Designing international interdisciplinary research in the field of management of natural resources.

Illustrated by the case of the INREF Terra Preta Project

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Executive Summary

Wageningen University has a long tradition in doing internationally oriented interdisciplinary research (IR) in the field of natural resource management. In the Wageningen context, interdisciplinary research is often used to generate applied science that helps solving complex, multidimensional problems. However, how collaboration and integration between distinct disciplines can be put in practice is not always clear, especially when it comes to international research efforts.

This report discusses problems and opportunities of IR and provides useful strategies and a framework for multi-organizational, international, interdisciplinary research in the field of natural resource management. Necessary data were gathered through literature review, interviews with Wageningen scientists involved in first round INREF programs[1]. The problems and strategies these programs encountered are presented using the framework as shown in Figure 3.

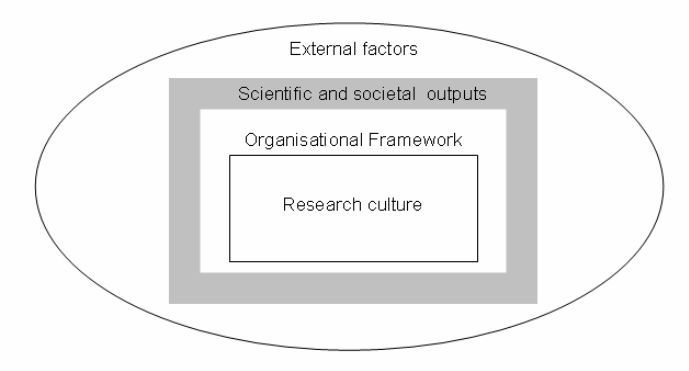

Figure 1: Analytical framework for interdisciplinary research developed during the study. The parts will be described in the following sections, which are ordered after this framework.

[1] The following projects were included: Optimisation of nutrient dynamics and animals for integrated farming (POND); Agro-industrial transformations towards sustainability (AGITS); Healthy people: Food-based interventions to alleviate micronutrient malnutrition (FNRHP); Convergence of science (COS); Regional food security policies for natural resource management and sustainable economies (RESPONSE). In total 16 PhD supervisors, 14 PhD students, 3 program coordinators and 1 INREF staff member were interviewed.

1.1 Research culture

The inner core of the framework forms the research culture. It draws on the differences in methods and methodology, goals, language and culture. These can be seen as the 'traffic rules' for IR. Different methodological problems were found, including problems between quantitive (natural science and economics), qualitative (anthropology) methods; and deductive and inductive approaches.

It is common sense that creating common goals is of importance for a successful interdisciplinary project, however, around half of the interviewed scientists thought that the program goals were insufficiently discussed during the planning of the project. Most scientists mentioned yearly workshops as a strategy to keep thinking on common goals, which might be changed during the program. Although all INREF programs organize such workshops, the majority of researchers state that the frequency of these workshops is insufficient. The differences in language, vocabulary, and concepts formed another problem that was mentioned by almost all informants, even between adjacent disciplines. Scientists point out that reading and discussing each others work are the main solutions.

Some cultural differences are historical, like the fact that social scientists write longer articles. These are not accepted in for example NJAS, which is regretted by one of the interviewed sociologists. The form of the dissertation (bundled articles vs monograph) is another historical-cultural issue influencing the possibility of cooperation between the disciplines.

Recommendations

Wageningen sociologists should make themselves more familiar with quantitative approaches.

The formation of common goals can be improved by organizing more discussion sessions in the start of interdisciplinary programs; publishing on found common concepts; and thirdly, organize more interactive reflective workshops with all participants during the program.

Wageningen University's leading journal, NJAS, can easily facilitate interdisciplinary work by increasing the maximum length of an article that nowadays scares off sociologists. Lastly, though close to common sense: IR team members should take time for collegiality, ask each other questions, and read each other literature.

1.2 Organisational framework

The second ring in the analytical framework forms the organisational framework. The organisational model of an IR program can be considered as the infrastructure. It determines the way the research is structured, the division of tasks and the planning in time and space. 10 out of 18 interviewed scientists say that the subprojects of the INREF program do not coalesce (Table 5) and half of the PhD students perceive little influence from the program coordinators. We propose that the lack of a consciously chosen organisational model partly caused this lack of integration.

Rossini & Porter (1979) provide a comprehensive overview for the organisation of interdisciplinary research based on 24 observations. They present four ideal types of integrating interdisciplinary research: 1) common group learning; 2) modelling; 3) negotiation among experts; and 4) integration of research by a leader (Figure 2).

1.2.1 Common group learning.

In this organisational model the research output reflects the common intellectual property of the entire research group. After the problem definition, the research is divided into areas based upon the expertise and interest of the members of the research group. Subsequently, the input of the members is discussed and evaluated in the group and rewritten. This procedure is repeated until the team is satisfied. According to Rossini & Porter (1979), this type of research is only suitable when research teams are small and when there is a need for broad rather then deep research. Common group learning is being used for the interdisciplinary project of WU's North-South Centre on Global Food Availability (2004-2006). The INREF financed Convergence of science (COS) program shows elements of the common group-learning model as well. This project consists of a number of PhD students that combine sociological and agricultural methods in their studies. The specific methodology is the result of intensive debates between social and natural scientists, field trips and interdisciplinary workshops. The entire team formulated the goals, and these were changed radically during the program. PhD students performed diagnostical studies to adapt research questions to practice. However, reconfiguring the research took so much time that no resources were left for a proper integration of the distinct PhD projects. Therefore, the final product will be a selection of individual interdisciplinary PhD theses and articles instead of an integrated study.

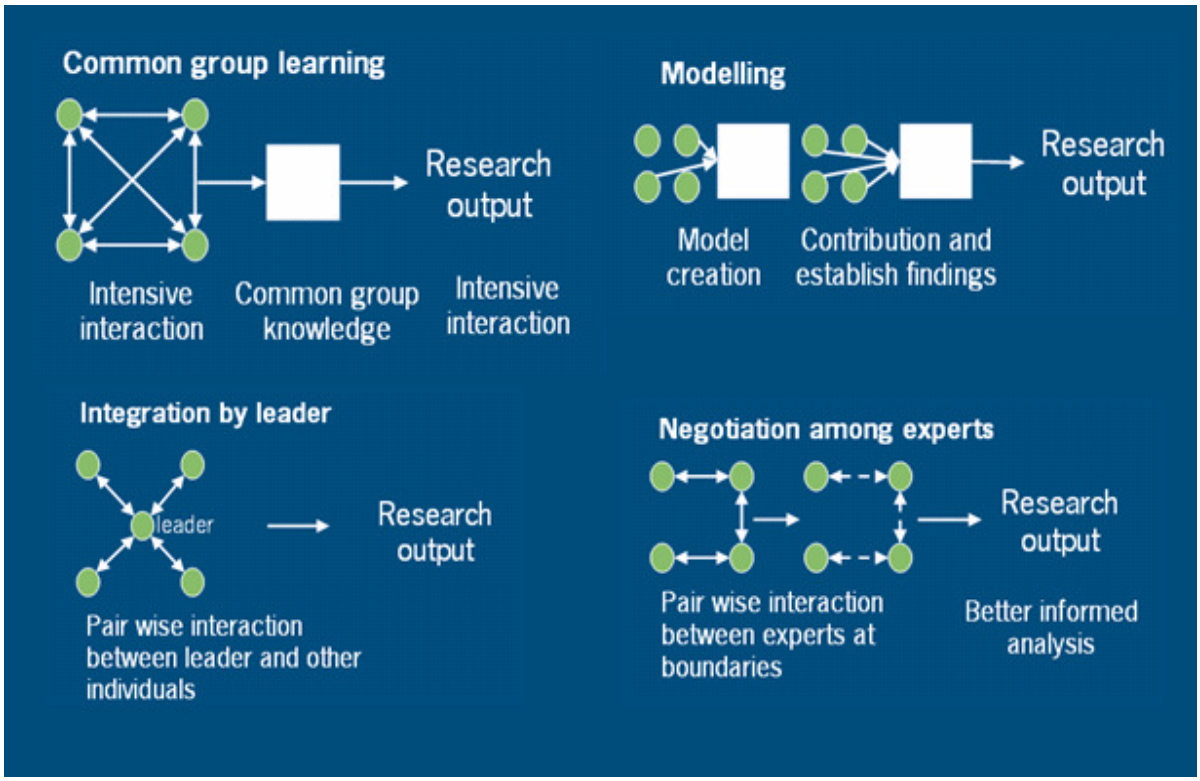

Figure 2Visualization of models of organisation of Rossini & Porter (1979)

1.2.2 Modelling

Another organisational approach is the combined scientific work on a model. An important drawback of modelling is that this technique can best be applied in a rather narrow range of closely related disciplines. None of the INREF projects used this form of organisation. The, predecessor of REPONSE, the sustainable land use program (DLV) can be considered as one. Interdisciplinary models should be transparent, understandable for all members, and rapid prototyping should be used (Nicolson et al, 2002). A major problem in the Wageningen context is that Wageningen sociologists dispute the validity of the system approaches that are often used for modelling agricultural systems. A possible solution is the use of models that combine valuable insights from the actor-oriented approach with system approaches like multi-agent modelling (Berger, 2001; An et al, 2005).

1.2.3 Negotiation among experts

In this organisational model the task division among the members of the team is based on their individual expertise. Integration takes place by negotiation between team members. This type of research is highly suitable for large studies with considerable depth. However, it can lead to less integration (Rossini & Porter, 1979). The INREF funded Agro-industrial transformations toward sustainability program (AGITS) is organized like this. The coordinator of this project told that the result of the program would be a set of loosely integrated, rather disciplinary reports (Table 5).

1.2.4 Integration of research by a leader

This organisational framework is considered effective for small research teams. The method is based on a division and allocation of parts of the problem based on members' expertise and later integration. Here, the multidisciplinary risk is clearly visible. The INREF funded programs POND, FNRHP and RESPONSE used this organisational model. Nonetheless, this was not without difficulties. The postdocs that were appointed by the POND and RESPONSE program quit, leaving their programs without an integrating force.

The question is, therefore, whether a postdoc is suitable for integrating such a research; this is further discussed under the paragraph when dealing with the roles of the team members. FNRHP has a part-time postdoc position, which project coordinators and supervisors experience as being insufficient for real integration. FNRHP tries to merge the set of disciplinary projects afterwards. As one of the FNRHP team members said, it is desirable to reserve money for such post research integration activities. Not one of the POND scientists thought there was real integration. One of them said they lacked the knowledge to design the integration of the program parts. Although the RESPONSE program had the same problem regarding the postdoc, involved scientists were more optimistic about the integration of the program. Experiences from the interdisciplinary DLV program might have created a better environment for integration.

Another organisational factor concerns the planning of the project. Main issues are that enough time is taken in the planning period of the program[2] and that program planning should be flexible and adaptive. A special feature in many Wageningen programs is the timing. Much design oriented research requires a chronological order; implying not all disciplines can start at the same moment. This problem can be tackled by increasing the length of the programs and by using planning tools, from industry, like network planning. Besides the social environment, shaping the right physical environment is also essential in IR. The same research area and the same research objects should be chosen. The latter was done in most projects but the first in none of them.

Table 1 Aggregate answers of supervisors and project coordinators

Questions	Yes	No	No response
Is your program interdisciplinary?	13	3	2
Did the programme influence your project?	8	6	4
Did the projects coalesce into one product?	5	10	3
Was your project interdisciplinary?	11	5	2
Should PhD students work interdisciplinary?	15	3	0
Would you like to do another IR?	17	1	0

Table 2 Perception of PhD students towards their project and IR

Answers of PhD students	Yes	No	No response
Do you think you are writing or have written an interdisciplinary PhD dissertation?	11	3	17
Can, according to you, interdisciplinary research be carried out by PhD students?	11	2	18
Is your PhD research influenced by interaction with the project coordinators	6	7	18
Is your PhD study influenced by interaction with other PhD students in the project?	9	5	17

In the organisation, the different team members have different tasks. Postdocs, supervisors, and PhD students are separately discussed. Most of the interviewed IR scientists draw attention on the importance of a good programme coordinator. While interviewing scientists involved in IR and reading literature, we collected a striking amount of qualifications that a team leader must possess to deal with the complexities of managing IR (box 1).

