Learning to fight a fly: developing citrus IPM in Bhutan

Frank van Schoubroeck

NN08201, 2729

Stellingen behorende bij het proefschrift
"Learning to fight a fly: developing citrus IPM in Bhutan"
van Frank van Schoubroeck.

1. *Bactrocera minax* vrouwtjes kiezen een vrucht om eitjes in te leggen eerder op grond van de grootte dan als functie van eerdere legsels in de vrucht.
   Dit proefschrift.

2. Het lokken van *B. minax* met eiwitachtige stoffen net voor de schade evident wordt (zoals boeren geneigd zijn te doen) of net voor de ovipositie (zoals de fruitvliegliteratuur suggereert) heeft weinig zin; lokken is wel effectief in de periode dat de vliegen uit hun poppen tevoorschijn komen.
   Dit proefschrift.

3. Investeringen in citrus IPM in Bhutan zouden zich in een of twee jaar kunnen terugverdienen als boeren niet alleen technisch, maar ook organisatorisch getraind zouden mogen worden.
   Dit proefschrift.

4. De opeenvolgende radicale veranderingen in het Nederlandse ontwikkelingshulpbeleid leiden tot voortdurende structurele kapitaalvernietiging op uitvoeringsniveau.

5. Het lukt zelden om kleinschalige successen op grote schaal toe te passen omdat beleidsmakers vaak slechts een enkel element ervan tot wondermiddel willen verheffen.
   Dit proefschrift.

6. Het opbouwen van een sociologisch betoog lijkt op het ontrafelen van de biologie van een organisme, met dat verschil dat de meeste begrippen in het eerste geval gedefinieerd worden door de onderzoeker, in het tweede door het beest.

7. "Generalistische kennis" is een contradictio in terminis.

8. Voor geïntegreerde gewasbescherming is locale specialistische kennis essentieel omdat spuiten anders te veel voor de hand ligt.

9. Vanuit het perspectief van de participatieve kennisontwikkeling was Eva's proeven van de boom der kennis een gerechtvaardigde daad, ook al reageerden de autoriteiten ook in die tijd al onsportief door haar daarop uit te sluiten van vele maatschappelijke privileges.

10. De angst van veel Boeddhisten om als insect te reïncarneren is, het luizenleven van vliegen wel beschouwend, geheel ongegrond.

11. Fruitvliegvrouwtjes voeren hun proefboringen veel schoner uit dan de NAM.

Learning to fight a fly:
developing citrus IPM in Bhutan.

Promotoren
dr. Ir. N.G. Röling
Hoogleraar in kennissystemen in ontwikkelingslanden

dr. J.C. van Lenteren
Hoogleraar in de entomologie

Learning to fight a fly: developing citrus IPM in Bhutan.

Frank van Schoubroeck

Proefschrift ter verkrijging van de graad van doctor op gezag van de rector magnificus van Wageningen Universiteit, dr. C.M. Karssen, in het openbaar te verdedigen op woensdag 15 december 1999 des namiddags te 13.30 uur in de Aula

CIP-DATA Koninklijke Bibliotheek, Den Haag

Schoubroeck, Frank H.J. van

Learning to fight a fly:
developing citrus IPM in Bhutan

Thesis Wageningen University and Research Centre. With summary in Dutch.
ISBN 90-5808-113-3
Subject headings: Integrated Pest Management, Participatory Technology Development, citrus, Tephritidae, extension, Bhutan

Cover design and lay-out: Lodewijk Creyghton
Cover photo "fly" by Ernst Neering, other photos by Frank van Schoubroeck
Copies can be ordered from the author at e-mail: frank_van_schoubroeck@yahoo.com

