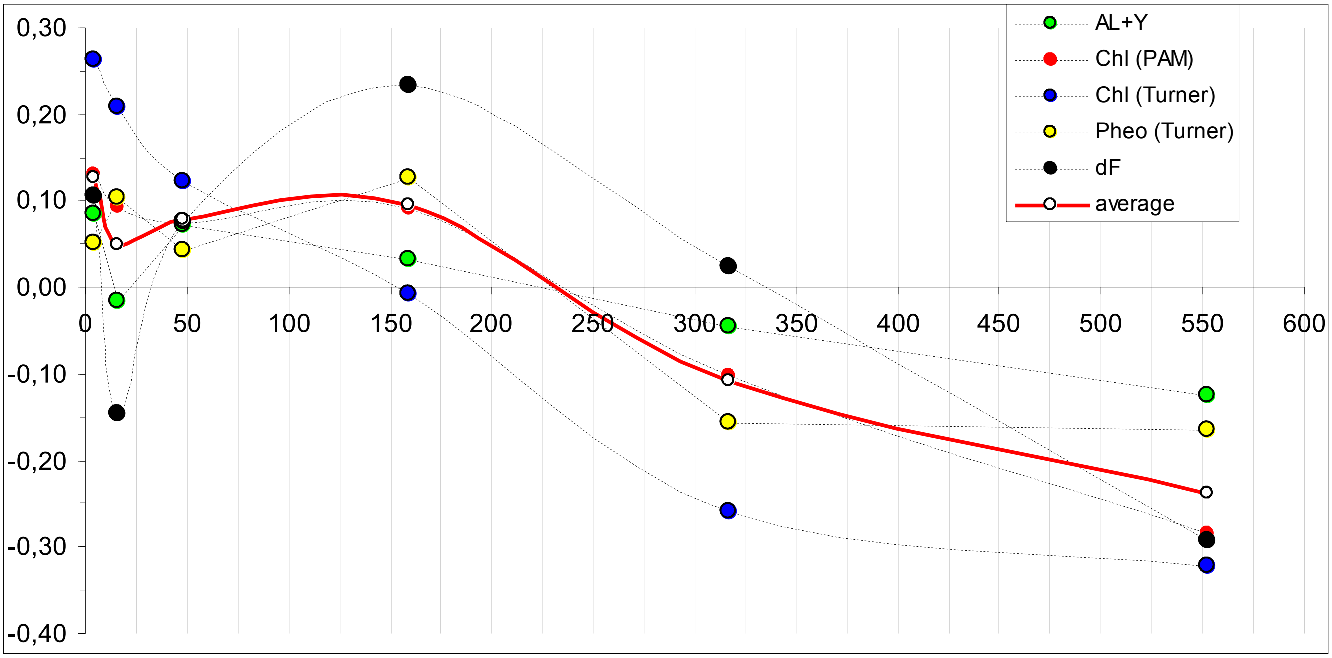


Figure 39 Indexes for the different parameters the 3rd day.

The picture has been prepared in considering the ratios to the blank on the last day of the experiment. For each indicator, this ratio is calculated for the different concentrations. After that, an index is developed for each of them in considering the mean value of the ratio (whatever the concentrations) for each indicator. In a second step the ratios are subtracted by their mean value, see Eq. 10. Like that, this index will vary from +1 to -1 for each indicator. All these indexes are shown in Figure 39. The red line corresponds to the mean of these indexes.

$$\begin{cases} Index_{i,j} = \dfrac{x_{i,j}}{\tilde{x}_i} - \tilde{x}_i; \\ i = Chl(Turner), Chl(PAM), dF, Pheo, Y + AL; \\ j = conc.[1,6]. \\ aver._j = \sum_{i=1}^{5} Index_{i,j} \end{cases} \qquad \text{Eq. 10}$$

When the red line cut the X-coordinate (index = 0), this corresponds to the graphical determination of the mean concentration inducing effect on the tested organisms. In that case, it is possible to estimate that such a concentration of Paraquat is around ≈ 230 µg.L^{-1}This can be compared with Figure 29 and we can conclude that we have estimated with a good accuracy the LOEC: *Lowest*

Observed Effect Concentration. Exactly the same estimation is provided when considering Chl PAM alone.