[2] According to Birnbaum (1977) there is however no relation between the amount of time spent on planning in a project and the calculated performance

Box 1: Fifteen points that might be included in an imaginary job description of a programme coordinator (from: interviews, Porter & Rossini (1986), Klein (1986), Zuckerman (1993), Uhrwing 2003))

1. Status as an established and respected person, with tenure in a university setting and full release time as well as support money
2. A person who can build bridges between disciplines
3. Bring people together in strange settings
4. Constantly ask questions to members of IR group
5. Create, indirectly a setting in which scientists see interdisciplinary project goals in line with their own goals, hence, you have to know the intrinsic goals of your project members
6. Be relatively free of own interests
7. Manager needs to be a figurehead. He / she has to be a networker
8. Manager needs to be a multi-tasker. He needs to deal with multiple parties, science and visa etc.
9. An energetic dedicated talented director
10. A strong leader
11. Previous interdisciplinary experience and some disciplinary /technological competence appropriate to team or program goals
12. Sensitivity towards different paradigms and disciplinary perspectives
13. A commitment to problem solving
14. Managerial skills for assembling and keeping personnel on schedule, getting to the core of a project's goals, serving as a liaison between personnel and funding agencies, setting and monitoring performance standards, performing public relations with other units of the university as well as external agencies/society
15. An enormous energy

There is disagreement about the question whether postdocs should be involved in this. Furthermore, there are different opinions about the characteristics of ideal postdocs and the amount of time they should be allowed to spend.

Box 2 Pros and cons of postdocs as leaders of interdisciplinary research projects

Postdoc sceptics (five interviewed scientists) state that postdoc positions are unsuitable for managing or integrating programs because of: a) the short term of postdoctoral positions (normally two years); b) a lack of incentives for the postdoc to stay when compared to a PhD student who has to finish his dissertation; c) postdocs are expensive when compared to PhD students.

Supporters of postdoc positions (13 scientists) argue that, postdocs that have enough feeling and experience in interdisciplinary projects are perfectly able to integrate the findings of individual subprojects into a consistent story. Most think that each program needs at least a full-time position, one scientist thought that there is a need for around 0.25 postdoc for each PhD position. According to the postdoc defenders, there is a need for a person with an overview. Professors do not have time for this, but postdoctoral students do. The risk that postdocs leave too early can be tackled by appointing them for four years.

There is a division between PhD students and senior scientists on the issues whether PhD students should perform interdisciplinary research (17 %) or not (83 %) (table 1 & table 2). Table 3 provides the reasons for this.

The sandwich PhD is a position that is relatively unique for Wageningen UR and forms the backbone of most INREF programs. Typically, a sandwich PhD student undertakes 6 months to a year of training in Wageningen, followed by (at least) two years of fieldwork in his/her home country. Subsequently, the rounding off phase and promotion is done in Wageningen. Advantages of the structure are: low costs because the PhD student only receives a salary when based in

Wageningen and it is a good way to train local scientists. Common heard criticism is that sandwich PhD students are underpaid both in their home country and in the Netherlands; that they do not receive enough supervision; that they lack infrastructure in their home country; and that they stay too long in their home country. Although, interviewed scientists state that nowadays they are keener on distance supervision, the sandwich PhD construction remains a point of attention.

Box 3: Pros and cons of interdisciplinary PhD students

Those that think PhD students should refrain from doing interdisciplinary research have the following arguments:
a) From a career perspective PhD students should focus on their own discipline because they have not yet established a reputation (Nicolson et al, 2002). Outside of education, a generalist training does not provide adequate 'expert knowledge' that is the norm in many specialist institutions (Acutt, 2000). Supervisors, indeed, observe that interdisciplinary work is not one of the personal goals of PhD students;
b) Most PhD students already lack disciplinary background in their own discipline;
c) IR can better be performed by staff members themselves;
d) PhD students cannot deal with the extra workload of IR;
e) Interdisciplinary projects have higher performance when most of the research team already possesses a PhD (Birnbaum, 1979);
f) Supervisors need more time for supervising interdisciplinary work.

Those who favour interdisciplinary PhD work do not deny the previous objections, but, claim that PhD students are easier to convince to work interdisciplinary. Some PhD students state that they are very able to work interdisciplinary because they are fresh and full of ideas. Interviewed Wageningen scientists mentioned that PhD studies will only be interdisciplinary when:
a) The questions are interdisciplinary right from the start;
b) PhD students are selected that like to work in a broad team;
c) The institute in the host country is able to supervise and conduct IR;
d) A shift can be made to put the PhD student on the disciplinary track, when IR fails;
e) It is possible to change the original research proposal during the research.

Recommendations

Overall, we noticed a serious lack of integration in most of the INREF programs. We suggest that future IR programs are more integrative when:

1. An appropriate organizational model is chosen;
2. Network planning techniques, like PERT, are used;
3. More attention is given to the appointment and selection of the project leader;
4. A common workplace for PhD students is created;
5. There is joint selection of the research area;
6. Money is reserved for post-program integration;
7. Resources are reserved for reconfiguration of the program.

When PhD projects are interdisciplinary, it is of crucial importance that:

1. Supervisors reach consensus on supervision in advance;
2. Supervisors ensure that the judgement committee is as interdisciplinary minded as possible;
3. There is a careful selection of PhD student;
4. In case of sandwich PhD there has to be:
    a) enough resources for supervisors to visit PhD student in their home country;
    b) enough facilities at the home institute.

1.3 Societal and scientific outputs

The third ring is scientific and societal output. This ring includes questions like what is the relevance of interdisciplinary research to society. What is the effect of IR on scientific quality and the amount of high rating publications? What are the benefits of IR for the host institute? Table 7 shows the major costs and benefits mentioned by the interviewed. Major costs are the extra time needed and the less or lower rated publications. Greatest benefit is believed to be that the acquired knowledge is more useful to society.

Table 3: Major costs & benefits of interdisciplinary research as perceived by researchers involved in INREF programs (n=18)

Costs		Benefits	
Costs more time than disciplinary work	13	Knowledge more relevant to society	14
Less or lower rated publications	11	You learn new things	5
		Chance on a scientific breakthrough	2
		Better education for students	2
		It is a lot of fun	2
		Through IR you can join top institutes	2

The problems surrounding publishing of interdisciplinary research can be relaxed in two ways. First, by appointing an experienced, eloquent leader that can function as lead author of outgoing interdisciplinary articles. Secondly, by using a code of conduct about sharing data from the start of a programme.

1.4 External factors

The outer ring of the framework includes the different external factors influencing all phases of IR. For instance several characteristics of Wageningen University Graduate Schools obstruct interdisciplinary research, because:

1) They are organized along disciplinary lines;
2) They are unable to assess the value of IR proposals, which are therefore often rejected;
3) They only limitedly allow students to extend their PhD.

Therefore, we recommend that Wageningen Graduate Schools cooperate in finding ways to assess interdisciplinary, inter-graduate school research and by composing assessment committees that are able to evaluate interdisciplinary proposals. Furthermore, the lobby for interdisciplinary research has been too top-down in Wageningen. Pro IR propaganda from headquarters caused widespread criticism against it at lower levels of the hierarchy. On the other hand, central policy on output payment gives a strong incentive for researchers to work disciplinary. We propose to attach a higher value to lower ranking, but societal relevant interdisciplinary publications. Interdisciplinary research in a broader sense is only possible in cooperation with other universities. New ways will have to be found to facilitate and finance inter-university IR.

Researchers from participating institutes in the South should play a bigger role in the problem definition of the research. This can be done by appointing a project leader from one of the foreign countries involved and by looking for (co-)funding from the participating countries in the south.

1.5 Problem-Strategy matrix

We summarized the problems and subsequent strategies that followed from literature review, interviews, and experience in the field of Terra Preta in a problem-strategy matrix which is shown in Table 11. This table locates strategies for some of the problems.

Table 4 Problem (left)-strategy (up) matrix

Problems	Strategies	Read each others work	Learn about each others methods	Use analogies	Use new statistical methods for integration	Use an integrating framework	Combine theories on different levels	Make time for joint planning	Publish articles on the integrative frame/outcomes	Invest time in collegiality	Choose the right model for the organisation	Do diagnostical studies	Do some rapid prototyping	Appoint a leader for the full-time of the project	Reserve time and money for post program integration	Build in more flexibility in the planning of the project	Have adaptive management	Choose the same research site/object	Choose the same office	Appoint full-time prof. for IR project	Tuning between supervisors	Select team member with understanding of IR	Have careful selection of the foreign institute	Have sandwich PhD students come back more often	Appoint lead editor	Have supervisors regularly visit location	Check local funds for co-financing	Map and check incentives of participants
Research culture	Divide between qualitative and quantitive research		x		x	x							x															
	Incompatibility deductive and inductive research		x		x	x																						
	Having wrong perceptions of other disciplines	x	x							x									x									
	Competing explanations		x		x		x					x	x															
	Lack of common goals			x		x		x	x			x							x	x								x
	Language problems between disciplines	x	x	x				x		x									x									
Organisational methods	Lack of integration			x	x	x		x	x		x			x	x			x	x	x		x						
	Uncertainty about the research direction								x			x	x		x	x	x					x				x		
	Continuity of the leadership and coordination													x						x								
	Projects run out of phase							x			x					x												
	More supervisors confuses the PhD student							x		x											x							
	Foreign PhD is often disciplinary															x						x				x		
	Lack of supervision for sandwich PhD																					x		x		x		
Scient. output	Difficulties publishing in high ranking articles				x				x											x					x			
External factors	Problems with immigration service															x												
	Lack of facilities sandwich PhD in home country															x								x				
	Little influence of foreign researchers																							x			x	

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1 Introduction

Interdisciplinary research is part of the so-called Wageningen approach. In the official vision of Wageningen, interdisciplinary means collaboration between the arts, the natural and social sciences (Klep, 2003). Wageningen has a long history in doing international interdisciplinary research. In the international context, it started when different support offices were founded in Turkey, Ivory Coast, Surinam, Indonesia, Burkina Faso (1992) and Costa Rica (1986). Here different research was undertaken, very often together with local researchers. It was in this setting that researchers from distinct disciplines started working together on issues regarding the use of natural resources. Some of the projects were interdisciplinary from the start like the Wageningen-Indonesian project INRES at Malang, Indonesia.
In the mean time, Wageningen scientists were involved as well in the Foundation for Global Food Supply Research that was initiated in 1977 and based in Amsterdam. In this foundation, Wageningen agronomists worked together with economists to find ways for increasing food security worldwide. This cooperation inspired the Sustainable Land Use Programme (DLV), which combined economical and agronomical modelling efforts in tools that were usable for policy makers. Another interdisciplinary initiative is the Wageningen Centre for Food Sciences in which the university works together with the food industry to design new food products. The design process is highly interdisciplinary and involves among others psychology, chemistry, nutrition. The examples given are just a small selection of the interdisciplinary history of Wageningen University; other examples include the Northern Frisian Forest project.
In 1999, the support centres in the different countries were dismantled, because of changing views on research in development countries. The funds were re-located to INREF. INREF is the development oriented Interdisciplinary Research and Education Fund of Wageningen University. INREF funds interdisciplinary research programs designed by Wageningen scientists that are problem oriented and strive for strengthening the institutional and human research, development and education capacity in the South, and developing new interdisciplinary and participatory approaches by creating an enabling learning environment. Currently there are six INREF programs running and four starting up.

This report focuses on interdisciplinary research in the international context concentrated on the field of the management of natural resources. When speaking about interdisciplinary research we mean a kind of investigation that involves multiple branches of learning. An important feature of interdisciplinary research is that the result is a real fusion of disciplines and not a loose collection of disciplinary studies.