Acknowledgements

This study is a result of a long-term co-operation between many people and institutions. First and foremost I wish to thank the Royal Government of Bhutan, in particular Lyenpo Kinzang Dorji and Lyenpo Khandu Wangchuk, for their kind co-operation in paving the way for an active and innovative Plant Protection Service, of which one component is reflected in this book. Acting Director Research, Extension and Irrigation Division, Mr Sherub Gyeltshen, and National Director of the Plant Protection Service, Mr N.K. Pradhan, played important roles in the shaping of this study. Throughout the study period the author was employed by the Netherlands Organisation for Development Co-operation (SNV), while the IPM Development Project (IPMDP) was funded by the European Commission. Dr. Hans Feijen, team leader of IPMDP motivated and guided me in turning valuable work experiences into a study worth a Ph.D.-thesis.
Practical implementation of village work would not have been possible without the supportive co-operation of Dasho Penden Wangchuk, at the time Dzongda of Pemagatshel District. The communities of Am Shing village, Samdrup Jongkhar District and of Dungmin village, Pemagatshel District were highly co-operative in exploring the social dynamics of technical experiments; they had to bear with quite a few failures before they could reap profits by the programme. Farmers of villages near Dungmin: Bainang Zor, Dena Woong, Jorphung and Kalishong, further tested the developed methods and their co-operation, hospitality and friendship are among the best memories from Bhutan I keep. I thank various DAO's and Extension staff of Pemagatshel District who were involved in village research, and some of whom did considerable efforts to make citrus IPM a success in their respective blocks. Particularly Mr Dendrup Dukpa and Mr L.N. Sharma introduced me to eastern Bhutan village life, while Mr B.B. Acharya was a key person in exploring the integration of technical and social aspects of citrus IPM.
I would like to thank all colleagues in the Regional Plant Protection Centre, Khangma, in particular DoeDoe and Marja Kool-de Rie, for the extensive discussions we had on the programme of the centre. I still regret that the final writing of this thesis has not become a joint effort of DoeDoe and me. I am sure that DoeDoe and Marja will find many familiar ideas in this book, and I hope that it reflects their opinion as well. Many students of the Natural Resource Training Institute carried out on-station experiments and I greatly enjoyed their enthusiasm and dedication. I would like to specially mention Tanka Maya, Cheki Wangmo, Laxmi Thapa, Zangpo, Lham Gyeltshen, Tenzin and Som Nath.
At Wageningen University, the positive reaction to the idea to write a Ph.D.-thesis by Prof. Dr. Joop van Lenteren and Prof. Dr. Niels Röling made me immediately feel at home in the departments of Entomology and Communication and Innovation Studies. Particularly Niels played an essential role in processing the study into a book rather than a series of articles. Prof. Dr. Paul Richards suggested social cognition as a perspective, which considerably deepened my insight of the social dynamics that had governed the programme. The Ph.D.-group of the department of Entomology critically read my entomological articles and gave useful comments. Lodewijk Creyghton designed the cover and lay-out of the thesis, Kees Bals and Irene Guijt went through the propositions, Joke Snel assisted in many arrangements, and many more friends contributed in one way or another to this book. Throughout the study my family, Paula Kleinheerenbrink, Jimmy and Carmen supported me and as a result they are now thoroughly versed in the biology of Bactrocera minax and its relation to society in Bhutan. Aren't they lucky?

Wageningen, August 1999
Frank van Schoubroeck

Table of Content

Prologue: about success, scale, fatigue and opportunities.

The community of Dungmin village, eastern Bhutan, grows maize for food and mandarins for cash. In 1992-1996 the government organised a citrus management programme and the Dungmin community succeeded in doubling its cash income. The programme brought a spirit of development and enthusiasm to the village: many families could clear their debts while some started small-scale businesses. In a few neighbouring villages the outcomes of the Dungmin programme were applied and further developed resulting in similar successes, and people requested for follow-up activities to further explore the economic opportunities in their area. This thesis documents how a network of farmers and extension and research staff developed an IPM strategy for key pests in citrus that included components such as pest monitoring tools and village organisation. Community members experienced development of their village, and government and donor officials visited the place or took note of (audio-visual) documentation so that the success was widely known. And so, policy makers wanted IPM technology disseminated across the country, for the benefit of thousands of citrus growing families that saw the greater part of their potential harvest being destroyed by pest and management problems.

So far, the programme proceeded successfully. However, it appeared that large-scale introduction of developed IPM methods was problematic. To our knowledge, outside the original experimental area, few or no villages succeeded in successfully applying citrus IPM, even if National Campaigns were launched for several years in a row. Therefore, this thesis also tells the story of the failure to extend the success. We did not understand why, with the vast amounts of national and international funds pumped into rural development programmes, there was little or no room for proven technology to be disseminated to hundreds of communities that could have equally profited. Policy making (both national and international) kept itself busy with goals such as "institutionalisation" or "integration" that were far-fetched or even counterproductive in the Bhutanese situation, and left directly applicable programmes on the shelf. Communities themselves could not copy successful practices, and the agriculture extension service was incapable of extending citrus management methods.