3.4.3 Cocktail of Calloxone Super and Lampride

Health status of algae and toxic effect

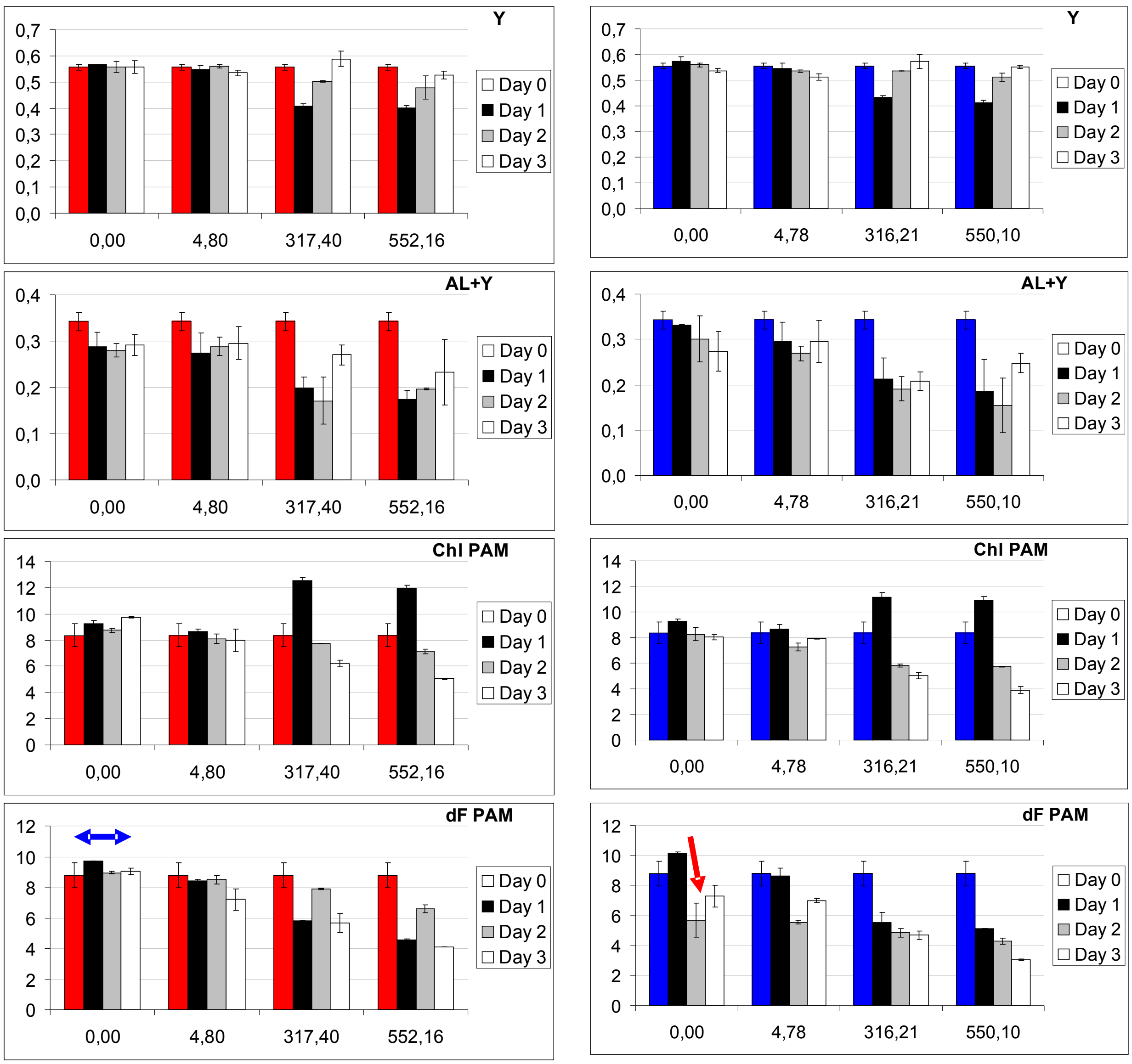


Figure 40 Phyto-PAM parameters variations with time and concentration for Paraquat.
The left column shows the results from an addition of 0,06 µg.l^{-1}Lampride. The right column shows the results from an addition of 1.2 µg.l^{-1}Lampride.

During the bioassays, two blanks were realized, one with H_20 alone, and the other with H_20 and 1cc of Acetone, to take into account the possible effect associated to this small amount of solvent. The blank with acetone corresponds to the maximum quantity of solvent added with the highest concentration of Lampride. Thus, treatments involving this concentration (and this quantity of solvent) have to be compared with the blank with acetone (in blue, on the right part of Figure 40). Inversely, for the second and smallest concentration of Lampride, treatments are compared to a blank realized without solvent (even if some traces of this product were added with the contaminant). Pragmatically, as we did not prepare a specific blank (involving the same small quantity of acetone), the blank with H_20 alone will be considered by default (in red, on the left part of the figure).

A succession of information is available when analyzing Figure 40:
- regarding the maximal yield (Y): there was no significant difference associated to the presence of different concentrations of Lampride; inversely Paraquat exerted a huge effect on Day 1 for the two highest concentrations, with as a recovery the following days. The same observation was made with Paraquat alone;
- Chl as measured by the Phyto PAM increased on Day 1 for treatments involving the highest concentrations of paraquat but exhibited sharp decreases the days later. The same observation was made with Calloxone alone. There is no significant effect associated to the concentrations of Lampride involved. For the blank, with as without solvent, concentrations remained the same for the duration of the bioassays, indicating that there wasn't any external factor inducing deleterious effect on the biomass measured;
- the effective yield (AL+Y) was strongly affected by the presence of paraquat, but again without apparent discrepancy between the two treatments with Lampride;
- the active biomass (dF) sustains the most important observation, regarding acetone toxicity. For the blanks with (blue) and without (red) acetone, responses are very different on Day 2 and 3. For the blank with H_20 alone, there is no significant evolution from day to day. Inversely, for the blank with acetone, there is a sharp decrease of dF on Day 2 and 3. Regarding the composition of this treatment, such a response could be only associated to the presence of acetone.

Consequently, for further comparisons, treatments involving the lowest concentration of Lampride (and the lowest quantities of acetone) will be compared to blank with H_20 alone, whereas treatments with the highest concentration of Lampride will be compared to blank containing 1cc of acetone.