This research is strongly directed at the situation at Wageningen University (WU) in the Netherlands. At Wageningen University, PhD students perform most of the research. A PhD study at Wageningen takes four years of which maximally one year is used for following courses. Most of the research on issues important for development countries is done by sandwich PhD

students. Sandwich PhD students are non-Dutch students that spent the majority of their research time in their home country and one or two years in the Netherlands. In general, they are in the Netherlands at the beginning and in the end of their study. However, some students may come three or four times to the Netherlands as well. The majority of the students are employed by a university or research institute in their home country.
Wageningen University started as an agricultural university. It possesses only one faculty. Most of the scientists are natural scientists but there are significant groups of social scientists as well. Wageningen University is widely known for its applied science for agriculture, water management, food safety etc., rather than its fundamental science.
In Wageningen, interdisciplinary research has been widely used for problem-oriented studies that a single discipline alone could not solve. Society and policy makers demand science that is applicable for them. Interdisciplinarity facilitates the development of more applicable science tailored to the needs of users or stakeholders. Non-surprisingly, research programs that are funded by governmental bodies like the European Union or ministries are mostly interdisciplinary.
Besides that, IR is used to tackle complex multidimensional problems. Many issues in the field of natural research management are multidimensional. Water use for example has a hydrological dimension (water capture), a public hygiene aspect (the supply of drinking water) an agronomic dimension (crop water use) and so fort. Do deal with this kind of multidimensional problems an interdisciplinary approach is required. (Westley et al, 2002; Booth et al, 2001; Nissani, 1997; Janssen & Goldsworthy, 1995).

Although, in general, the desirability of interdisciplinary research (IR) has been widely acknowledged, the methods of interdisciplinary collaboration generally remain undescribed (Robertson et al, 2003). Besides this, 'real' interdisciplinary research itself, even if it is the mantra of science policy, is far away from common sense (Silitoe, 2005; Rossini & Porter, 1979). In many cases interdisciplinary research projects end up being a set of separate disciplinary studies, which are more easily manageable and less time consuming. When planning a project in which multiple international research agencies are about to work together the incentive of dividing the work in disciplinary work packages is even greater. This is worrying, because for the understanding and sustainable management of coupled human-natural systems, like the agricultural system of the Amazon, real integration of social and natural sciences is needed.

Therefore, the main objective of this thesis work is to develop a framework for multi-organizational, international, interdisciplinary research in the field of management of natural resources. The research uses the INREF (Interdisciplinary Research and Education Fund of Wageningen-UR) Seed Money project on Terra Preta as case study, the vast amount of literature in the field of IR and the personal experiences of the participants in five large-scale INREF programs.

In developing such a framework the following questions and sub-questions are of vital importance:

What are the problems and opportunities of interdisciplinary research and how can these be managed?

c) What problems and opportunities of interdisciplinary research have been described in the literature?
d) What problems and opportunities of interdisciplinary research have been experienced by the managers, supervisors and PhD students involved in INREF-projects?
e) What problems opportunities for interdisciplinary research were found during the Terra Preta INREF seed money project?
f) What is a suitable framework for assessing IR?

Some other issues are not unique to IR, but are crucial in designing international research projects in general. Questions like that include: how can knowledge gaps be assessed? How can future international co-researchers are best selected and motivated? What are suitable design criteria for the research project? What are appropriate ways to find funding for the project? In the Terra Preta case study, attention is given to these issues.

In our attempt to answer the research questions we focussed especially on IRR in the field of natural resource management and concentrated on the context of Wageningen University.

The next chapter will describe the methodology used to find answers to these questions. Chapter 3 describes the results from the literature research and the interviews, while in chapter 4 the results from the Terra Preta Case study will be given.

2 Methodology

Three methods were used for answering the research questions: a literature review, interviews with Wageningen scientists and finally a case study.

2.1 Literature research & interviews

First, the general literature on interdisciplinary research was studied. Secondly, we collected information through semi-structured interviews with 24 managers, PhD supervisors and PhD students of the first round of programs funded by INREF. The following projects have been included: Optimisation of nutrient dynamics and animals for integrated farming (POND); Agro-industrial transformations towards sustainability (AGITS); Healthy People: Food-based interventions to alleviate micronutrient malnutrition (FNRHP); Convergence of science (COS); Regional food security policies for natural resource management and sustainable economies (RESPONSE). To complete the dataset, an e-mail survey was held among all PhD students involved in the different projects. The interview and survey questions of the different participants are shown in Appendix 10 and the list of participants are added as Appendix 11.

Secondly, all data collected in the interviews, surveys and literature review was analyzed. We did this by grouping and regrouping the gathered data during discussion sessions. We decided to merge the information from interviews and the literature into one chapter.

This was done in order to compare and combine Wageningen experiences on IR with results from the literature. We propose that this is a suitable way to present a combination of tacit and explicit knowledge in one story. We are fully aware that this is a risky approach because the data sources are not of the same kind and because a mix of information from literature and interviews might confuse the reader and dilute the message. Furthermore, data from interviews might not always be comparable with literature as the interview data are very context bound. Therefore, we tried to sort the information in a way that minimized the threats described above. In each section, we firstly provide general information from the literature, followed by more anecdotic views from the literature and thirdly we provide insights from interviewed Wageningen scientists.

The information obtained from literature and interviews was grouped in order to build an analytical framework (see chapter 3). The framework was of great use in structuring the gathered information on problems and opportunities of interdisciplinary research as well as the conclusions.

Chapter 3 presents the results of the activities described above.

2.2 The case study

We used the INREF Seed Money project on Terra Preta (Appendix 1 and 12) as a case study for designing a research project in the field of management of natural resources. Chapter 4 provides the results of the case study. The case study was used to find new heuristics for doing IIR and to compare the findings of the interviews and the literature research with our own experience. Furthermore, the case study was used to consider some issues that are not specific for IR, but are crucial in designing (international) research projects in general.

Designing a research includes the search for the right balance between 1) knowledge gaps; 2) interests and capabilities of the research team; and 3) design criteria and possibilities and conditions for funding (after: Klein, 1990) (Figure 5). Therefore, we first describe how the relevant knowledge gaps were identified, followed by a description of the way human capital needed to fill in these gaps. Subsequently, fund-determining activities are mentioned shortly. Lastly, attention is paid to the integration of the previous points into a number of research proposals.

2.2.1 Identifying relevant knowledge gaps

We have identified all relevant gaps in our understanding of Terra Preta. We did this by reviewing the existing literature on Terra Preta and interviewing the scientists currently involved in Terra Preta research. As research in Terra Preta is rather new, a substantial amount of data is still unpublished. Interviews with scientists currently involved in TP research provided major insights in the most recent results of today's research and in the future research agenda of the stakeholders. Thirdly, a prototype model of the main nutrient and carbon fluxes on village level was constructed using existing data on Terra Preta (appendix 2). Prototype modelling is a proven tool for identify knowledge gaps (Nicolson et al, 2001).

2.2.2 Selecting scientific capital for filling holes in knowledge

The second part of the design of a research in the field of management of natural resources deals with how future research teams are best selected and motivated. The aim is the composition of an international, interdisciplinary research team.

First, we developed a format for a database (MS Access) in which information of all potential stakeholders could be included (Appendix 3). In this framework the expertise, research interests, current research activities, experience in interdisciplinary projects, incentives for collaboration and access to funding of the potential partners was mapped and afterwards critically evaluated. Because trust between stakeholders can be influenced by past joint activities, we have aimed at identifying the major bottlenecks in trust relations between stakeholders. Joint international research projects can be seriously jeopardized by, among others, bio-piracy regulations that prohibit the export of living materials like soil samples, plants and animals from some countries. The information needed to address these different issues was all obtained during interviews with the potential participants. Finally, the data were used to compose an exhaustive list of the possible participants (Appendix 4) which provided the required information about the potential participants in the future research.

2.2.3 Design criteria and funds

The third part of the design deals with the identification of potential funds and their conditions. It is very important to know which part of the research is eligible for funding. Some grants only fund sandwich PhD positions while others will only fund equipment for universities in Latin American countries. Information on funds was obtained from funds themselves and through

participants or informants. The information about potentially useful funds is summarized and discussed in chapter 4.

Funds, but as well participating institutions and team members often impose certain design criteria to the research program. Possible criteria include effectiveness of the research, scientific depth, internal coherence, efficiency, novelty creation, poverty alleviation, sustainability. We investigated views on design criteria of the funds and potential research team members.

2.2.4 Integration

In the final part of the design, the information about funds, potential participants and knowledge gaps was integrated. This was done by carefully comparing and matching the three components. First, an overview of possible projects was made based on the knowledge gaps and potential cooperating institutions. Then the rough research plans were filtered and combined based on fundability of the proposals, design criteria of funds and potential research team members, and of course on the available knowledge in Wageningen.

3 Results from literature research and interviews

This chapter provides the analysis of the information gathered in literature and interviews of the first round of INREF projects. First, we will give a short overview of the definitions of interdisciplinary research (IR). Secondly, we introduce the IR framework. Paragraphs 3.2 to 3.5 further clarify the contents of the framework.

3.1 Definitions and framework of IR

"Interdisciplinary research is over-defined and there is a lot of fake IR.", sighed one of the interviewed scientists. Indeed, all interviewed scientists used another definition of IR apart from those that could not provide one. This does not imply, however, that Wageningen researchers are speaking about completely different things. Most researchers define IR as a kind of research in which several disciplines work jointly on one theme. Others do not disagree with this viewpoint but add a certain *need* to work interdisciplinary in order to reach a high scientific level, added value or to solve societal problems. A natural scientist stated that IR is impossible in research groups because the boundaries of the disciplines will never fade away within an interdisciplinary team. A social scientist provided a more pluralistic view in which the definition of IR varied from occasion to occasion. As made clear before, we define IR as a kind of investigation that involves multiple branches of learning. An important feature of interdisciplinary research is that the result is a real fusion of disciplines and not a loose collection of disciplinary studies.

Defining IR is only the start. The goal of this research is to develop a framework for multi-organizational, international, IR in the field of management of natural resources. As mentioned in the second bullet of the methodology all data were analyzed and grouped during discussion sessions. After this process, we developed a framework describing the problems and opportunities of IR. Figure 3 gives a graphical representation of our framework.

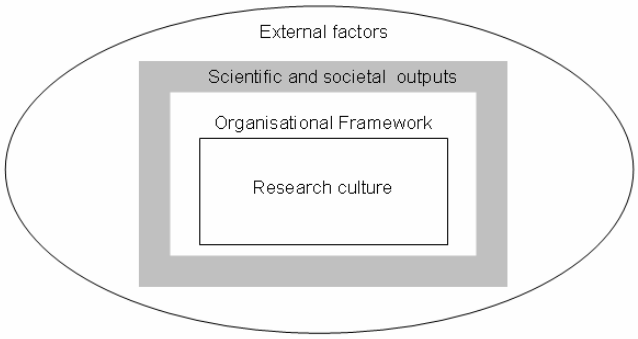

Figure 3: Framework for interdisciplinary research

The framework consists of four parts. The inner core forms the research culture. It draws on the differences in methods and methodology, goals, language and culture. These may be seen as the traffic rules of IR. The second ring is the organisational framework and contains organizational models for establishing IR. The organisational model of an IR program can be considered as the infrastructure. It determines the way the research is structured, the division of tasks and the planning in time and space. The third ring is (scientific and societal) output. This ring includes questions like what is the relevance of interdisciplinary research to society. What is the effect of IR on scientific quality and the amount of publication? What are the benefits of IR for the host institute? The outer ring of the external factors includes different factors influencing all phases of IR. The different parts of the framework will be further reflected upon in the upcoming four paragraphs.

3.2 Research culture

According to Mar et al (1976), "Disciplines have inherent intolerance of disciplines". Scientists have to overcome differences in research culture when performing an interdisciplinary research. This paragraph discusses problems that arise from differences in methodology, language, and tradition.

3.2.1 Methodology

This section deals with differences in methodology of disciplines. The first part provides the main problems and the second provides possible strategies to solve those problems. This section first describes the problems that arise from clashes between quantitative and qualitative approaches; subsequently attention is given to the difference between inductive and deductive approaches and its impact on IR. This is followed by an overview of difficulties in IR that are caused by so-called competing explanations of two or more disciplines. Lastly, we focus on misperceptions on other disciplines. After specifying the problems, some strategies are provided to cope with the problems provided earlier, like finding common goals and the use of new statistical methods.

3.2.1.1 Perceived methodological problems

3.2.1.1.1 Quantitative and qualitative science

Quantitive research relies on measuring variables and comparing groups on those variables, or examining the strength of the relationship between two or more variables. Paramount in this research is objectivity in the data collection process. Repeating such a quantitive study, using the same instruments and methods would yield approximately the same figures. Qualitative research use approaches that are more subjective and frequently use interviews, focus groups, or single case designs, that lack objective measurement and are less general.

Some disciplines (e.g. some fields in sociology, anthropology) use more qualitative methods while others are more inclined to use quantitative methods (e.g. economics, chemistry).