After my leaving the programme, I badly felt the need to learn and develop a vocabulary and a theoretical framework to be able to communicate on mechanisms that underlie this failure. Thus, apart from documenting the successful part of the programme, this study also evaluates the processes that lead to the failure to introduce proven methods to large groups of farmers. And in Bhutan, as policy makers hold the key positions to change things for the better, they should be informed of the unexplored economic potentials for the people that they are supposed to work for. So, the question is not only: "How is it possible that interesting opportunities are ignored by mainstream developments?" but also: "How can they be brought into mainstream thinking?". The question gains importance as evidence from elsewhere shows that all over the world scaling-up of successful and economically sustainable technology is problematic (e.g., Auerbach 1999, Matteson et al. 1992, van Weperen *et al.* 1998). The Bhutan citrus programme can play a role as one of the many examples from which lessons can be drawn for future initiatives of similar kind to be more effective.

This thesis explores the social setting of IPM technology development, its application and its dissemination in the farmers' community. It tries to place thorough technical research in the context of the end-users. Thereby technology is both *adapted* to the social context *and interfering* in it. The study can therefore be criticised from three positions. Hardcore technicians may maintain that in a more confined technical research set-up similar results would have been achieved with less effort. This argument is dealt with in Chapter 2. Advocates of participatory approaches may argue that the research agenda originated more from technological opportunities than from the priorities and understanding of farmers and the extension service. Although this argument bears some validity, I think that there is little scope for development of sustainable technology if existing know-how is not occasionally enhanced with outcomes of technological research. Some policy makers (both international and national) argued that the research was not in line with mainstream policy intentions in Bhutan. In some cases I could not see how such policies would lead to improved socio-economic development in rural Bhutan. In other words: following those policies was like closing one's eyes for the needs of farmers.

This study used a variety of research methods. I started my work in Bhutan as a "junior extension specialist" at the Regional Plant Protection Centre of Khangma, eastern Bhutan, which was founded early 1991. Part one of the thesis broadly follows the development of the programme I worked on. Chapter 1 deals with the early days of the eastern Bhutan plant protection service. It substantiates why in eastern Bhutan, where rural life is organised around maize that is far from devoid of pest problems, it is still better to work on IPM in cash crops. Experiential learning theory is used to describe an early extension programme designed for the dissemination of IPM in citrus, which shows how communication with farmers led to major improvements of proposed IPM technology (Chapter 2). The next part briefs on diffusion of innovations theory and social cognition theory and describes how IPM for the chinese citrus fly, a most damaging pest, was developed in two village research programmes. The programmes were called "pilot village programmes" at the time and took place in one progressive village called Am Shing, and in one more conservative village, Dungmin (Chapter 3). Technological needs were identified in the villages, research was carried out both in the village and on-station, and outcomes were used and fine-tuned by the farmers' community. IPM made control activities concerted over entire villages necessary, and the chapter dwells on making organisational structures in village communities work for the control of the citrus fly. Then, the thesis documents initial efforts to disseminate IPM technology outside Dungmin area (Chapter 4). Dungmin programme staff appeared in a position to disseminate citrus IPM outside Dungmin area, but dissemination by other extension staff soon ran into institutional constraints that hampered scaling-up of the technology, and it shows initial reactions of various stakeholders in the process. Chapter 5 and Chapter 6 contain the technical findings of the technical research programme and they are written according to technical-academic conventions. The biological data appeared to shed light on the way flies select fruits for oviposition and suggested one more method to control the fly that we had overlooked in the field, i.e., the use of catch crops. In the last part, in Chapter 7 and 8, conclusions of the study are presented.