T_0-T_3 comparaisons

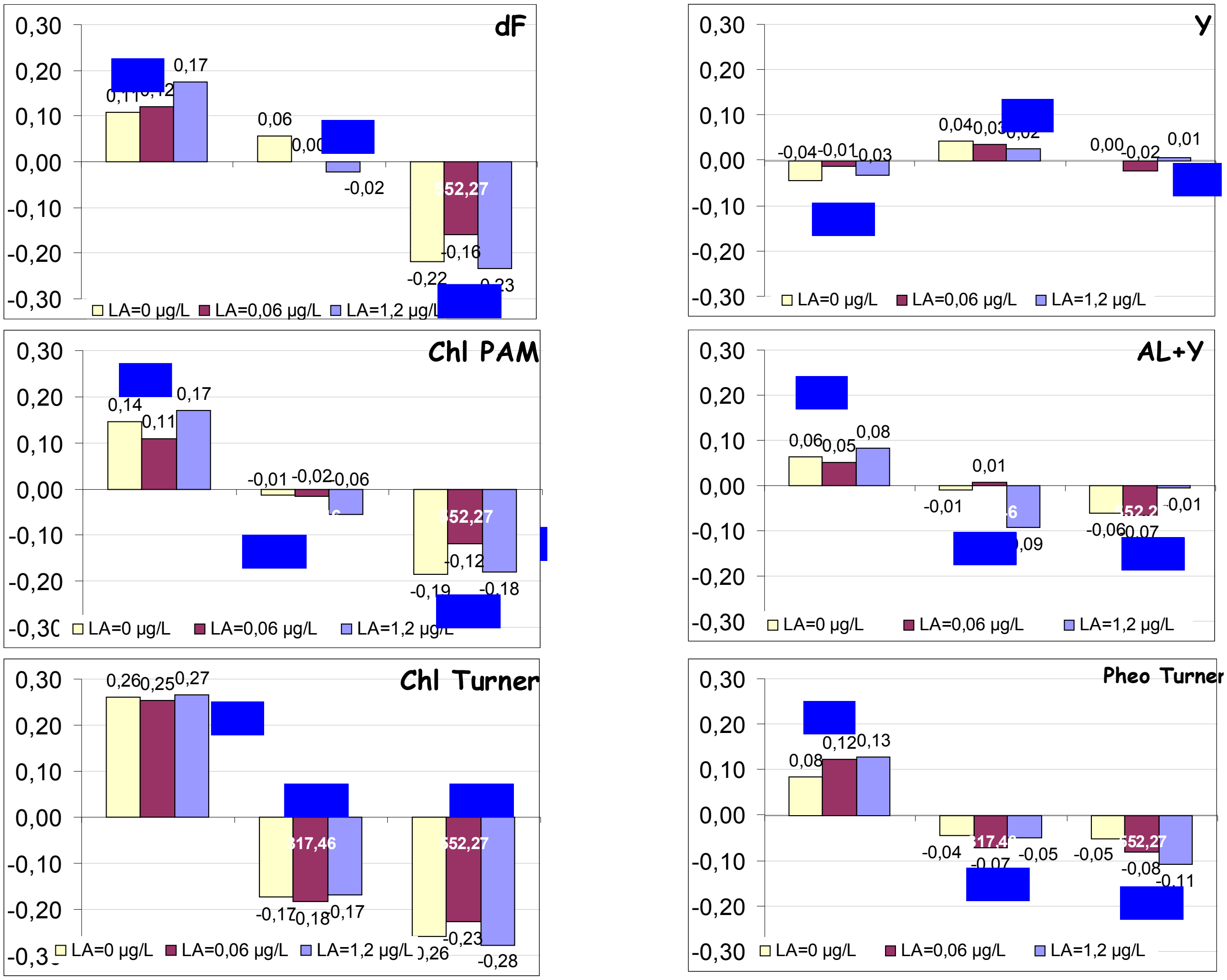


Figure 41 Comparison of ratios (indexes) from Day 3 for the different treatments of Paraquat mixed with Lampride to the value of the blank without acetone on Day 0.

Three concentrations of Lampride are considered:
- Lampride = 0; corresponds to the experimentation with Paraquat alone. For each concentration of Calloxone, indexes have been calculated as previously described (ratio to the blank on Day0, mean of all calculated ratios whatever the concentration of paraquat, index involving ratio and mean: numerator and denominator). In that case and by definition, blank is without acetone.
- Lampride = 0.06 µg.L^{-1}; corresponds to the cocktail bioassay. For this concentration, the blank is made with H_2O alone, by default. The same indexes have been calculated.
- Lampride = 1.2 µg.L^{-1}; corresponds to the same current bioassay but for these concentrations of Lampride, the blank is made with H_2O and 1 cc of acetone, see Figure 41.

Information obtained with the Turner fluorometer is also taken in account.

Paraquat effects

In such presentations, the line "0" corresponds to an absence of effect. All observations realized with the Phyto PAM indicate that with the intermediate concentration of Paraquat, there is quite no effect. Some redundancy with observation made during bioassays paraquat only with the graphical determination of LOEC: it's the same magnitude.

Expected and observed huge effect of Paraquat at its highest concentration, particularly apparent on Chl PAM and Chl Turner and dF. Inversely, quite no observed effect on Y and AL+Y. For this last indicator, amplitudes of variations are very small: that limits the interpretation.

Lampride effects

In case of a synergetic effect, it will be expected to find significant differences between the treatments involving the same concentrations of Calloxone. There is no indication of such effect: either indexes remained very small (around 0, see Chl PAM as example), interpretation is then impossible (no apparent effect), or observed differences between the blank (without paraquat) and the contaminant's treatments are not significant (see Chl Turner and dF as example). These observations ultimately confirm the absence of effect of Lampride.

LOEC graphical determination

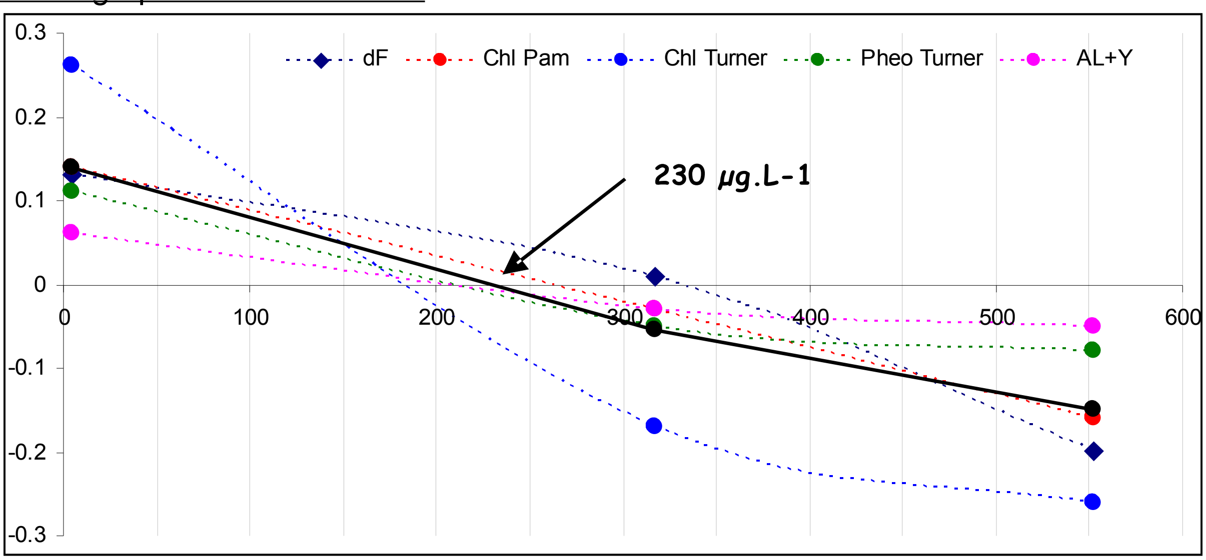


Figure 42 Indexes for the different parameters the 3rd day.

It is possible to try to determine again the LOEC associated to this bioassay, see Figure 42. Mean values obtained, whatever the concentration of Lampride, are represented against Paraquat concentration. The mean tendency is used to graphically estimate the LOEC. We obtain the same value as for paraquat alone.

3.5 Discussion

The Phyto-PAM proved its efficiency and precision when evaluating the toxicity of Paraquat on phytoplankton in the laboratory. The generalization of this method, quite simple, non-invasive, non-pollutant, and quick could be also efficient for the rapid screening of the possible toxicity of unknown products. It is an important issue but the accuracy and feasibility to evaluate toxicity with phyto-PAM has to be confirmed with other studies involving contaminants with a known toxicity.

Nothing can be said about the composition of algae species, because the Phyto-PAM which normally successfully separate different algae from each other by the colours radiated by the specie's setup of chloroplasts in one sample, has been calibrated for other circumstances. The measurements we have done have evaluated the impact of the pesticides on the phytoplankton community considered in its totality: biomass and global photosynthetic efficiencies have been used as proxy.