According to a diverse group of supervisors, cooperation between disciplines that use quantitative methods (e.g. plant sciences and economics) is easier than between 'quantitive' and 'qualitive' disciplines. Some even indicate that the methodological gap between these approaches is too big to be bridged. Although there are quantitive fields within sociology, most sociologists working at Wageningen University are a qualitative worker, which makes collaboration between natural and social sciences more complicated.

3.2.1.1.2 Inductive or deductive science

Deductive reasoning works from the more general to the more specific. It starts with inventing a theory, and then this theory is narrowed in a testable hypothesis. Based on the hypothesis a test can be designed of which the outcome can be used justify the proposed hypothesis and theory. In inductive research, on the other hand, scientists move from specific observations to broader generalizations and theories by using pattern recognition etcetera.
As interdisciplinary research is relatively new, there is a lack of interdisciplinary theories. Therefore, IR needs inductive approaches to build a common theory based on interdisciplinary observations. Most natural scientists are not trained in doing inductive research, which causes problems in doing IR (Picket et all., 1999). Interviewed scientists recognized this problem.

3.2.1.1.3 Competing explanations

Another problem occurs when disciplines are rather similar and use competing explanations to define the same problem. Competing explanations hinder the selection of a common set of values and variables because each sub-discipline within the social sciences considers other drivers to be the most important (LéLé & Norgaard, 2005). Competing explanations, according to some of our informants and LéLé & Norgaard (2005) make sociological-economical cooperation more difficult than e.g. sociological-plant science cooperation. This does not mean however, that competing explanations do not exist in the natural sciences, but as an interviewed economist remarked "natural scientists do not make a war about them." Methodological clashes within natural sciences include mismatching taxonomies like the FAO and USDA soil classifications (LéLé & Norgaard, 2005).

3.2.1.1.4 Perceptions on the other discipline

Misperceptions of one discipline to the other are a source of misunderstanding in interdisciplinary working. First, disciplines have misperceptions about the questions that can be answered by other disciplines and second, they possess wrong prejudices about the methodology of the other discipline (Campbell, 2005).

3.2.1.2 Solutions for methodological problems

3.2.1.2.1 Learn about the other discipline's approaches

Campbell (2005), among others, stresses the importance of reading some of the literature of the other disciplines as an option to avoid problems when working together. The majority of interviewed scientists agreed on this. Phrases like: "You should become a BSc-student of the other discipline and gain understanding of the other discipline's methods and methodologies" and

"I had to read the book of Norman Long first before I understood Wageningen sociologists" were often heard during interviews.

3.2.1.2.2 Find common goals

According to a PhD-supervisor, creating common goals is of importance for a successful interdisciplinary project. The importance of this is shown by Wächter (2003) who found that a lack of common goals was the main reason for the deficiency of integration of 27 German IR programs. Furthermore, Hollaender (2003) found that joint questions and goals were found most important in an evaluation under 254 scientists. Finding common goals can be the help in overcoming conflicts in methodology (Picket et al., 1999)

Tools for creating common goals include the use of hierarchies of models and theories and searching for analogies between different (competing) theories (ibid). Common goals require: 1) strong investment in problem definition early in the project (Nicolson et al, 2004); 2) use common rather than translated and merged problem definitions (Pickett et al. 1999). Furthermore, Pickett et al (1999) add that making a joint conceptual framework can be rewarding by publishing the newly found concepts.

With respect to Wageningen, the majority of the interviewed scientists think that common goals are very important in performing interdisciplinary research. However, around half of the interviewed scientists thought that the program goals were insufficiently discussed during the planning of the project. This can partly have caused the lack of integration of the programs, 10 out of 18 interviewed scientists said that the subprojects of the programme did not coalesce. The COS programme changed their goals drastically during the program, the scientists involved published a special NJAS issue on the process. (NJAS volume 52 number 3-4). Most Wageningen scientists came up with the following strategy to force participants to keep thinking on the common goals: organize at least yearly workshops in which PhD students, and senior staff participates and formulate questions for each other. Although, all INREF programs organized such workshops the majority of researchers stated that not enough workshops were organized.

3.2.1.2.3 Coping with competing explanations

A potential strategy to deal with competing explanations can be to consider all explanations true, but some are truer for different situations and scale. Keeping this in mind, one can shop around and pick the theories needed (LéLé & Norgaard, 2005). There are for example some frameworks for combining sociological with economic approaches, for example as described by Siegers (1992). Mazucatto (1997) provided two ways to bridge the gap between anthropologist and economist while doing research after indigenous populations. Such frameworks, although scarce can be used to find common ground.

3.2.2 Jargon language

Different disciplines have a very strong tendency to use their own vocabulary and concepts. This may cause serious problems when discussing an interdisciplinary problem. Therefore, there needs to be a consistent theory or common conceptual framework to make communication

between disciplines possible and to integrate the different disciplines (Butler 1999; Naiman, 1999). The main solution for solving this problem is taking time for collegiality and understanding (Campbell, 2005; Mar et al, 1976).
The problem of language was another issue mentioned by almost all informants even between neighbouring disciplines. Wageningen scientists mentioned reading its others work and asking each other questions as main solutions.

3.2.3 Culture, values en norms

Some cultural differences are historical, like the fact that social scientists write longer articles. These are not accepted in for example NJAS which is regretted by one of the interviewed sociologists.
The form of the dissertation is another 'cultural' issue influencing the possibility of co-operation between the disciplines. Sociologists and anthropologists generally write longer PhD theses. More and more economists and natural scientists prefer to base their dissertation on peer reviewed articles. When looking at potential solution for these issues, no real management options have been mentioned.

3.3 Organisational framework

If methodology and research culture are the traffic rules, the organisational framework is the infrastructure of an IR program. The organisational framework determines the way the research is structured, the division of tasks, and the planning in time and space. Firstly, a theory of structuring IR is provided and applied to some IR programs; secondly, features regarding the planning and timing of IR programs are discussed; thirdly, attention is given to the distinct roles of scientists involved in IR programs.

3.3.1 Models of organisation

Rossini & Porter (1979) provided a comprehensive overview for the organisation of interdisciplinary research based on 24 observations. They presented four ideal types of integrating such a research: 1) common group learning; 2) modelling; 3) negotiation among experts; and 4) integration of research by a leader.

3.3.1.1 Common group learning.

In this organisational model, the research output reflects the common intellectual property of the entire research group. After the problem definition, the research is divided into areas based on the expertise and interest of the members of the research group. Subsequently, the input of the members is discussed and evaluated in the group and rewritten. This procedure is repeated until the team is satisfied. According to Rossini & Porter (1979), this type of research is only suitable when research teams are small and when there is a need for broad rather then deep research. This type of research is being used for the interdisciplinary project of Wageningen University's North-South Centre on Global Food Availability in 2004/2005. The INREF-financed Convergence of science (COS) program shows elements of the common group learning model as well. This

project consists of a number of PhD students that combine sociological and agricultural methods in their studies. The specific methodology is the result of intensive debates between social and natural scientists, field trips and interdisciplinary workshops. The entire team formulated goals, and changed these radically during the program. PhD students performed diagnostical studies to adapt research questions to practice. Reconfiguring the research took so much time that no resources are left for a proper integration of the distinct PhD project, therefore the final product will be a selection of individual interdisciplinary PhD theses is and articles instead of an integrated study.

3.3.1.2 Modelling

Another organisational approach is the combined scientific work on a model. An important drawback of modelling is that this technique can best be applied in a rather narrow range of closely related disciplines. The Sustainable Land Use and Food program (DLV) and the Wageningen based NUANCES project on soil fertility are good examples of this organisational model, as is the proposed research on nutrient balances in Appendix 6.

The development of a model, based on systems theory, is an excellent way of combining quantitatively oriented disciplines. The identified solutions can be researched by single disciplines but the model approach guarantees that this research is relevant to the problem and that it can be evaluated about the overall problem (Janssen & Goldsworthy, 1995). An economist and agronomist mentioned that working with models is unsuitable when working together with Wageningen sociologists.

Nicolson et al (2002) provide a number of issues that have to be kept in mind when designing an interdisciplinary program around a model. First, the models should be transparent and simple to understand. Therefore, it is recommended to work with comprehensible spreadsheet models rather than with complex C or FORTRAN models. In all cases comprehensibility and validity increases when loose coupling of sub-models is used instead of creating one integrated model. Furthermore, rapid prototyping of the models is necessary to adapt the models quickly and to be able to submit the current understanding to stakeholders or experts. However, building a prototype model in the beginning of the process requires creativity and intuition (Janssen & Goldsworthy, 1995).

A major problem in the Wageningen context is that Wageningen sociologists dispute the validity of the system approaches that are often used for modelling agricultural systems (Slingerland, personal communication). A possible solution for this is the use of models that may combine valuable insights from the actor-oriented approach with system approaches like multiple agents modelling (Berger 2001; An et al, 2005).

3.3.1.3 Negotiation among experts

This is a multidisciplinary rather than an interdisciplinary organisational model in which the task division among the members of the team is based on their individual background. Integration should take place by negotiation between team members. This type of research is highly suitable for large studies at considerable depth. However, it can lead to multidisciplinary rather than interdisciplinary integration (Rossini & Porter, 1979). The INREF funded Agro-industrial

transformations toward sustainability program (AGITS) is organized like this. The coordinator of this project told that the result of the program would be a set of loosely integrated, rather disciplinary reports (Table 5).

3.3.1.4 Integration of research by a leader

This organisational framework is considered effective for small research teams. This method is based on a division and allocation of parts of the problem based on member's expertise and later on integration. Here the multidisciplinary risk is also present. The INREF funded programs Optimisation of nutrient dynamics and animals for integrated farming (POND), from natural resources to healthy people: food-based interventions to alleviate micronutrient malnutrition (FNRHP) and Regional food security policies for natural resource management and sustainable economies (RESPONSE) used this organisational model. Nonetheless, this was not without difficulties. The postdocs that were appointed by the POND and the RESPONSE program quit, leaving their programs without an integrating force. The question is therefore whether a postdoc is suitable for integrating such a research; this is further discussed under the paragraph when handling the rolls of the team members. FNRHP has a part time post-doc position, which project coordinators and supervisors experience as being insufficient for real integration. FNRHP tries to merge information of the set of disciplinary projects afterwards. As one of the FNRHP team members said, it is recommendable to reserve money for such post research integrating activities. Researchers from POND state that there should first be some disciplinary PhD projects that generate disciplinary data that are later on used by other PhD students to make the knowledge applicable.

No one of the POND scientists thought there was real integration; one of them said they lacked the knowledge to design the integration of the several program parts. Although the RESPONSE program had the same problem regarding the postdoc, involved scientists were more optimistic about the integration of the program. Experiences from the interdisciplinary DLV program, on which the RESPONSE program is based, might have created a better environment for integration.

3.3.2 Planning of the project

Joint Planning was found the third most important aspect in an evaluation under 254 German scientists involved in IR (Hollaender, 2003). The initial phase of interdisciplinary projects is often unstable and unproductive and may take up to a year. According to Mar et al (1976) this can only be overcome by investing more time and resources in this phase. Just a year later, while evaluating 104 interdisciplinary research projects, Birnbaum (1977) found that the time spent on

planning by the leader was correlated with the performance[3] of the program (Birnbaum, 1977). Birnbaum is contradicted by Naiman (1999), Pickett et al (1999) and Janssen and Goldsworthy (1995) who all state that more time should be taken for the group process.
Furthermore, as a conceptual framework for IR is often lacking, adaptive management is required according to Turner & Carpenter (1999).
The majority of the interviewed scientists in Wageningen state that much time is needed to understand and to get to know the other persons and disciplines in the first phases of the research design. In all phases, IR teams should jointly solve problems and be adaptive, because, according to one project coordinator, "walking against a wall is a normal part of the IR process".

3.3.2.1 Timing

A special feature of many Wageningen interdisciplinary programs is timing. Much design-oriented research requires a chronological order of doing things, implying not all disciplines can start at the same moment. Ideally, research programs should therefore be spread in a time span of around six years instead of the usual four years. Now, this is not possible. Another issue regarding timing is that the nature of the research of the separate program parts inhibits meetings in which all researchers come together. E.g. while one researcher is in the analysis phase, it might be the best moment for another researcher to do field work. This seriously jeopardizes 'cross-fertilization' between the program's subprojects. A tool that has been proven useful in planning the chronosequence of large projects is network planning.
The US navy and DuPont ™ delivered tools that can be useful in research project planning. The Program Evaluation and Review Technique (PERT) can be a useful tool in planning the chronosequence of large research programs. The technique, originally developed by the US navy, is principally a tool for analyzing the tasks involved in completing a given project, especially the time needed to complete each task, and identifying the minimum time needed to complete the total project.