After I left Bhutan, late 1997, I contacted two departments in Wageningen University. Prof. Dr. Joop van Lenteren (Department of Entomology) and Prof. Dr. Niels Röling (Department of Communication and Innovation Studies) readily agreed to supervise my writing a Ph.D.-thesis, and introduced me to the ways scientific reporting is usually done. I must admit that I had real difficulties separating the more technological and sociological data, to conform to scientific standards. For this reason, a large amount of village data is not used for the technical reports, although they partly tell the story of the village research programmes. For the sociological part it appeared essential to choose a theoretical perspective and a research question to analyse the story through, which was a novelty to someone like me with a natural sciences background. Again, I must admit that it took me months to grasp the meaning of such a set-up, and eventually I used a blend of learning theory, diffusion of innovations theory and social cognition theory to describe and explain the citrus IPM programme as it had developed over the years. It was this work that has yielded me most additional insight in the questions that I had posed myself.

Another problem was the choice of an audience for the book. Should I write it for the Bhutanese Ministry of Agriculture that could use this study for further extension policy development? I had initially intended to write this thesis as part of an on-going co-operation with the Royal Government, but, when in May 1998 it became clear that such a programme was not endorsed, it naturally occurred that the thesis should be written for a more general audience. Therefore, the thesis includes an introduction to Bhutan for readers not familiar to the country, and it avoids using terms generally used in Bhutanese English such as "Dzongda" (translated as "administrator") and "gewog" (translated as "block") which might sound odd to Bhutanese readers. Over all, superficially seen, the thesis reports on the development of an IPM strategy for the chinese citrus fly. Yet, the study aims to contribute to a wider discourse, i.e., how can the generation of knowledge of use for subsistence farmers be organised? The research model includes the set-up of a research dynamics parallel *on-station* and *in-village* with strong emphasis on the transformation of knowledge from one site to the other and vice versa. Such a model can be applied in any field of study where it is local *knowledge* rather than *inputs* being the bottleneck to more economic, or sustainable, practices. This is what I want to say about the place of the thesis in the on-going international debate on research for small farmers. Now that recently the Honourable Minister of Agriculture expressed his will to publish this thesis in Bhutan, there is hope it will find a public there and thus I added Part III with the main conclusions of the study. The very last part of this thesis is not to be written, but to be carried out. It is hoped that this book will be of use to people who want to contribute to a better citrus production in Bhutan and in neighbouring citrus growing areas. But, more in general, this thesis aims to show how thorough technological research and local organisation may work together to develop technology of high potential. It substantiates that governmental institutions must think about their policies and their role for the development and dissemination of such technology, and on their view on target groups and civil servants that goes along. Such visions must be developed for a next generation of programme implementers to be more successful than us in enabling large groups of farmers to utilise sustainable and highly economical technology.

Part I. IPM and society.

1. Area and object of study: eastern Bhutan and citrus.

1.1. The kingdom of Bhutan.

Bhutan is an Himalayan kingdom, with strong cultural and historical links to Tibet. The inhabitants' political, cultural and social life is deeply influenced by Buddhism as it was introduced from Tibet. Early this century the country became a unified kingdom under the great-great grandfather of the present monarch. In the 1960's, technical assistance from India started to flow into the country, followed by western development aid and UNDP in the 1970's. Now there is a growing amount of literature (e.g., Crins 1998, Pommaret 1990), most of which deals mainly with western Bhutan. The western Bhutanese people, Druk-pa, speak Dzong-kha, the official national language, that is particularly important in administration and in jurisdiction. The Western-Bhutanese are most influential in the national affairs of the country, although sizeable other minority groups exist that the government recognises by generously allowing media in a few local languages. Outside Bhutan most well-known minority group is the Lhotsham-pa or southern Bhutanese group of Nepali origin, that early this century brought the southern valleys under cultivation. Less well-known are minority groups in central and eastern Bhutan, who have a local identity based on the language they speak and distinct habits, obviously related to local living conditions and historical background. In those areas a dozen local Tibeto-Burmese languages are spoken.