Lampride 46 EC

When used alone for bioassays and within the concentration series we used for that, Lampride didn't exhibit any significant toxicity. For the highest concentration used, the deleterious impact observed was clearly associated to the Acetone used as solvent for the preparation of contaminant's solutions. Due to the very low solubility in water of this product, the preparation of realistic concentration series imposed a series of dilution involving acetone as solvent. Other solvents have to be tested for the preparation of this dilution series, with the objective of increasing the highest levels of toxics tested but without inducing such toxicity.

Bioassays showed also that the toxicity associated to Acetone was not perceptible when testing the second highest concentration. No effect was associated to this treatment. Later we used this concentration as the highest to be tested when performing bioassays with a mixture of Lampride and Calloxone.

Calloxone Super

When used alone for bioassays and within the concentration series we used for that, the Paraquat involved as active molecule within Calloxone Super exhibits a very significant toxicity on natural algal communities tested. Responses produced by the use of the Phyto PAM allow the identification with a valuable accuracy the LOEC of this product (as mentioned in the specialized scientific literature), highlighting the efficiency of these apparatus for such analysis. After three days of exposition to the highest concentration of contaminant tested ($\approx 550\ \mu g.L^{-1}$), properties all algae were significantly reduced, within a range of [-35 to - 56%] depending on the indicator (Chl Pam, dF and Chl Turner, respectively). The potentially deleterious impact of paraquat is largely demonstrated.

Mixture of Lampride 46EC and Calloxone Super

The aim of this bioassay was to evaluate a possible, synergetic (and direct) effect of Lampride on the observed paraquat toxicity. Without additional precautions regarding the possible toxicity of the solvent used to add Lampride, results indicate a tendency to synergy. But a re-assessment of the acetone toxicity showed that the addition of the solvent introduced a significant bias in our observation. Ultimately, it appears that acetone exerted a deleterious effect on algae whereas no significant effect could be attributable to Lampride.

Several important modifications in the bioassay's protocols have to be introduced for future analyses:

- creation of a realistic bank of references using ALL products associated to the contamination of samples (acetone in the current example);
- evaluation of other solvent (without physiological impact on phytoplankton) for Lampride bioassays;
- systematic cross validation of bioassays as we tried to do here.

3.5.1 Error estimation

To efficiently calculate the LOEC, more samples would probably have been needed to ensure that the response from the algae has reached the endpoint, i.e. that the curve is not descending any more (see Figure 39 as an example). Due to few samples, it is difficult to evaluate if the endpoint has been reached in our experiments. Even though the range of concentrations has been confirmed through literature studies, it is not sure that the commercial products (Lampride and Calloxone Super) contain the concentrations indicated on the bottles. This contributes to an error in our experiment that is difficult to calculate. More samples, higher concentrations and longer time would possibly have assured that an endpoint had been reached.

4 Conclusion

This conclusion is written to give a review of the theses and to conclude that the objectives have been thoroughly studied. Below follow a short review of the objective and the results.

(1) Description of the different agricultural practices around the Toukoumtouré reservoir

Pesticide use in small scale farming in Burkina Faso is not controlled by regulations, but by the family economy of the farmer. "Petit à petit l'oiseau fait son nid" ("little by little the bird build its nest") is the principle for any commercial activity, everyone is starting up culture with scallion, the most rapid and cheap crop there is. Yearly scarcity of water forces people to stop cultivating and also to get water for house-hold needs far away.

The evaporation is the greatest loss of water in any surface water, but the irrigation is consuming a considerable volume as well. Watering beef cattle also takes some water and finally the household use constitutes a smaller part. A fundamental question remains whether and how the water reservoirs are recharged and/or drained by the touching groundwater aquifer.

The water reservoirs are still recent in time; old people have seen the evolution of the village life through the years. The landscape has changed from being dried out most of the year into a green and more tropic environment all year around. The possibility to grow crops near the water reservoirs also let private persons start a small business by selling the harvest in town or in the market place, introducing money to families who until then never used any money. The change is seen as a miracle and a blessing; the monastery who initiated the construction of the reservoirs has increased in popularity. The management and the sustenance of the water reservoirs are going to be taken over by the Belgian catholic NGO "Broderlijk Delen".

From the field study surveys, it appears also that gardening is known by the farmers themselves as a threat for aquatic ecosystems. Two situations were mentioned: (1) siltation and the consecutive accumulation of settling materials in the reservoir are said to progressively reduce the water storage capacity; (2) at the end of the dry season, water consumption seems deleterious for cattle. In both cases, farmers assume that these consequences are directly associated to their gardening activity

The field study has been executed with surprisingly little friction. Even if a first questionnaire survey didn't generate satisfying answers it was very easy to return to the field and get hold of all 23 farmers to complete the missing information. This was provided for by a frank dialogue with respected citizens from the start. One thing to keep in mind for the future study is to avoid demand characteristics by asking the questions carefully.

(2) Identification of xenobiotics locally used by farmers:

The number of pesticides used is very limited, since only the ones produced inside Burkina Faso, or the ones originally addressed for the huge industrial cotton plantations, are cheap enough to the ordinary small-scale farmer. Fertilisers are more expensive but still indispensable for harvest. Natural products such as the fermented berries from the common Neem tree (margousier, *Azadirachta indica*) are widely used. The manure from cattle and the compost heap are also used as a complement to the chemical products, but never alone. Herbicides were never mentioned by the interviewed farmers. Probably because they are considered too expensive and that they are unnecessary as one can easily clear the weeds by hand on such small areas.

(3) Evaluation of the potential deleterious effects of application of the xenobiotics on algal communities.

The most used active substance is the Lambda Cyhalothrin. It is present in the two chemical products Lampride 46 EC and Lambda Super 2.5. It is proved to be very toxic in background literature, but as the solubility in water is very low, our experiments were limited to extremely low concentrations. As an effect the solvent acetone was proved to have a toxic influence on the algal community in certain test samples. One interesting conclusion from this result is that this toxic substance never appears in hazardous concentrations dissolved in natural waters, but always stock in the sediments and the ground.

The herbicide product Calloxone Super contains the widely known active substance paraquat, lethal to human beings in small doses and an efficient but expensive product on the Burkina market. Toxicity was shown in laboratory, and the concentration 230 $\mu g.l^{-1}$ determined as the lowest concentration with an observed effect on the algal community, the LOEC. The phyto-PAM has in this experiment shown to be an easy device to measure the LOEC on phytoplankton communities. Further studies are needed to confirm this result.

The combination of the two above pesticides was tested to reveal possible cross-class mixture synergetic effects, but no such enforced or weakened toxicity could be proved.

The laboratory experimentations were similar to the ordinary routines of the IRD, and no difficulties or delay interfered with our time planning. Statistical treatment of data and interpretation of the results were performed together with the staff of IRD, Rémi Buchet and Philippe Cecchi.