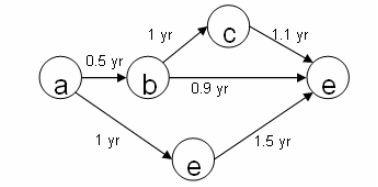

Figure 4 Pert Network Chart for a project with five milestones (circles) and six activities (arrows)

[3] Performance is here a factor score composed of group members average perception of effectiveness, a factor score composed of three in-process predictors of performance, and indicator of the project's goal attainment.

In the mean time, DuPont developed the critical path method (CPM). The critical path is the sequence of the project network elements with the longest duration (a, b, c, e in Figure 4). Logically the duration of the critical path determines the duration of the project (Malcolm et. al. 1959).

3.3.2.2 Physical environment

Besides the human environment, shaping the right physical environment is essential in IR. Sharing the same working environment can help in doing IR (Picett et al. (1999).
As far as Wageningen UR is concerned, interviewed scientists mentioned that the same research area and the same research objects should be chosen. In the INREF programs however, this was not always done. Three interviewed scientists thought it would be beneficial when PhD students work together in the same place, in that case, they argued, they will have better working conditions than disciplinary PhD students will. Although tried once, INREF funded PhD students were never placed in the same office.

3.3.3 Roles of different team members

Depending on the chosen organisational model, there are several roles to play in an interdisciplinary team. We do not want to focus on how teamwork in universities can best be performed but moreover on the necessities of an interdisciplinary research team. We distinguish the following functions: project leaders, senior scientists, postdocs and PhD students.

3.3.3.1 Project leaders

Birnbaum (1979) found that projects that have higher performance are said to be led by managers who organize the work, define roles, create communication channels, and stimulate mutual trust, friendship, support and respect. Most of the interviewed IR scientists draw attention on the importance of a good manager. Besides that management and moderation was found second most important in an evaluation under 254 German scientists (Hollaender, 2003).

Box 1: Fifteen points that might be included in an imaginary job description (from: interviews, Zuckerman (1993), Uhrwing 2003, Klein (1986), Porter & Rossini (1986))

1. Status as an established and respected person, with tenure in a university setting and full release time as well as support money
2. A person who can build the bridges between the disciplines
3. Bring people together in strange settings
4. Constantly ask questions to members of IR group
5. Create, indirectly a setting in which scientists see interdisciplinary project goals in line with their own goals, so you have to know the intrinsic goals of your project members
6. Be relatively free of own interests
7. Manager needs to be a figurehead. He / she has to be a networker and a contact maker.
8. Manager needs to be a multi-tasker. He needs to deal with multiple parties, immigration etc. and science
9. An energetic dedicated talented director
10. A strong leader
11. Previous interdisciplinary experience and some disciplinary /technological competence appropriate to team or program goals

12. Sensitivity toward different paradigms an disciplinary perspectives
13. A commitment to problem solving
14. Managerial skills for assembling and keeping personnel on schedule, getting to the core of a project's goals, serving as a liaison between personnel and funding agencies, setting and monitoring performance standards, performing public relations with other units of the university as well as external agencies/society
15. An enormous energy

While interviewing scientists involved in IR and reading literature, we collected a striking amount of qualifications that a team leader must possess to deal with the complexities of managing IR (box 1).

Not surprisingly, one of the interviewed scientists thought that there are only three persons capable of managing interdisciplinary programs at Wageningen University. One program leader put the importance of a manager in perspective by saying that the more the manager does, the less the team does itself. Few PhD students indicate that their research is influenced by the project co-ordinator (Table 6), which illustrates the relative authority of INREF programme coordinators.

Table 5 Aggregate answers of supervisors and project coordinators

Questions	Yes	No	No response
Is your program interdisciplinary?	13	3	2
Did the programme influence your project?	8	6	4
Did the projects coalesce into one product?	5	10	3
Was your project interdisciplinary?	11	5	2
Should PhD students work interdisciplinary?	15	3	0
Would you like to do another IR?	17	1	0

Table 6 Perception of PhD students towards their project and IR

Answers of PhD students	Yes	No	NR
Do you think you are writing or have written an interdisciplinary PhD dissertation?	11	3	17
Can, according to you, interdisciplinary research be carried out by PhD students?	11	2	18
Is your PhD research influenced by interaction with the project coordinators	6	7	18
Is your PhD study influenced by interaction with other PhD students in the project?	9	5	17

3.3.3.2 Senior scientists

Senior scientists play multiple roles in interdisciplinary programs. They can be leaders, researchers and supervisors of postdocs, PhD and MSc students. Here we will focus on their role

as supervisors of PhD-students that work on interdisciplinary research. This implies that the PhD student has at least two supervisors. Although very relevant in Wageningen, there is little literature about this aspect of interdisciplinary working.
Although the supervision of interdisciplinary PhD research improved the last 20 years, for many PhD students interdisciplinary supervision is still confusing, especially when supervisors do not come to an agreement be-forehand. A majority of scientists stated that interdisciplinary PhD students are still supervised worse than others are. One of the interviewed researchers stated that the more supervisors a PhD student has, the less supervision he gets because no one really feels responsible for the supervision.
Supervision of a PhD student can be done in two ways. Both supervisors can supervise the entire PhD or the work can be divided into separate parts. The latter option might be more time efficient but produces multidisciplinary rather than interdisciplinary thesis. Therefore, a supervisor from the COS program stated that when working with several supervisors, they should not send their feedback individually to the PhD student but send it combined after bilateral consultation.
According to the majority of interviewed supervisors, interdisciplinary PhD students should be carefully selected. Furthermore, in order not to frustrate the promotion, supervising professors should put scientists in the promotion committee that are familiar with IR.

3.3.3.3 Postdocs

As has been said, in a couple of research programs postdocs played the key role in project management. There is disagreement about the question whether postdocs should be involved in this. Furthermore, there are different opinions about the characteristics of ideal postdocs and the amount of time they should be allowed to spend.
Postdoc sceptics (five interviewed scientists) state that postdoc positions are unsuitable for managing or integrating a program because of: a) the short term of postdoctoral positions (normally two years); b) a lack of incentives for the postdoc to stay when compared to a PhD student who has to finish his dissertation; c) postdocs are expensive when compared to PhD students.
Supporters of postdoc positions (13 scientists) argue that, postdocs that have enough feeling and experience in interdisciplinary projects are perfectly able to integrate the findings of individual subprojects into a consistent story. Most think that each program needs at least a fulltime position, one scientist thought that there is a need for around 0.25 postdoc for each PhD position. According to the postdoc defenders, there is a need for a person with an overview and time to think on broader issues. Professors do not have time for this, but postdoctoral students do. The risk that postdocs leave too early can be tackled by appointing them for four years.

3.3.3.4 PhD students

There is a division between PhD students and senior scientists whether PhD students should perform interdisciplinary research (17 %) or not (83 %) (Table 5 & Table 6). Those who think that PhD students should refrain from doing interdisciplinary research have the following arguments: a) from a career perspective, PhD students should focus on their own discipline because they have not yet established a reputation (Nicolson et al, 2002). Outside of education, a

generalist training does not provide adequate 'expert knowledge' that is the norm in many specialist institutions (Acutt, 2000). Supervisors, indeed, observe that interdisciplinary work is not one of the personal goals of PhD students. Though these views are rejected by Rhoten & Parker (2004) (paragraph3.4.2.3); b) Most PhD students already lack disciplinary background in their own discipline; c) IR can better be done by staff members themselves; d) PhD students cannot deal with the extra workload if IR; e) Interdisciplinary projects have higher performance when most of the research team already possesses a PhD (Birnbaum, 1979); f) Supervisors need more time for supervision interdisciplinary work.
Those who favour interdisciplinary PhD work, do not deny the previous objections, but, claim that PhD students are easier to convince to work interdisciplinary. Some PhD students state that they are very able to work interdisciplinary because they are fresh and full of ideas.
Interviewed Wageningen scientists mentioned that PhD studies will only be interdisciplinary when: 1) the questions are interdisciplinary right from the start; 2) PhD students are selecterd that like to work in a broad team; 3) the institute in the host country is able to supervise and conduct IR; 4) a shift can be made to put the PhD student on the disciplinary track, when IR fails; 5) it is possible to change the original research proposal during the research.

The sandwich PhD is a position that is relatively unique for Wageningen UR and forms the backbone of most INREF programs. Typically, a sandwich PhD undertakes 6 months to a year of training in Wageningen, followed by (at least) two years of fieldwork in his home country. Subsequently, the rounding off phase and promotion is done in Wageningen. Advantages of this structure are: low costs because the PhD students only receive a salary when based in Wageningen and it is a good way to train a local scientist. Common heard complaints of sandwich PhDs are that they are underpaid both in their home country and in the Netherlands, and that they do not receive enough supervision, that they lack infrastructure in their home country and that they stay too long in their home country. Although, interviewed scientists state that nowadays they are keener on distance supervision, the sandwich PhD construction remains a point of attention.

3.3.3.5 A general profile for interdisciplinary workers

All interviewed workers agreed that interdisciplinary scientists require special competences. Box 2 provides an incomplete list of requirements from interviews and literature.

Box 2: List of requirements for interdisciplinary scientists (from interviews, Nicolson et al (2002), Acutt (2000), Turner & Carpenter (1999))

1. Know their own discipline well
2. Requires a broad set of skills and is involved in a constant process of education. Some of the core skills are flexibility, being able to communicate, co-ordinate, integrate, and draw on various disciplines, methods, and perspectives.
3. Interest and esteem for the other discipline(s).
4. Willing and able to ask question to other disciplines

5. Being romantic researchers (who like to focus on multiple things) rather than classical ones who dedicate their lives to one narrow issue.
6. Explorative
7. Be committed to study interrelationships rather than on individual components
8. The ability to simplify what is known and when necessary guess at the unknown: therefore people need a deep grasp of their own discipline
9. Good listeners
10. Experienced in work with people outside their own discipline

Further, it is worth mentioning that at least one big-picture researcher is a necessity in an IR-team to explore the linkages (Nicolson et al, 2002). For an unknown reason, women (in UK at et least) are more often involved in interdisciplinary research (Mitchell, 1999).

3.3.3.6 Teamwork and meetings

Team oriented research is always difficult but not a unique feature of IR, therefore we will not go in full depth into it here.

3.4 Scientific and societal outputs

When designing an interdisciplinary research understanding the reasoning and incentives of different stakeholders is of great importance. In this chapter, we explore the potential output of interdisciplinary research for both society and the scientific community. Furthermore, an analysis of the costs and benefits of IR is presented. As in the other chapters, management options are provided in the end. First, the impact of interdisciplinary research on society will be discussed followed by its impact on scientific community. Finally, the potential of IR for scientific capacity building is elaborated on.

3.4.1 Output for society

Birnbaum (1981) concluded, based on experience of 67 ongoing interdisciplinary teams, that IR is more appropriate for very complicated research purposes. Naiman (1999) agrees on Birnbaum's findings and adds that good IR means conducting good science that is useful and used to resolve current and emergent issues.

Following interviewed scientists, interdisciplinary research is considered to help society solve problems that cannot be solved with disciplinary work. The greatest perceived benefit of IR, mentioned by 14 interviewed scientists (Table 7), is that IR outcomes are more relevant to society. All agree that IR is needed to make science applicable, especially in developing countries and when studying complex issues at several scales. They explained that through IR future problems and opportunities can be assessed in a better way. Several informants told that IR provides tools to put science in a broader perspective.

3.4.2 Scientific output

What is the scientific output of interdisciplinary research? Many scientists observed that new scientific insights arose from interdisciplinary work between neighbouring disciplines during

their program. In this respect, "good disciplinary research cannot exist without good interdisciplinary research and vice versa", as one of the INREF coordinators stated. Nevertheless, whether IR benefits only emerge between closely related disciplines or not, remains a point of dispute. Some coordinators and scientists argue that interdisciplinary work between social and natural sciences does never yield any scientific breakthrough. On the other hand, other scientists emphasize that their co-operation with not overlapping disciplines delivers new scientific insights. However, obtaining these new insights through co-operation with other disciplines may come at a price, due to the significant loss in disciplinary depth and, hence, scientific output. All interviewed agreed that whatever synergetic effects might emerge, they are not enough to compensate for the loss in disciplinary depth.