The programme this thesis is based on was carried out in eastern Bhutan, an area characterised by deep valleys and steep slopes, and considered poor and backward. It is reportedly given the priority for development in the 8th five-year plan, 1997-2002. The area is relatively densely populated and dominated by a people speaking Tshangla-lo or Sharchop-kha ("language of the eastern dwellers"), a language of the Tibeto-Burmese group and Indo-Mongolian of origin (as contrasted with the Tibeto-Mongolian origin of western Bhutanese people; Hasrat 1980). Sharchok people form the biggest minority group in Bhutan. Most work for this thesis was done in the southern (lower) parts of eastern Bhutan bordering Assam, in an area locally called Dungsam, which includes the southern subdivision of Tashigang, and Pemagatshel and Samdrup Jongkhar districts. Most of the work was carried not more than to two days' walk from the Tashigang-Samdrup Jongkhar highway, while areas accessible only through roads in Assam were hardly visited. Station-led research was carried out in isolated orchards between Khangma and Tashigang Dzong and in Phiskhang and Kharsa in lower Kanglung area. Although the work started off as a technical programme, it later touched social issues such as village organisation and the configuration of the agriculture extension service. Thus, a few notes on the society in general, the culture and the language, which together formed the socio-economic context within which this study was carried out, will be useful. It should be noted that this account is based on fragmented information from history books (particularly Hasrat 1980), narration by individual people and observations done during my stay in eastern Bhutan. It is not based on thorough historical research, which would be worth a document many times the volume of this book.

1.2. Administrative structure, village organisation and religion.

National and regional administration.

Before the 17th century, eastern Bhutan was divided into petty kingdoms ruled by local kings. Still quite a few of them are known through written history. The foundation the modern state was reportedly done by *Shab-drung* Ngawang Namgyel who entered the country after taking refuge from political strife in Tibet in 1616. The esteemed lama had eight *dzongs* (castles) built to rule the area, some of which exist up to now. One of the old dzongs is Tashigang dzong from which the eastern part of the country used to be ruled. The *Shab-drung* introduced a system of local governance through the *Pönlops* (the rulers of regions) and the *Dzongpöns* (district administrators); some reforms resulted in an equivalent function presently called *Dzongda*, the administrative head of a district. Now the core local administrative structure consists of twenty districts. The role of dzongs as administrative centre is quite different in western and eastern Bhutan. This difference is possibly caused by the fact that the administrative system was introduced from Tibet and therefore fits best with the tradition of the western Bhutanese people, who are after all of Tibetan-Mongolian origin, while eastern Bhutanese are of Indo-Mongolian origin (Hasrat 1980). In western Bhutan, the administrative language and people's language are the same, while the religious practices stem from the same origin, i.e., the Kajupa sect of the Mahayana school of Buddhism. Both language and religion are uniform in the administrative centres throughout the country. In eastern Bhutan, the people speak various local languages, mostly Sharchop-kha. Eastern Bhutanese lamas follow the Nyingma-pa tradition of the Mahayana-school of Buddhism, one of the bigger traditions in Tibetan Buddhism (that is also quite popular in Europe and the USA). In daily life, eastern Bhutanese people respect the traditions of both sects: religious festivals (so-called *tshechus*) organised in dzongs are equally well visited as local religious festivals, although the people's right to invite high lama's from outside to the country is subject to permission by the government.

Village administration.

When one travels the countryside in Bhutan for the first time, it looks like individual houses and villages exist independently and isolated from the rest of the world. Closer observation reveals that even the remotest village and even that one single house up the ridge is integrated into the political and legislative system. In daily life, the district administrative centre plays an important role in jurisdiction beyond the power of village elders, and in developmental programmes. Each household pays taxes in money and labour. Most households have one or more relatives working as civil servants or in the army outside the village. People are regarded to represent their families, and suspected contentious behaviour of one family member may result in temporary restricted access of the relatives to government procedures. Thus, individual civil servants display overwhelming support to the government and not always form or formulate their individual opinion. One's permanent assignment may not be a guarantee against developments out of one's control. This influences most individual civil servants' readiness to do an outstanding job, particularly once he or she is progressing in his or her career. In villages, people are expected to show polite interest in programmes organised by the government. This makes initiating activities in villages relatively easy, although it is difficult to say whether people co-operate warm-heartedly, or as a duty towards government people. When programmes need further co-operation of villages, they need to be embedded in the village community in one way or another, which is beyond the power of the district administration. Thus, some basic knowledge of the administrative structure of villages is a prerequisite for successful work, and in the following paragraphs I will give a rough and generalised sketch of the local set-up of villages as found during IPM programme implementation.