5 Future studies

This is a pilot study supposed to be continued. The IMPECA project was set off for a two year period, our contribution is merely the initial effort. The aim has been to find out a functioning methodology in the field and in the laboratory, to test it in practice, and finally to improve it for upcoming similar studies within the same frame.

Next up in the IMPECA project will be the studies on ground water motions in the aquifers of the Nariarlé basin, by the American Master's Student Drew Gower at the University of Wisconsin, starting in July. Maybe we will be able to have an idea of how the ground water communicates with the reservoir volume, the missing information in our Water Balance.

The use of pesticides has been studied by the United Nations and the governmental authorities of Burkina Faso, but needs a continuous surveillance. The aquatic ecosystem is less known, and only IRD is working on these numerous water reservoirs that are so vital to the production of fruits and vegetables, as for the local economies around in the more populated areas of Burkina Faso.

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Appendix 1 History of the Reservoirs in the Nariarlé Basin

Figure: Frère Adrien and the authors of this thesis.

“Frère Adrien” (figure above) is the founder and the guardian angel of most of the reservoirs in the Nariarlé basin. He has told the whole story in detail from the very beginning to Mr Etongo Ilengo, the responsible for the Belgian NGO “Broderlijk Delen”, that is taking over the maintenance of the reservoirs successively as the monastery abandon the task. Nobody is as committed as this extraordinary monk originally from France but claiming to be Burkinabé, who despite his 80 years still controls the well-being of the reservoirs.

It has been presented in a text document in French by Mr. Etongo Ilengo, (Etongo Ilengo 2006), but the words are directly from “Frère Adrien”. Here follows a translation in English.

1961-1962

After the independence of the republic of Upper Volta the European Community decided to construct 100 reservoirs in the whole country. One of them is Nakamptenga, which will be the reservoir of the monastery in Koubri, it is built downstream of the reservoir. One NGO, CIDR, was also present and they established at the same time one free clinic and one school.

The same company, SNTP, builds the Moktedo-Zabré-Manga-Bazega reservoirs, and starts the Napagptenga construction on March 8, 1962. It turns out to be very problematic because in 1962 the rain is exceptionally strong; the double compared to normal years. The reservoir wall breaks, and the work is stopped many times before they finally may put the spillway in its position by the end of November 1962.

On the way back to Ouagadougou, one of the bulldozers gets stuck in the mud, outside Banro. It sinks until only the tail pipe is visible. People around believe that the ground have eaten the machine, and nobody touches it. 15 days later another bulldozer comes by to help it up by digging, the electrical contacts are cleaned and the motor starts at the first try. If it were these days, the whole bulldozer would have been stripped down.

1963
No rain, but an extraordinary dew from July to November gives the best harvest before 1986. The reservoir is filled for the second time in 1974.

1965
The Minister of Agriculture, Mr Edouard Yaméogo, want to build the reservoir of Naba Zana on the Nariarlé River, but the nuns' monastery do not want it, they would loose their seclusion. The discussion goes one for a couple of years, then the prominent bishop of the monks' monastery decides to make a demand to Canada in 1970, who accepts to take on the work with brother Lucien, an Egyptian construction engineer.

1972
The large reservoir is finished in May, but is too big to fill up. One valve is installed but it does not have the desired effect.

1974
The water level is lowered with three meters; it is then a successful reservoir. The people demand us to build reservoirs in their villages, about 100 have been accomplished, and another 300 are asked for. Only two reservoirs have been imposed by authorities, the first one in Napagptenga, and the discussed one in Naba Zana.

The experience of reservoir building since 1961 until 2007 is summed up by following:

The village people are allergic to any maintenance
Before and after the rain season the reservoirs need some sanitation treatment
Bad surprises may happen, it is necessary that all reservoir water users contribute with some money at yearly basis for example for the build-up of the reservoir wall.

(Etongo Ilengo 2006)

Appendix 2 Agenda

Date	Time	Activity
17/3	09:00	Kick off IMPECA at Auberge des Bougainvillers, Koubri
18/3	10:30	Meeting with “Frère Adrien” at the monastery. Make a tour around the different reservoirs.
19/3		Working at the office in Ouaga
20/3	10:00 11:00 15:00	Meeting Christian Etongo and Lydia Yelemou, from the NGO Bde, at Koubri Visiting the market at Koubri. Buying pesticides and manure available at the market Meeting with the “Comité de barrages” in Toukoumtouré. Get to see the “cahier de recensement”.
21/3	08:30 09:00 10:00 11:00 16:00 17:00	Meeting with the village chief Interview no 1 Interview no 2 Interview no 3 Interview no 4 Interview no 5
22/3		Free day
23/3	09:00 10:00 11:00 15:00 16:00 17:00	Buying additional bottles of pesticides, tea and sugar at Koubri market Interview no 6 Interview no 7 Interview no 8 Interview no 9 Interview no 10
24/3	09:00 10:00 11:00 16:00 17:00	Repairing the mopeds in Nakamtenga near Toukoumtouré Interview no 11 Interview no 12 Interview no 13 Interview no 14
25/3	10:00 11:00 12 ish 16:00	Interview no 15 Interview no 16 Wille has an accident with the moped, the wound is stitched in the clinic near the monastery. Visiting the clinique francais in Ouaga for a consultation, buying a necessary medicine for vaccination in Ouaga.
26/3	10:00 11:00 15:00	Interview no 17 Interview no 18 A tour is made around the reservoir to measure the actual water limit.
27/3	07:30 15:00	Working in the office in Ouagadougou A tour is made around the reservoir to measure the limit of the highest water level.
28/3	09:00 15:00	Mapping the different fields with GPS. Mapping the different fields with GPS.
29/3	09:00 15:00	Mapping the different fields with GPS. Meeting Aude Meunier, Nicolas Moiroux and Korotimi Sanou in Koubri. Making a tour along the reservoir in Toukoumtouré visiting different fields.
30/3	09:00 10:00 11:00 15:00 16:00	Interview no 19 Interview no 20 Interview no 21 Interview no 22 Interview no 23

Appendix 3 Hazard Assessment- fieldwork

A two weeks field work like this is associated with some potential hazards. Below are listed some of the hazards and possible actions to eliminate the risk.

Hazard	Risk	Action
Dehydration in the strong sun.	High	Enough water will be brought all the time. Hats will be worn
Broken bones, muscle strains	low	Basic first aid kits can be brought.
Insect bites, malaria	low	Insect repellent will be brought and used if necessary.
Motor bike accident	Medium	The motorbikes will be checked and repaired regularly, each one of us will drive a motor bike in case one of the motor bikes will break down. Sensible driving will be applied.
Poisoning from handling the pesticides.	low	The pesticides will be stored in well ventilated areas

Mobile phones will be brought all the time. Hopefully they work at the countryside…..