3.4.2.1 Publishing

Eleven of the eighteen interviewed scientists perceive that a major cost of IR is that fewer articles are published with a lower rating (table 3). Mentioned reasons for this are: 1) Interdisciplinary publications are hard to write and edit because of different methodology (van Keulen in: Klep, 2005); 2) disciplinary journals do not consider IR as being state of the art; 3) there is a lack of well-rated interdisciplinary journals (Butler 1998; Campbell 2005). The latter point however, seems to be improving (Naiman 1999).

Two ways of coping with the problems around publishing were suggested 1) accept lower rankings and publish in journals that do accept interdisciplinary novelties 2) have an experienced lead author who writes well enough to weave the messages from team members to a coherent one (Naiman, 1999). However, an interviewed economist told that this might help within natural sciences but not within economics.

3.4.2.2 Scientific capacity building

This paragraph discusses the role of IR as a generator of scientific capacity. Participation in interdisciplinary research can deliver useful tools and knowledge for disciplinary work. For example: A food technologist found new grain grinding techniques while working with a metal expert. Other contributions to scientific capacity include: 1) joint fact finding and the disclosure of so called "tacit" knowledge; 2) learning each other's scientific language and methods which enhances future cooperation; 3) IR improves the education at university 4) by performing IR a connection can be made with top universities like MIT and Cornell (table 3).

Capacity building may not always be achieved. According to an INREF coordinator, his program fell short in capacity building. The amount of people that gained capacity to work interdisciplinary did not increase, although those who were already capable of doing so came out more skilled.

Table 7: Major Cost & benefits of interdisciplinary research as perceived by researchers involved in INREF programs (n=18)

Costs		**Benefits**	
Costs more time than disciplinary work	13	Knowledge more relevant for society	14

Less or lower rated publications	11	You learn new things	5
		Chance on a scientific breakthrough	2
		better education for students	2
		It is a lot of fun	2

3.4.2.3 Career (dis) advantage

Rhoten & Parker, (2004) undertook research to find out what kind of impact researchers think IR have on their career. According to the authors, 413 out of 571 researchers working in projects of the NSF Environmental Research and Education programme think that interdisciplinary work has a positive effect on their career. 44 think that it is negative, while 114 expect no effect. Thus, the researchers in this recent study found that the experience of conducting IR has a positive impact on their career.

'You learn new things' is mentioned as a benefit of interdisciplinary research. (Table 7). However, most interviewed Wageningen scientists considered IR to have a negative influence on career possibilities.

3.5 External Factors

Hickey & Nitshke (2005) suggest that academic departments, academic supervisors, and funding agencies present the main barriers to effective cross-disciplinary research among scientists. This section provides an enumeration of factors that are influencing IR which are external to the IR program itself. Factors are divided in three levels, namely, the research institutional level, the national level and the international level. All data in this section are based on the interviews we had with scientists.

3.5.1 Institutional level

Enthusiasm of the institutional level towards IR does, according to our informants, not always induce positive feelings at lower levels in the hierarchy. Furthermore, the current financial structure of the university discourages outsourcing of tasks from one department to another. Wageningen departments are evaluated on the amount of published articles. These targets, according to an interviewed sociologist, dispirit scientists from becoming interdisciplinary workers, because they need a couple of years to get into the other discipline and during these years, they cannot accomplish their publication targets. An undeniable feature of Wageningen University is its small size. Although this can be an advantage, one of the interviewed scientists thought Wageningen UR is too small to form the critical mass needed for real IR.

3.5.1.1 Research schools

Interdisciplinary working scientists criticize research schools for hampering IR: 1) by dismissing PhD students that take too much time in order to improve the performance indicators; and 2) rejecting interdisciplinary PhDs. Furthermore, the structure of Wageningen University with multiple graduate schools makes it hard to design an interdisciplinary PhD project with two

promoters from different research schools. A positive characteristic of the schools is that they usually allow PhD students to deviate from their original proposal, making it possible to adapt their research to diagnostic studies as is done in the COS program.

3.5.1.2 Interdisciplinary research funds at university level

Although the literature still claims the contrary (Kane, 1999) many interviewed scientists observed that an increasing amount of funding is available for interdisciplinary research. Most noted that a potential financial advantage of IR can trigger strategic behaviour and hence stimulate fake IR. Researchers mentioned the following issues to improve the way IR is funded: 1) avoid nepotism, which is observed nowadays; 2) funding should allow possibility to change and to undertake an extensive exploring study. It should be mentioned that the latter is already included in the INREF funding program. According to the founder of an INREF funded program, the way INREF finances projects (50% of projects cost are funded, the rest has to be found elsewhere) makes the programs excellent in terms of cost-benefit relation.

3.5.2 National level /inter-institutional cooperation

Bureaucracy and lack of customer service of the Dutch immigration service (IND) makes it almost impossible to organize work permits for 6 months. Threatening letters from the same state service do not facilitate international research projects.

3.5.3 International level

INREF researchers brought up the following issues that hampered IR in the international context:

- insufficient English language skills of scientists in foreign countries;
- lack of local facilities, competing activities of PhD students (management functions, consultancy);
- shortage of communication between foreign team members;
- disciplinary education in development countries;
- increased time consumption;
- difficult supervision of sandwich PhD students because of the distance;
- lack of institutes in the South that are scientifically good and able to work interdisciplinary;
- hard to find matching, especially in poor countries;
- hard to find local matching of funds;
- bio-piracy regulations that prohibit the transport of living materials.

These problems can tackled by: 1) regular visits to the research locations, when possible with the entire team; 2) getting the sandwich PhD students to the Netherlands for three months a year instead of twice six months; 3) careful selection of partner institutes.

Most INREF funded programs are designed in Wageningen. Foreign partners played only a minor role in setting the goals. Scientists mentioned two reasons for this. Firstly, Dutch Wageningen scientists tend to speak more during international meetings, therefore their influence on the project is likely to be greater than that of the other participants. Secondly, foreign institutions

cannot always be involved in proposal writing because they do not know the funding conditions.

3.6 Conclusions

We propose that the framework as presented in 3.1 was useful to analyze problems and opportunities in interdisciplinary research from both interviews and literature. Below we provide the main recommendations for interdisciplinary research in the Wageningen context that have been abstracted from this chapter. An overview of problems and solutions mentioned in this chapter is shown in chapter 5.

3.6.1 Research culture

To increase the capacity of Wageningen scientists to work interdisciplinary Wageningen natural scientists should be taught inductive methods, whereas Wageningen sociologists should train them self in understanding quantitive methods.

In the context of interdisciplinary programs in Wageningen, the formation of common goals can be improved by organizing more discussion sessions in the start of interdisciplinary programs; publishing on found common concepts; and thirdly, organize more interactive reflective workshops with all participants during the program.

Furthermore, there are three points that can reduce methodological clashes, although they are almost too obvious to be mentioned. Firstly, take time for collegiality; ask each other questions; read each other literature.

Finally, Wageningen University's leading journal, NJAS, can easily facilitate interdisciplinary work by increasing the maximum length of an article that nowadays scares sociologists off.

3.6.2 Organizational framework

We noticed a serious lack of integration in most of the INREF programs. This is partly caused by the fact that INREF programs did not consciously chose an organizational model. We recommend therefore that more attention is given to choosing and refining an organizational model that is suitable for the proposed research. Besides choosing an appropriate model, the proper selection of a leader can increase interdisciplinarity of future projects. A postdoc can be suitable for this role, but he has to be appointed for the full time of the program. We suggest that future programs consider the possibility of appointing a full time professor or other type of senior scientist as full time coordinator of the project. Integration can also be improved by creating a common workplace for the PhD students of the program and joint selection of the research site. As a last resort, research programs should reserve money for post-research integration activities.

Uncertainty is a common feature of IR. Therefore, we propose that enough resources should be reserved for reconfiguring the program when needed.

As far as PhD students are concerned we propose that supervisors need to reach consensus about their supervision before starting the job, besides that supervisors should use all their powers to compose the judgement committee as interdisciplinary minded as possible, thirdly we propose a careful selection of the PhD student. We suggest that the sandwich PhD construction is only used

when sufficient facilities are available at the home institute and when its Dutch supervisors can visit the PhD regularly.

3.6.3 Societal and scientific outputs

Whether interdisciplinary science is only beneficial to society and not to science remains to be investigated using a larger dataset of interdisciplinary programs.
We propose however, that problems around publishing of interdisciplinary research can be managed in two ways: First of all, by appointing an experienced, well writing leader, that can function as lead author of outgoing interdisciplinary articles. Furthermore, less attention should be given to the ranking of the journal and more to the intrinsic value of the message.
Besides this, we believe, that given the figures, Wageningen scientists are generally to pessimistic about the career perspective of interdisciplinary workers.

3.6.4 External

Several characteristics of Wageningen University obstruct interdisciplinary research. First, the disciplinary nature of the research schools does not create an enabling environment for interdisciplinary proposals. Second, research schools often reject interdisciplinary proposals and the large number of graduate schools makes it hard to hand in a joint research proposal. A third way in which the graduate schools obstruct IR is the increased target orientation of the schools; PhD's who need a long time to finish their dissertation are dismissed from the school, even when they have sufficient funds. Therefore, we recommend that Wageningen graduate schools should cooperate in finding ways to assess interdisciplinary, inter graduate school research and by composing assessment committees that are able to evaluate interdisciplinary proposals.
Furthermore, the lobby for interdisciplinary research was too top down in Wageningen. Pro IR propaganda from headquarters caused widespread criticism against it at lower levels of the hierarchy. On the other hand, central policy on output payment gives a strong incentive to researchers to work disciplinary. We propose to attach a higher value to low ranking, but relevant interdisciplinary publications.
Interdisciplinary research in the broader sense is only possible in cooperation with other universities. New ways will have to be found to facilitate and finance this kind of IR.
Researchers from participating institutes in the South should play a bigger role in the problem definition of the research. This will increase applicability of the research as well as the local matching possibilities.

4 The Terra Preta Case study

This chapter describes the method that was used for designing interdisciplinary research projects on highly fertile soils in the Amazon watershed. The aim of the suggested research is to increase our understanding of the processes that formed Terra Preta, with the final aim to reconstruct it and develop sustainable, highly productive management practices for the susceptible soils of the humid tropics (Appendix 1 and 12). In this chapter, we will first explain how the project was organisationally structured. This is followed by our model for designing an IR and finally a reflection on the utilisation of knowledge described in chapter three is given.

4.1 Organisational structure

The Terra Preta project was started after approval of the INREF seed money project: 'reconstructing the Amazonian Dark Earths: Ancient technology as a tool for sustainable management of tropical soils' (Appendix 12). Prof. Thom Kuyper of the soil quality department of the Wageningen University is official co-ordinator of the project. The day to day management and co-ordination is done by the two authors of this report and Joep van den Broek. Due to the nature of the project, we have chosen to involve an interdisciplinary support group. This group of Professors, experts, from different disciplines have agreed to spend some of their time supporting the Terra Preta project. Different presentation and discussion sessions were organised in which the support group members had the opportunity to ask questions, give advice and come up with new ideas.

The project includes three phases; it started with a preparation phase in the Netherlands. In the second phase visits to Germany, the USA, Colombia, Peru, and Brazil were made. Appendix 4 provides a report and results of these trips. Finally, in phase three, which is still going on, we are writing a proposal in the Netherlands. During the first and last phase, Thom Kuyper and the support group were involved in the work.

4.2 Design of the TP research

We suggest that designing such a research includes finding the right balance between: 1) the knowledge gaps, 2) the interests, and capabilities of the research team and 3) possibilities and conditions for funding (Figure 5). Therefore we will first describe how the relevant knowledge gaps were identified, followed by a description of the way how the human capital needed to fill these gaps was acquired, then a short overview is provided of the funds. Subsequently, attention is given to the integration of the previous points into a number of research proposals and, lastly, a preliminary evaluation of our method is provided based on the lessons learned in chapter three.