The official block headman, the *gapu,* is a kind of mayor. The people nominate him and when people chose an acceptable candidate the district administrator endorses his candidacy for the post. The mayor represents his block in the district development committee, heads the block development committee, in which all block villages are represented by their respective *tshok-pas* or village heads. Such village heads are important partners in village level development activities. In most villages there is an *amchu-tshokpa,* a lady village leader by her membership of the national women's association. The association organises a variety of activities for rural women such as training on handicraft production, nutrition and hygiene and study tours. Amchu-tshokpas are often important counterparts in extension programmes, some may be village health workers, others carry out innovative work in vegetable growing, etc. They are often well-motivated to participate in programmes and they are stable residents of villages (Schoubroeck *et al.* 1999). Other official local functions include helpers of the mayor, *mang-aps,* helpers of the village headmen, *chupen or tshopla,* and in some districts households that are expected to provide food and shelter to visitors from outside, *tosapa phai.*

Individual households.

So far, only official administrative village-level functions have been discussed, but, when choosing working partners in programme practice, awareness of individual farmers' informal roles is often equally important. During six years or so field work in villages we developed an informal classification of various individuals' roles in villages, based on the classification of the individual's innovativeness as proposed by Rogers (1995). A first small and very important category of farmers form the *innovators,* sometimes isolated and often hard-working farmers who solitarily experiment and carry out best practices found in the area. These people often have some religious schooling, or are retired armymen, and they are important innovators, although their colleague farmers are hesitant to take over many of their practices. *Early adopters* often do most of the work to try out and adapt new technology; they are the best learners in technical sense, but often do not have the social skills or status to have innovative practice accepted in the community. Such people often need support from outside facilitators for carrying out their constructive work and withstand scepticism in the community. If programme staff does not support *early adopters* properly, or if the programme is discontinued before positive results are achieved or recognised (see Chapter 4), these people may suffer social "damage", particularly if they openly involved in the programme. Most women village leaders participating in the programme were *early adopters.* Important sources of local influence were the *opinion leaders,* one or two houses in each village that play a key role in communication, often because one of the household members is a vocal member of the community. In Bhutan, *opinion leaders* are often well-respected young ladies and occasionally village-based educated men. It takes some time to identify such leaders and it appeared essential to keep track of the sentiments they spread as they often "make or break" programme support in a village. In every village there is at least one *programme opponent* (not identified by Rogers, possibly because he mainly studied adoption and not so much rejection of innovations): that one old man who opposes any innovation, on whatever ground he can find. Programme opponents are a factor to reckon with when technology is to be introduced over an entire village. Sometimes the community keeps opposing sentiments within the group, to pop up when programme success is delayed or poorly recognised. Even when the programme is successful, it is good to have programme opponents express their doubts, and go and talk to them to discuss on-going activities, even if they rarely change their views. These people may make a lot of hassle during processes of change, but they play a key role in bringing in emotion, and therefore commitment, to discussions.

In eastern Bhutan there is no worked out caste system like common in Hindu societies, although older people tell that there used to be caste type of divisions between houses. The few remains of the old caste system include the presence of high caste households, locally called *khotsi* houses, which to me do not look very different from other houses. On the other end, there are cursed households whose food is supposed to be poisonous (in spiritual sense), such poison is locally called dook that you may encounter through eggs and local drinks. It is the fear of every eastern Bhutanese to get in touch with dook, and it takes a great many religious ceremonies to undo the poisoning (if this is possible at all). Even worse than getting poisoned is the threat to be marked as dook-household one self. This fear is definitely one of the binding factors in village societies, where black magic is commonly feared and suspect households are occasionally expelled from the community. When walking around in villages, most of our staff made it known that they did not believe in such black magic, and took food in houses irrespectively of their supposed poisoned food and drinks, which, apart from the regular hick-ups, never had a lasting influence on our health. Eastern Bhutanese were tolerant to this unusual behaviour and attributed our apparent immunity to dook to our explicit disbelief in the idea.

Religious organisation.