Useful phone numbers:
IRD Ouagadougou: 50306737

Hospital Ouagadougou: Centre Médico-social de l'Ambassade : 50.30.66.07
Médecin de garde : 70.20.00.00 (tél. cellulaire)
Assurance Wille and Stina: +46 8 587 717 00
Accommodation Koubri: Monastery, nuns: 405512
Monastery monks:405511

Clinic nearest to Toukoumtouré: Dispensaire Sœurs de St Gildas near the monastery.

Appendix 4 Questionnaire survey

1. General

   Time of survey. *La date:*
   Name of household. *Chef de famille:*
   Family size. *Combien de personnes y habite:*
   Location of farm. *Où est-elle située* ?:

2. Land and Landownership

   How many hectares do you farm? *Vous cultivez sur combien d'hectares?*
   How many parcels do you farm? *(if the farmer is using parcels)*

   Does the area change according to the access to the water in the reservoir ? *En fonction de l'accès à l'eau, change-t-elle la superficie utilisée?*

   What month in the year do you start to farm this field ? *A partir de quel mois cultivez-vous cette parcelle?*

   How many months do you farm this field each year ? *Combien de mois cultivez-vous ce terrain?*

   Does the size and location of the area that you use for farming change during the year. Until when? *La superficie cultivable, change-t-elle ? Jusqu'à quand ?*

   How long have you lived in this farm or operated this farm? *Depuis combien de temps cultivez-vous ce terrain?*

   Do you own the land that you farm? Rent? Other? *Ce terrain est à vous, ou bien vous le louez/impruntez?*

   Owns it : pass on to 3.   Si propriétaire : continue sur 3.

   Has somebody given you the right to farm this field?

   How do you pay the rent for your field ? *Comment payez-vous votre parcelle(argent, travaille, services) ?*

   Who own the land where you work? *Qui est le propriétaire du terrain en question?*

   Where does the person live who owns the farm where you work? *Où est-ce qu'il (elle) habite ou travaille, ce (cette) propriétaire?*

   Of the amount you own/rent, how much do you farm during the dry season? During the wet season? *Quelle partie du terrain utilisez-vous pendant la saison seche/pluvieuse?*

3. Current Agricultural Practices

   What kind of agricultural education do you have? Do you have an agricultural education? *Avez-vous suivi une formation de maraîcheur?*

   If yes, what kind of agricultural education do you have? *Si oui, laquelle?*
   If no, how have you learnt cash crop agricultural practices? *Si non, comment avez-vous appris?*

   What crops are you growing this year?   *Quelles plantes faites-vous pousser cette année?*

   Do you harvest more than once a year from your field? *Faites-vous des plusieurs récoltes sur une même parcelle ?*

Do you grow different plants on the same field throughout the growing season? *Changez-vous les plantes qui se succèdent sur cette même parcelle ?*

a. Why are you growing these? *Pourquoi avez-vous choisi ces plantes-là?*

b. Which are the most profitable? *Lesquelles sont les plus rentables?*

c. What are the chemical input requirements for each on your crop? *Quels produits chimiques ajoutez-vous afin d'améliorer le résultat?*
   i. Fertilizers. *Engrais*

   ii. Pesticides. *Pesticides*

Do you recognize these chemical fertilizers(taking out the chemical products from a bag)? *Est-ce que vous reconnaîssez ces engrais chimiques(en faisant sortir des produits chimiques d'un sac-à-dos)?*

How much do you use of the chemical products respectively (Make him express himself in terms of sacks per month)? *Combien mettez-vous de ces produits respectivement(Pour qu'il précise combien de sacs il consomme par mois)?*

Do you recognize these chemical pesticides(taking out the chemical products from a bag)? *Est-ce que vous reconnaîssez ces pesticides chimiques(en faisant sortir des produits chimiques d'un sac-à-dos)?*

How much do you use of the chemical products respectively (Make him express himself in terms of bottles per month)? *Combien mettez-vous de ces produits respectivement(Pour qu'il précise combien de bouteilles il consomme par mois)?*

Where do you buy the chemical products? *Où est-ce que vous trouvez ces produits là?*

Do you have a compost? *Avez-vou une fosse-fumier?*

Do you use traditional pesticides such as "nemier"? *Connaîssez-vous le système de nemier(pesticide traditionnel)?*

What other products could you possibly find on the market? *Qu'est-ce qu'il y a comme produit que vous n'utilisez pas, mais qu'il est possible de trouver dans le marché?*

Since how many years have the products been available on the market? *Les produits sont disponibles au marché depuis combien d'ans?*

Are they expensive? *Ca coûte chère?*

What do you do with the used bottles of pesticides*? Où foutez-vous les bouteilles vides usagées?*

Do your crop choices change over time? *Vous changez les plantes sur un même parcel d'année en année?*

d. If so, why? *Ça dépende de quoi?*
e. How have they changed (e.g. what have you been growing?) *Quelles plantes avez-vous fait pousser ici auparavant?*

What factors affect your choice of crops planted? *Quels facteurs joue sur le choix de plante?*

f. Soil type. *La qualité du sol*
g. Input expenses. *L'investissement*
h. Weather. *Le temps*

i. Water availability. *L'alimentation en eau*
j. Market demand. *La demande du marché*
k. Other. *Autres*

How long is the growing season for each crop? Or, when do you cultivate/farm your crops? *Les plantes mettent combien de temps pour pousser, à partir du moment de les planter jusqu'à la récolte?*

Is the reservoir normally drying out completely during the dry season, do you think the reservoir is going to dry out this year? *Est-ce que le barrage normalement tarisse en saison sèche, croyez-vous qu'il va tarisser cette année?*

Will you have time to harvest before the reservoir is dried out? *Aurez-vous récolté le moment où le barrage se tarisse?*

4. Agriculture and the Market

Do you sell your crops? *Vous vendez votre récolte?*

If yes, where do you sell them? *Où est-ce que vous les vendez?*

How much of the field is used for cash crops? *Quelle partie du terrain est destinée à la vente sur le marché?*

Do you make descent money? *C'est un bon business?*

5. Water and Agriculture

Do you irrigate your crops? *Vous arrosez votre champs?*

If so, which ones? *Lesquelles?*

If not, how do the crops receive water? *Sinon, comment recoivent-ils suffisemment d'eau?*

From where is the water for irrigation taken? *Où prennez-vous l'eau d'irrigation?*