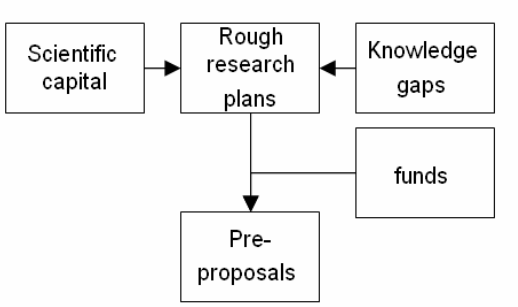

Figure 5 Overview of approach for designing TP pre-proposals

4.2.1 Identification of the knowledge gaps

First, all the relevant gaps in our understanding of Terra Preta were identified. This was done by a review on the existing literature on Terra Preta combined with insights from researchers that operate on the forefront of the research on these soils. The insights during the interviews were discussed again with other scientists involved in Terra Preta (Figure 5). Appendix 1 presents the result of this action. The figures collected in Appendix 1, together with some additional literature provided the input for the construction of nutrient and carbon balances on village level (Appendix 2). Both exercises generated many questions, which were partly complementary, partly overlapping. The nutrient and carbon modelling effort can be considered as the construction of a first prototype of a model that might be the organisational approach to an interdisciplinary research project (paragraph 3.3.1.2 Modelling). As Nicolson et al (2002) stated, rapid prototyping is useful to find the right problem definition when studying complex issues; besides that, rapid prototyping helped in distinguishing the relative importance of each of the components.

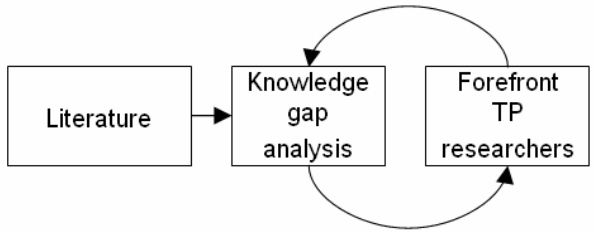

Figure 6 Literature in combination with continuous feedback from the forefront of Terra Preta research completed the knowledge gap analysis

4.2.2 Selecting scientific capital for filling holes in knowledge

This part deals with filling the gaps identified in the first part. We systematically assessed all potential partners as described in the methods. The results are provided in Appendix 4; the Microsoft Access database in which all information is stored is available on request only. Table 9 gives a summary of the visited institutions and their major research interests, whereas Table 8 provides the major incentives for foreign researchers to participate in a joint research project.

As can be seen, publications are an important incentive for Latin American scientists. Projects that involve local PhD students are suitable for increasing the number of publications of the supervisors. Besides publications, financial resources (for buying equipment and fuel) are important incentives to researchers.

Many of the identified knowledge gaps are of anthropological or sociological nature; unfortunately, we were unable to encounter sufficient Latin American anthropologists and sociologists to join the project. This problem has three causes. First, we did not visit enough sociologists and anthropologists because the current Terra Preta scene consists mostly of natural scientists. Secondly, the gaps identified may be too quantitatively formulated to be interesting for social scientists (see chapter 3). Thirdly, the executive team did not possess enough knowledge of anthropology and sociology to be able to think out suitable anthropological or sociological research questions (see chapter 3). The fact that the support group contains enough sociologists did not overcome this problem. The problem could be prevented by putting an anthropologists or sociologist in the executive team from the start, or by spending more time on understanding the research and methods of Amazonian anthropologists.

The views of the researchers on the design criteria are very important in designing a research project. An important group of participants (Cornell, Embrapa) found finding ways to increasing agricultural productivity the most important design criteria for a future project. Bayreuth, USP (all departments), UNC, UFLA, UFV and UFAM are most interested in increasing scientific knowledge, whereas IIAP, Tropenbos, INPA, UFRA are more interested in improving smallholder agriculture by using indigenous and scientific knowledge.

Table 8 Incentives for researchers to participate in a new project

Incentive	Number of researchers
Publications	13
Money	3
Own job	2
PhD students	2
More equipment	1
More Staff	1
Total	22

Table 9. Knowledge capital matrix: An overview of visited institutions and their major research interest.

Major research interest	Foreign institutes**	Dutch partners
Soil microbiology	LA: USP-CENA, , UFLA^; US: Cornell	Wageningen-UR
Archaeology	LA: USP-MAE, UNC-ICN, Goeldi*; US: UK,	UvA, VU
Anthropology	LA: USP-MAE, UNC-ICN, Tropenbos Colombia, IIAP UNALM*,	UU, Wageningen UR
Agronomy	LA: INPA*, Embrapa-CPAA,	Wageningen UR

	,UFRA, IIAP	
Soil chemistry	LA: UFV, Embrapa-solos, USP-CENA, UFAM*, UFLA*, MPEG*, USP-ESALQ^, UFPA*; US: Cornell; EU: Bayreuth	Wageningen UR
Micromorphology	LA: UFV*	Wageningen UR, VU
*Doubts on quality or low national ranking. ^ not willing or no time for cooperation **LA is the abbreviation of Latin American, US of United States of America and EU for European Union		

4.2.3 Finding funds

Thirdly, funds and their conditions were identified (Table 10). The method for doing this was similar to the method for identifying knowledge gaps. An initial overview of funding possibilities was made before the field trip, which was complemented and refined during and after the field trip. This approach had the advantage that we could inform potential participants about the probable design of future research. Researchers from the south only limitedly influence most of Wageningen UR's international, interdisciplinary programs. This is partly caused by the fact that funding came from Dutch institutions. This does not apply for the CAPES fund, which is provided by the Brazilian Ministry of Education. The agreement states that from 2006 onwards ten Brazilian PhD students, five postdocs and four visiting professors can come to the Netherlands each year. The call specifically asks for integrated projects and delineates five research areas: natural resource management; genomics; food safety; biomass for fuels and horticulture for export. CAPES gives more negotiation power to the Brazilian counterparts, which we consider beneficial for an equal distribution of tasks, responsibilities, and influence.
An important drawback is that most of the funds only cover sandwich PhD's and not salary or research costs. So, matching is needed from the local institutions. This is especially a problem for resource poor northern Brazilian universities. Besides being more resource poor, northern (Amazonian) research institutes generally possess a lower quality ranking than southern Brazilian institutions, which is worrying because CAPES demands high scores for fund approval.

Some of the funds have strict criteria for the design of the research programs. DGIS, INREF and recently WOTRO, want programs to contribute to sustainable development. Furthermore, an important criteria for INREF is local research and educational capacity building combined with the enforcement of the international strategic network of Wageningen UR. The main design criteria of FAPESP and CAPES are increasing scientific capital in Brazil and increase the amount of Brazilian scientific publications. The NUFFIC and ALBAN aim at providing higher-level training for Latin American professionals/future decision-makers at European institutes.

Table 10 The funds and their conditions

Fund	Applicable institutes	Finances what	Scientific area	Deadline
CAPES-Wageningen	USP-CENA, USP-MAE, USP-ESALQ, UFV, UFLA	Brazilian sandwich PhD's, postdocs, visiting professors	Wageningen Issues	15 May 2006; but information is lacking
Dutch Fund for research in the tropics - integrated programme (WOTRO)	Unknown but might focus on donor countries. So probably Peru and Colombia, but not Brazil	Probably sandwich and normal PhD positions	Unknown	Unknown
Interdisciplinary Research and Education Fund of Wageningen University (INREF)	New call unknown, probably in two continents, focussing on developing countries	Probably: Sandwich PhD positions, some research costs, postdocs	Development related, interdisciplinary research.	Not before 2007
Netherlands Organisation for Scientific Research (NWO)	Wageningen UR (with partner)	One PhD salary	Any but mostly disciplinary	Several possibilities
Foundation for Applied Technology (STW)	Wageningen UR (with partner)	Research	Technical, in co-operation with business	Continuous
NUFFIC - Netherlands Fellowship Programmes	Peru, Colombia, Brazil	Sandwich PhD students that need fixed position in their home country	Any	1 June 2006, 1 October 2006
DGIS – Wageningen (Dutch Directorate-General for Development Cooperation) partnership	Unknown, but agreement to be signed in May	Not known yet	Development related issues	Not known, but after May 15th
Sao Paolo State Fund (FAPESP)	USP-CENA, USP-MAE, USP-ESALQ	Not known yet	All	Unknown
ALBAN: European Union Programme of High Level Scholarships for Latin America	Latin American institutes, students	MSc and PhD	Any	01-02-2007

4.3 Integration

The previous points were integrated iteratively and adaptively. First, an overview of possible projects was made based on the knowledge gaps and potential cooperating institutions (Appendix 5). Some of the listed ideas are indeed rather disciplinary so the support group could use then to

make interdisciplinary by combining some of them into one project. We presented this overview of projects to the Wageningen support group. The disciplinary character was needed to keep the ideas short. The rough plans were long enough to inspire people and short enough to prevent overkill. This helped to enthusiasm, motivate, and activate the support group. The shortness of the plans made it easier for the involved scientists to reject plans that are not fundable or lack scientific depth.

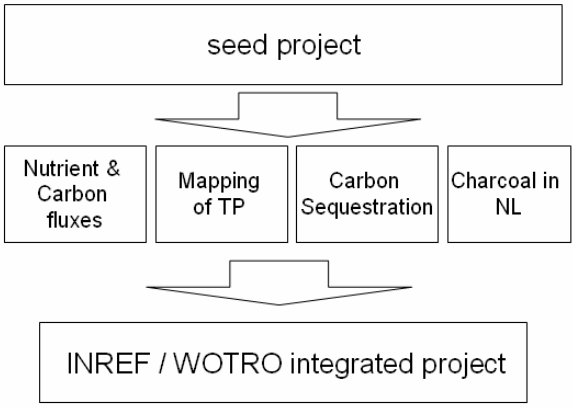

Figure 7 First let one thousand flowers bloom and than concentrate again

As shown in Figure 5 the rough research plans were filtered and combined based on fundability of the proposals and of course available knowledge in Wageningen. The support group decided to start exploring possibilities for a couple of smaller initiatives that can be elaborated without the backing of big funds, because it was still a long time to go before the deadlines of funds that finance big, integrated projects like INREF or WOTRO integrated programmes.
These small projects can be considered as a preparation for an application for an INREF or a WOTRO program. The concept of letting a thousand flowers bloom first and then concentrate again on one project, which is practiced here, was proven successful in the Wageningen Support Centres in Burkina Faso and Costa Rica (Stroosnijder, pers. comm.) (Figure 6).
Four projects (appendix 6-9), mostly combinations of the suggested ideas (Appendix 5) were designed. The first one aims at gaining insights in nutrient and carbon fluxes, the second is directed at interdisciplinary mapping Terra Preta in combination with the disclosure of local knowledge, the third focuses on charcoal use in Dutch agriculture and the fourth is a project on carbon sequestration for resource poor farmers in the tropics (box 3).

Box 3. Overview of future Terra Preta Projects

Project 5, 6 and 7 and 10 (paragraph Appendix 5) were selected for one integrated project on carbon and nutrient fluxes in Terra Preta. Together with Brazilian counterparts, a pre-proposal was written (paragraph Appendix 6), and a Brazilian professor was appointed as leader of the program. This project is interdisciplinary within the natural sciences. Participating scientists include chemists, microbiologists, agronomists and soil biologists. It will be a major challenge

to be sure that all will focus on the central theme. We selected Porters modelling method as the organisational framework. Important design criteria in this proposal are increasing scientific knowledge and improving smallholder agriculture by using indigenous and scientific knowledge. The proposal is to be funded by the CAPES-Wageningen programme. Unfortunately, the guidelines for this proposal are still unclear, although the deadline is May 15, therefore the proposal cannot yet be finished.
Etnopedology is the theme of the second project that is starting up (paragraph Appendix 6). This highly interdisciplinary research project is probably of great value for discovering new Terra Preta on the one hand and researching farmers' perceptions on the other hand. A study on the farmers' perceptions can yield important insights in how Terra Preta is used nowadays and even whether they are still in the process of formation. The project is to be financed by the NUFFIC Fellowship program. Important design criteria in this proposal are increasing scientific knowledge and improving smallholder agriculture by using indigenous and scientific knowledge.
Another highly interdisciplinary proposal is the carbon sequestration for resource poor farmers in the tropics (paragraph Appendix 8) will try to combine poverty alleviation with decreasing global CO_2 levels. This project might be funded by DGIS or other development related funds. In this upcoming project, poverty alleviation and increasing agricultural productivity are important design criteria.
The project on charcoal use in agriculture is a rather disciplinary result of project 14 in Appendix 5. A follow-up project might be financed by STW and is probably more interdisciplinary as we are planning to work closely together with farmers (paragraph Appendix 7).