The religious organisation is very influential in any village. The local Nyingmapa-tradition regards high lamas as reincarnations of various historic religious leaders, and people travel for days if not weeks to meet an important lama. There is a hierarchy of lamas; the most important leaders live in Sikkim, where many local boys enter religious schooling. Locally reincarnated lamas are usually associated to one temple, and cover a few hundred to a few thousand households. On top, there is a local network of religious workers: possibly one in ten households is headed by a lay monk who is educated in religious skills, and occasionally women play a religious role as well. Some religious functions may be of pre-Buddhist origin. Lay monks' tasks vary from assisting higher lamas during religious ceremonies, doing small ceremonies to heal one person, to local healing practices such as removing (spiritual) poison through blood-letting. There is an extensive vocabulary on diseases and the classification of diseases is often not compatible with western medicine. Chasing bad spirits and undoing black magic is definitely one of the important tasks of the religious class. Religious leaders play an important role in local acceptance of pest management programmes, as there is some incompatibility between pest control practices (that often entail killing insects) and religious prescriptions (that forbid killing of any living creature). Chapter 3 touches on the tensions that sprouted from this emergent inconsistency between innovation and tradition.

1.3. Pest management and language.

People originating from eastern Bhutan speak a language called Sharchop-kha (Box 1). A few villages in bordering Arunachal Pradesh reportedly speak a similar language, while there is one settlement of Sharchop-speakers in Tibet consisting of people originating from Bhutan whose ancestors once fled the high taxes imposed by the government at the time. The language is one in the Tibeto-Burmese language family although it is not closely related to any other language in Bhutan. Possibly, it is related to Bodo or other tribal languages spoken in Arunachal Pradesh, Assam or Meghalaya under India. The language is one of the four languages in which the radio broadcasts. The national newspaper is not printed in Sharchopkha, as the language does not have its written equivalent.

Box 1. A few notes on the grammar of Sharchokpa-lo, the language of eastern Bhutan.
Sharchokpa-lo is a language of the Tibeto-Burmese group that has little in common with Indo-European languages. It is not a tonal language like Chinese or Thai. The guiding principle of conjugation is different from Indo-European languages, as it is not so much based on the person number (1st, 2nd and 3rd), but also on the relation between the speaker and what he or she wants to express. For example, I can say ***"Tshalu se bu lhakpa la."*** *meaning: "the mandarin fruit is infested with maggots" in the distant form, meaning that I quote some research or other source of information that I have not checked myself. On the other hand, if I say* ***"Tshalu se bu lhakpa cha"****, it means the same with the notion that I have seen the infestation myself, and that I am more knowledgeable about maggots in fruit. Basically speaking, the two forms reflect comprehensive and apprehensive knowledge respectively (see section 2.2) These different forms are difficult to master for speakers who are not used to the direct expression of their personal involvement in the words they speak.*

Another interesting feature is the detailed way in which probability can be expressed. An expression such as: ***"aha khotken shekpa cha"*** *means: our brother-in-law just came (I met him just now), contrasting with* ***"aha khotken shekpa la"*** *(my sister said he came);* ***"aha khotken shekpa giwala"*** *(I think he must have come);* ***"aha khotken shekpa cha ophe"*** *(possibly he might have come)* ***"aha khotken shekpa la gidu"*** *(if you say he would come then I think he should be there). However, some words reflect facts, even if expressed in doubt:* ***"jang waktsha malhakpa cha gidu ko may"****, "I think it is not likely that I am pregnant" means that the lady uttering the remark is pregnant but does not want to straightly express so.*

In Sharchokpa-lo, verbs can be easily made into nouns. ***Tshong-me*** *means: to show, to sell.* ***Tshong-pen*** *is shopkeeper,* ***tshong-khang*** *means shop,* ***tshong-khan*** *means: seller,* ***tshong-me chala*** *means things to sell, etc. This feature (of which many variations exist) make that one needs just a few verbs to be able to express oneself in detail, and thus non-Sharchopkha speaking Bhutanese maintain that the language is easy to learn.*

Rather than a polite form, the language has a particular vocabulary for speaking in respect, thus ***jonme*** *is a polite form of* ***dele*** *(=to go), which is particularly difficult when you are asked a question in polite form. Where are you going* ***"Nan o jonme ya?"*** *should not be answered with the same* ***jonme****, as this means the speaker respects himself. It should be answered* ***"Jang Dungmin ga dele"****: I am going to Dungmin.*