How much do you irrigate the different crops*? Combien d'eau utilisez-vous pour arroser les plantes chaque jour?*

How do you irrigate?(pump or buckets) *L'arrosage se fait comment (moto-pompe ou seaux)?*

If with buckets : *Si avec des seaux :*
How many buckets for every crop bed ? *Combien de seaux par place (petite parcelle)?*
How many crop beds do you have ? *Combien de petite parcelles avez-vous ?*

6. Water and the household

What kind of water(surface water, ground water) is used for the household(washing, drinking water etc)? *Quelle type d'eau sert pour les besoins domestiques? (Puits, barrage ou autre)*

Does the water source change when the reservoir is completely dried out ?

a. Proximity to water source *L'eau se trouve loin de la maison?*

b. How much time do you spend from your house until you have reached the water source? *Combien de temps mettez-vous afin d'atteindre le point d'eau*

c. How much time do you spend filling your buckets with water? *Combien de temps vous faut-il pour remplir vos bidons, l'attente et le remplissage ?*

d. Do you pay/how much for the water? How do you pay for the water? *Combien/comment payez-vous pour l'eau ?*

7. Water as a conflict

Are there any conflicts concerning the utilisation of the water in the reservoir? What kind of conflicts? Y-a-t-il des conflits pour l'utilisation de l'eau de barrage, lesquelles(concurrence entre maraîcheurs, abreuvage des troupeaux, disponibilité d'eau, etc.) ?
En quelle période ?

Where are the people moving when they are no longer cultivating around this reservoir ? Où se déplacent ils, les uns qui ne cultivent plus autour de ce barrage?

8. Further questions of interest not being posed
Do you mix your pesticide with other products? *Ajoutez-vous des produits supplémantaires pour booster l'effet du pesticide?*

Where do you rince the spraying equipment? *Où rincez-vous le bidon de pulvérisaton?*

How do you spray if the equipment is not functioning? *Comment faites-vous pulvériser lors que l'équipement tombe en panne?*

Appendix 5 Short summary of the answers from the questionnaire

Time of the interviews: 21/3-1/4 2007

No of farmers : 23
No of fields: 49
Size of property: -------*
Does the location change according to access to water in the reservoir: 45% (14/31 fields)
Farmers owning their land: 6 farmers renting in 2nd hand: 15 Farmers owning some and renting some: 2
Where does the person lives who own the land: Tanvin, Toukomptouré, Bolla.
How long have you been growing here: 1-15 years
Do you have an agricultural education: yes 4

Fields:

Papaya, banana	Scallion	Eggplant	Onion	Tomato	Zucchini
3	22	15	2	4	3

Do you grow the same plant throughout the growing season: yes: 21, no: 2.

Start of the cultivation:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
4 fields	4 fields	---	13 fields	8 fields	11 fields	1 field	4 fields	3 fields	---	---

Farmers irrigating with – buckets:12, motor pump:6, both:5

Uses Lambda Super: 16
Uses Lampride: 11
Uses the Neem tree: 6

Uses NPK: 18
Uses Urea:21
Uses NPK-minerals: 18

Where do you buy the chemical products:
Koubri:21
Nabazabha:1
Tanlarghin:2
Saaba: 2

Where are your crops sold
Koubri:10
Ouagadougou:19
Tanlarghin:1

From where do you get your drinking water
When there is water in the reservoir; well: 14 drained well: 6 drilled well: 3
When the water is finished: well:1 drained well:1 reservoir: --- drilled well: 21

Most farmers had learnt the agricultural practices by working together.

*Impossible to get any information as the hectares were a unit difficult for the farmers to relate to

Appendix 6 Pesticides in Burkina Faso

FAO has done some detailed research on the use of pesticides in Burkina Faso, and present following problems:

- Recommended doses are not being respected.
- The soil never rest between cultures.
- Export of the vegetables produced often meet problems with respect to the Maximal Pesticide Rest Products.
- There is no effort on the national level to impose the Maximal Pesticide Rest Products.
- There's not enough true worthy data on the pesticides' active substances and there rest products in the surface- and ground waters, and the soils. The effects are yet unknown.
- There's not enough data on the pesticides' rest products in the drinking water.

The European Union, who is receiving more produced crops than other non-African consumers, set the limits of Maximal Pesticide Rest Products by their own standards. They are often equal to the threshold of detection, i.e. the analytical zero concentration. To guarantee the safety in the Burkinabé agriculture is a difficult task, and sometimes exported crops are stopped because they do not pass the European tests. This implies the national economic interest in controlling the use of pesticides, so to keep sustainable buyers in the EU, but few efforts are yet made.

The Burkinabé cotton company Sofitex is providing the cotton farmers with pesticides such as Lampride 46 EC. The left overs from last years campaign is being distributed on the local markets to a very low price, and anybody can easily buy for his/her personal use. Only some Chinese products and the natural Neem insecticide might break the Sofitex monopoly, (TOE 2003).

The Neem tree (*Azadirachta indica, Melia azadirachta, Melia indica):*
The Neem tree originates from India and is now cultivated all over the trophic zones. The tree is fast growing and often used at road sides to add to the shadow. The tree has been extensively studied and the uses are many: traditional medicine, fertilizer, food for cattle just to mention some of its possibilities. The fruits are also used as an insecticide as they contain the active substance azadirachtine (CIRAD-GRET 2002).