4.4 Reflection on chapter three

It should be noted that the projects are still in an early stage, and that therefore many of the valuable knowledge gathered in chapter 3 could not yet be used. However, we want to draw attention to a number of choices (and implications of the choices) we made during the construction of the CAPES project, and reflect these choices on the theory provided in chapter 3. We will reflect on the support group, the choice of the model, the data collected, team member, team leader, funds and some external implications. The reflections are grouped according to the previously described framework for interdisciplinary research (Figure 3).

4.4.1 Organisational framework

Concerning the upcoming CAPES project, we started with the choice for using a model as a tool for integration. As Rossini & Porter (1979), state models can be useful to organize and integrate interdisciplinary work at considerable depth with neighbouring disciplines. So this model of organisation is highly suitable for the suggested research.
In the CAPES project, the data will be collected through PhD students. We decided that the PhD students involved will do a rather disciplinary PhD, but within the context of a greater goal. We have no information about the implication of this choice for the overall project. Besides that, we do not know yet if it is possible to contract a postdoc for the entire period of the project so that good integration and management of the project is ensured.

The support group helped in defining the direction of the project and helps to get all relevant disciplines involved. However, in practice due to specialisations and personal preferences in the group some relevant areas may have received less attention than they deserve. Although all members agree that it is very important to have all relevant knowledge covered there is a (possibly unintended) steer of the research in a direction. In our project, this has possibly led to less anthropological focus and more agronomical and soil science focus. A support group is a great asset to start up and run a project but may facilitate the exclusion of relevant issues and include less relevant issues.

An important and large part of the TP project was the visit to Brazil, Colombia, Peru, Germany and the USA. During the trip, the mapping of incentives helped to gain insights, which were very valuable when establishing the interdisciplinary proposal. Through the establishment of the database and the different visits, more clarity was obtained about the stake-holder's interest to spend time (and resources) in IR. Besides that, we gained understanding about whether they and their institute were willing and able to invest in IR or not. We compose a team with the characteristics needed. This resulted in the selection of a team most likely capable of IR.

More difficult was the choice of the Brazilian team leader. It is almost impossible to find leaders that fulfil all characteristics shown in 3.3.3.1; therefore, we had to be pragmatic. The identified leader is at least experienced in research projects on nutrient flows, has a good status, and is fluent in English and Portuguese. The choice of a leader in both countries was an important one for smoothing the international co-operation and involvement of the Brazilians with the project design and proposal writing. We found that the choice of the Brazilians co-ordinator (or leader) improved the communication and involvement.

4.4.2 Scientific and societal output

Concerning scientific output, we think that the suggested project can yield major scientific breakthroughs by bringing together state of the art techniques from several disciplines. We think that disciplinary working is not the road to take, when whishing to gain understanding in Terra Preta. A combination of the disciplines is a necessity for understanding the dynamics of nutrient and carbon in Terra Preta.

4.4.3 External factors

An extra impulse to the international co-operation and input from Brazil was according to us not only gained by the choice of a (local) leader but even so by the choice of the fund. Our first integrated projects will is hopefully funded by CAPES, a Brazilian fund. Thus, the funding conditions and the institutional rules surrounding this fund are more understandable for the Brazilians then for us. We experienced that this gave a great impulse to involving them more in the direction and form of the project.

Besides the choice of team members, a leader, and funds, another important choice made during the project was the choice of institutes. In the project, we selected the institutes that have

relatively good facilities and that are relatively experienced in interdisciplinary work. We found that this helped in reducing the problems with establishing the cooperation.
Finally, the bio-piracy laws of Brazil, as mentioned in chapter 3 under external factor, are a great challenge to any further TP research. Exporting living material thus also soils in almost all cases, is impossible. We cope with this by performing all analysis in Brazil.

5 Conclusions

This chapter provides an overview the problems and opportunities of interdisciplinary research and the following management options. The conclusions are ordered according to this framework for interdisciplinary research provided in chapter 3, which we consider suitable. After this, we will shortly go into some aspects of international research projects that are not specific to interdisciplinary research but very important in initiating international research projects in general.

We summarized the problems and subsequent strategies that followed from literature review, interviews, and experience in the field of Terra Preta in a problem-strategy matrix which is shown in Table 11 . In this table for each problem, a strategy can be located. More information about the strategy is provided in the previous chapters.
However, a number of problems faced by interdisciplinary workers are not shown in the table,

Table 11 Problem (left)-strategy (up) matrix

Problems	Strategies	Read each others work	Learn about each others methods	Use analogies	Use new statistical methods for integration	Use a integrating framework	Combine theories on different levels	Make time for joint planning	Publish articles on the integrative frame	Invest time in collegiality	Chose the right model for the organisation	Do diagnostically studies	Do some rapid prototyping	Appoint a leader for the full time of the project	Reserve time and money for post program integration	Build in more flexibility in the duration of the project	Have adaptive management	Chose the same research site/object	Chose the same office	Appoint full time prof. for IR project	Tuning between supervisors	Select team member with understanding of IR	Have careful selection of the foreign institute	Have sandwich PhD students come back more often	Appoint lead editor	Have supervisors regularly visit location	Check local funds for co-financing	map and check incentives of participants
Research culture	Divide between Qualitative and quantitive research		x		x	x							x															
	Incompatibility deductive and inductive research		x		x	x																						
	Having wrong perceptions of other disciplines	x	x							x									x									
	Competing explanations		x		x		x					x	x															
	Lack of common goals			x		x		x	x			x							x	x								x
	Language problems between disciplines	x	x	x				x		x									x									
Organisational methods	Lack of integration			x	x	x		x	x		x			x	x			x	x	x		x						
	Uncertainty about the research direction								x			x	x		x	x	x					x			x			
	Continuity of the leadership and coordination													x						x								
	Projects run of phase							x			x					x												
	More supervisors confuses the PhD student							x		x											x							
	Foreign PhD are often disciplinary															x						x			x			
	Lack of supervision for sandwich PhD																					x		x	x			
Scient. output	Difficulty publishing high ranking articles				x				x											x					x			
External factors	Problems with immigration service															x												
	Lack of facilities sandwich PhD in home country															x								x				
	Little influence of foreign researchers																							x			x	

because their drivers are mainly external to the IR team. Two examples of such issues are: 1) bio-piracy laws that may hamper transport of soil samples (research projects can cope with these regulations by performing analysis in the country were the samples are taken; 2) the length of articles of sociologists, which prevents publication in journals. Paragraph 3.5 provides an overview of external factors influencing IR.

5.1 Research culture

To increase the capacity of Wageningen scientists to work interdisciplinary Wageningen natural scientists should be taught inductive methods, whereas Wageningen sociologists should train them self in understanding quantitive methods.
In the context of interdisciplinary programs in Wageningen, the formation of common goals can be improved by organizing more discussion sessions in the start of interdisciplinary programs; publishing on found common concepts; and thirdly, organize more interactive reflective workshops with all participants during the program.
Furthermore, there are three points that can reduce methodological clashes, although they are almost too obvious to be mentioned. Firstly, take time for collegiality; ask each other questions; read each other literature.
Finally, Wageningen University's leading journal, NJAS, can easily facilitate interdisciplinary work by increasing the maximum length of an article that nowadays scares sociologists off.

5.2 Organizational framework

We noticed a serious lack of integration in most of the INREF programs. We suggest that future IRR programs can be more integrative when

5. an appropriate organizational model is chosen;
6. more attention is given to the appointment and selection of the project leader;
7. common workplace of PhD students is created;
8. joint selection of the research site;
9. money is reserved for post program integration (as a last resort);
10. resources are reserved for reconfiguration of the program.

When PhD projects are interdisciplinary, it is of crucial importance that:

1. supervisors reach consensus on supervision in advance;
2. supervisors ensure that the judgement committee is as interdisciplinary minded as possible;
3. there is a careful selection of the PhD student;
4. in case of sandwich PhD there has to be
    a) enough resources for supervisors to visit PhD in its home country;
    b) enough facilities at the home institute.

In the planning phase of a project, a structure with an executive group and a support group is useful to start up and run a project but may facilitate the exclusion of relevant issues and include less relevant issues. Furthermore, planning tools that are widely used in industries like PERT can be helpful in planning IRR. Besides that, an early visit to the potential international collaborators and their institutes is crucial in composing a team, which possesses the characteristics needed to perform IR.

5.3 Societal and scientific outputs

Although in the Terra Preta Case study IR was explicitly chosen in order to increase scientific depth, whether interdisciplinary science is only beneficial to society and not to science remains to be investigated using a larger dataset of interdisciplinary programs. Scientific output measured as the number of high ranking articles can be increased by appointing an experienced, well writing leader, that can function as lead author of outgoing interdisciplinary articles.
Besides this, we believe, that given the figures, Wageningen scientists are generally to pessimistic about the career perspective of interdisciplinary workers.

5.4 External factors

Several characteristics of Wageningen University obstruct interdisciplinary research because 1) they are organized along disciplinary lines, 2) IR proposals are often rejected 3) do only limited allow students to extend their PhD. Therefore, we recommend that Wageningen graduate schools should cooperate in finding ways to assess interdisciplinary, inter graduate school research and by composing assessment committees that are able to evaluate interdisciplinary proposals.
Furthermore, the lobby for interdisciplinary research was too top down in Wageningen. Pro IR propaganda from headquarters caused widespread criticism against it at lower levels of the hierarchy. On the other hand, central policy on output payment gives a strong incentive to researchers to work disciplinary. We propose to attach a higher value to low ranking, but relevant interdisciplinary publications.
Interdisciplinary research in the broader sense is only possible in cooperation with other universities. New ways will have to be found to facilitate and finance this kind of IR.
Researchers from participating institutes in the South should play a bigger role in the problem definition of the research. This can be done by appointing a project leader from one of the foreign countries involved and by looking for funds from the participating countries in the south that are more understandable for foreign team members.

Finally, we expect intellectual property rights to become a serious factor in doing IRR in the field of natural resources. Performing all analysis right at the place were the research is done, is the only option for continuing research anything that consists of (parts of) living organisms. Unfortunately, this will sometimes exclude the possibility of using high tech research machinery.

5.5 Issues not specific to IR

We propose that a literature review, interviews, and prototype modelling are all suitable ways to assess current available knowledge but that, even when time consumption and overlap is taken into account, combining both creates a sharper picture of the issues we do not know yet. Furthermore, the sequence of firstly determining which ways look most promising based on an initial literature review and then refining this analysis later on by extensive talks with the key researchers in this area was crucial in accurately discovering the issues that remain to be studied. A remaining point of debate is whether more time should be spent on the initial literature survey and less on visiting researchers in the field or the other time around. One should however, keep in mind that the available literature is limited when compared to the available data in the heads of TP scientists. In other cases, however, a greater emphasis can be put on literature review.

We think it is of great value to consult foreign scientists in an early stage, in order to: 1) make sure that the proposed research will be tailored to the interests of the foreign counterparts; 2) identify local available financial and human resources. Storing all information of the researchers that might be included in the future research in a database has the following advantages: 1) quick accessibility by sort and query functions; 2) database structure demands a systematic way of gathering information about the potential participants which made afterwards make comparisons easier; 3) when project co-ordination is carried over to some-one else, a profound insight in the network can quickly be found; 4) minimal loss of information. However, it should be mentioned that it is impossible to really catch the complexity of the network in a static database. First, interrelations between the participants can only partly be captured in MS Access. Besides that, the database outdates quickly because of quick changes within institutions and people's careers.

We propose that it is better to look only at knowledge gaps and available scientific capital when sketching rough research plans. The financial part may limit creativity and should be included in a later phase. Pre-filtering and creatively combining the data from the knowledge gap analysis and the scientific capital analysis into rough and short research plans is highly beneficial in terms of stimulating the scientists to become more involved in the project. In the initial phase of a research, it might be better to focus on more than one project then only one to spread risks and to include more people. In a later phase, these projects might join again, however, one must keep in mind that, using this design, the risk of creating mono-disciplinary uncoupled research emerges when overall co-ordination looses its grip. We recommend that in future seed money projects aiming at designing an international research, funds are reserved for a workshop in which delegates from all participating institutions come together to do the final writing and editing of the proposal.

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