Appendix 7 Potential evapotranspiration data from Ouagadougou airport

ETP PENMAN (mm) POUR OUAGADOUGOU AERO													
Année	*Jan*	*Fév*	*Mar*	*Avr*	*Mai*	*Juin*	*Juil*	*Août*	*Sep*	*Oct*	*Nov*	*Déc*	*TOTAL*
1970	189,7	182,6	217,1	197,7	170,3	140,9	108,4	101,9	125,0	182,5	178,2	183,0	1977,3
1971	194,5	191,2	215,9	196,2	176,5	142,5	110,5	109,6	124,8	176,1	178,8	176,7	1993,3
1972	187,8	208,1	220,2	173,2	147,9	109,9	107,1	103,6	135,9	174,4	171,8	179,1	1919,0
1973	206,5	187,0	222,6	182,3	171,8	127,1	117,2	110,6	136,4	179,5	200,9	178,9	2020,8
1974	188,4	194,9	214,0	182,1	175,7	142,1	105,3	107,9	123,4	167,5	171,6	182,1	1955,0
1975	194,9	181,6	214,3	186,9	164,7	131,7	95,1	108,2	122,5	173,2	177,7	193,7	1944,5
1976	191,6	193,8	213,7	183,9	154,7	112,5	110,6	104,7	128,8	150,2	174,1	176,2	1894,8
1977	185,9	191,8	220,5	183,0	163,8	124,0	113,9	109,6	132,8	174,9	175,2	169,7	1945,1
1978	180,4	162,9	189,3	161,9	146,6	111,0	101,9	112,2	129,1	168,6	189,1	181,4	1834,4
1979	218,8	211,1	232,7	209,7	161,0	118,3	107,7	113,4	125,6	169,7	176,1	198,3	2042,4
1980	195,3	199,6	225,9	191,2	189,2	124,0	118,8	109,8	142,3	186,5	181,8	199,3	2063,7
1981	187,2	**	195,1	185,9	**	172,3	147,7	145,0	151,4	**	197,9	191,1	1573.6*
1982	195,5	**	184,3	203,2	191,2	168,5	**	135,3	150,1	168,3	175,5	183,4	1755.3*
1983	187,9	**	189,5	197,1	204,6	162,4	157,8	**	**	167,0	155,5	153,9	1575.7*
1984	193,0	191,4	218,2	207,8	170,7	126,9	126,9	131,0	135,7	175,6	184,6	188,9	2050,7
1985	171,7	**	191,5	186,1	204,7	181,3	144,6	146,0	140,0	**	164,6	172,2	1702.7*
1986	169,1	**	183,0	206,6	185,9	171,5	143,8	138,2	132,9	**	154,9	173,8	1659.7*
1987	172,5	**	187,8	204,7	206,5	168,2	155,5	140,1	147,4	156,7	155,7	160,4	1855.5*
1988	156,7	**	178,2	174,5	192,8	**	139,1	132,7	136,1	168,1	154,8	168,0	1601.0*
1989	171,7	**	174,4	**	**	**	153,0	129,3	141,8	156,8	169,6	163,6	1260.2*
1990	165,6	**	212,2	183,3	198,9	163,1	152,0	**	145,3	173,2	164,2	165,7	1723.5*
1991	186,3	154,6	185,0	182,9	159,3	158,3	150,7	132,9	150,6	162,1	160,1	177,5	1960,3
1992	174,0	182,5	185,5	179,8	194,1	169,5	150,5	124,4	144,1	161,1	156,4	158,8	1980,7
1993	163,7	153,6	170,5	169,3	198,4	163,0	148,1	141,0	143,4	167,9	150,7	171,7	1941,3
1994	171,1	165,3	177,0	181,8	196,1	164,3	153,4	124,8	138,3	153,3	158,7	187,4	1971,5
1995	172,6	161,9	201,7	187,5	193,7	177,8	150,7	137,1	147,0	171,4	170,6	181,2	2053,2
1996	178,0	177,3	192,4	177,1	202,6	176,8	166,3	147,7	138,8	174,0	174,5	175,5	2081,0
1997	186,1	196,9	203,1	178,4	195,5	168,3	163,4	144,5	149,6	175,3	161,4	173,8	2096,3
1998	178,7	181,7	214,1	194,4	192,1	167,2	151,9	134,9	138,2	173,0	172,0	177,1	2075,3
1999	192,2	168,8	213,6	201,7	207,9	190,0	145,2	125,1	127,7	166,3	170,9	180,4	2089,8
2000	183,3	189,8	202,5	172,2	175,5	173,0	139,2	137,2	161,5	168,8	172,6	173,0	2048,6
2001	181,9	186,1	205,7	206,7	202,2	173,4	153,7	141,5	143,1	174,0	174,0	186,4	2128,7
2002	193,7	179,2	196,7	188,6	200,8	182,8	162,8	143,4	150,2	167,7	172,2	185,9	2124,0
2003	178,6	172,6	205,2	206,6	205,7	154,5	155,0	142,4	139,5	178,7	172,0	184,4	2095,2
MOY	183,7	182.7*	201,6	188.6*	184.4*	153.7*	136.6*	127.1*	138.8*	169.8*	171,1	178,0	2011.5*

Appendix 8 Water poverty index

Water poverty index, WPI, represent a composite index for the assessment of poverty in relation to water (Sullivan et al. 2005). WPI is intended to identify areas where water is most needed and hence could benefit the most from an amelioration of access to clean water.

Among many different poverty indices, water poverty index seems to be an appropriate choice in the project of IMPECA. The benefits of WPI are that it allows assessments at a community level, and links water and poverty issues. Agriculture is generally supposed to be a big user and polluter of water. This can lead to water scarcity and poverty which can be indicated by the WPI. It can hence be easily measured where resolving problems of agricultural water use has a direct, favourable impact in reducing poverty. WPI can be used in both local and regional scale and WPI has already been used in Burkina Faso in a regional study (Lawrence et al. 2002), where the country was listed among the 14th water poorest countries in the study. The local variation can differ noticeably from the regional index (Sullivan et al. 2005).

WPI consists of five general concepts which hardly can be quantified as such, hence sub components has been evaluated and by studying these sub components and overall index can be quantified and calculated.

(source: Sullivan et al. 2003)

• Resources	The physical availability of surface and ground water, taking account of the variability and quality of the resource as well as the total amount of water.
• Access	The extent of access to water for human use, accounting for not only the distance to a safe source, but the time needed for domestic water collection, and other significant factors. Access means not simply safe water for drinking and cooking, but water for irrigating crops or for industrial use.
• Capacity	The effectiveness of people’s ability to manage water. Capacity is interpreted in the sense of income to allow purchase of improved water, and education and health which interact with income and indicate a capacity to lobby for and manage a water supply.
• Use	The ways in which water is used for different purposes; it includes domestic, agricultural and industrial use.
• Environment	An evaluation of environmental integrity related to water and of ecosystem goods and services from aquatic habitats in the area.

The WPI is meant to capture and gather all the issues above that relate to water resources availability and their impacts on people. The various elements from the different sections are evaluated and aggregated together using the expression:

$$WPI = \frac{\sum_{i=1}^{N} w_i X_i}{\sum_{i=1}^{N} w_i}$$

WPI is the Water Poverty Index value for a particular location, Xi refers to the component I of the WPI structure for that location and Wi is the weigth applied to that component.

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

The components are made up by subcomponents and weighted so that it falls into the range of 1 to 100. The highest value 100 is taken to be the best situation whereas 1 is the worst (least water, most poverty). Different subcomponents are suggested by Sullivan (Sullivan et al. 2003). Among those subcomponents, some has been found being more suitable to use at a community scale (Sullivan et al. 2003). The same sub components could be of interest when deciding what further studies have to be done to evaluate a local water poverty index.

Appendix 9 Areas cultivated around Touloumtouré year 2006-2007.