Sharchopkha borrows words from Tibetan for its religious vocabulary, from Tibetan and Dzongkha (that again originates in Tibet) for its political vocabulary, from Hindi and English for its technical vocabulary, and from Dzongkha for its polite vocabulary. The assimilation of polite speech from

Dzongkha occurs in most Bhutanese languages (with perhaps an exception of Lhotsampa language in southern Bhutan). Possibly, the rulers in the various Dzongs used to (and mostly still do) speak Dzongkha, and farmers pay them respect by using words of the polite form of Dzongkha, even if they do not speak the national language. The basically Indo-Mongolian language of eastern Bhutan has become heavily influenced by the Tibeto-Mongolian language through centuries of political originating from Western Bhutan. Thus, the polite form of the language consists of Dzongkha vocabulary, and when people use the polite form most Northern Bhutanese language speakers basically understand each other.

Although Sharchopkha is a farmers' language, it lacks a vocabulary on pest management. There are terms for the process of decaying but there is no vocabulary for causal organisms for diseases and rotting, which people often believe to be caused by spiritual influences. The naming of insects does not always reflect their functions in agro-ecosystems and is not always consistent with the division in orders and families entomologists use. On one hand, bugs (Hemiptera) are just like in scientific tradition put in one group called *na-bu*, even if the group is highly variable in look and in the ecological niche individual species occupy. On the other hand, there is no common word for "beetle", beetles are named according to their size and colours and the place where they are found (*Borang-toka*: big insect from the forest). Sometimes we invented names for important pest species. For example, when farmers saw living individual chinese citrus flies, they often referred to them as *warongma*: wasp (not to be touched as it may sting: the fly exhibits apparent successful mimicry of a wasp common in citrus). This name was misleading with reference to the fly's function in the citrus ecosystem: the fly can not sting, and oviposits in fruit rather than honeycomb-like nests as the particular wasps do. Farmers of a few villages distinguished a damaging fruit fly species they called *kaki-bu* that oviposited in cucumbers and pumpkins. Thus, we named the chinese citrus fly *tshalu se ga kakibu* (mandarin-fruit fly), or later just *kaki-bu*. By just tagging this name to the organism previously perceived as a type of wasp, people changed their perception of the organism. This was a start of demystification of fruit drop, that so far had been regarded a supernatural or otherwise non-understood phenomenon. Similarly, during village organisation activities, functions had to be invented for people who were actively involved in citrus pest management. The term *tshalu tshokpa* (mandarin-leader) made a nice alliteration and gave the active members of the committee a status, as the word *tshok-pa* (village leader) had an official denotation. It must be noted that such language-tinkering is not very common in contact between government officials and farmers, as it is official policy is to use the national language during extension activities.

1.4. Culture, economics and opportunities for agriculture development.

Bhutan's culture and social system is deeply influenced by religious beliefs and organisation. The country is proud to have a living tradition and a rich cultural heritage. The Kajupa organisation of monks is well represented in the national assembly and the head of their organisationstands next to the district administrator in the official hierarchy. This influence of religion is equally important in villages where (lay) monks are consulted for issues varying from making sure that construction ground is free from evil influences to healing of people who are possessed by spirits. More scientifically-based education has been introduced only recently and, compared to the religious tradition it does not play a very important role as yet, although its influence is growing steadily. This has certain consequences for the (science-based) innovations in agriculture, as promoted by developmental plans. Religion is often very tolerant to such innovations, yet, causal thinking and its consequences for technology application has often not entered mainstream thinking. Examples of this phenomenon will be discussed in Chapters 2 and 3.

The locally variable climate and soils and topography to a great extent determine local farming systems, including cropping patterns. Maize and chillies are important at all altitudes, and other locally important crops include potato, wheat, barley, millet, buckwheat, mustard, a liliaceous root crop, and many more smaller crops including a wide variety of vegetables. In most villages it is common practice to collect ferns, orchids and mushrooms from the forest to process them into tasty curries. Households keep cattle for traction, milk and manure production, and sometimes pigs and poultry are kept for meat and eggs. Most of the agricultural production is for households' own use. Within villages there is some trade of maize and local drinks, as well as an occasional exchange of eggs, diary products and meat, apart from exchange of labour. Most important cash crops are potato and mandarin in high and low altitudes respectively, both for export to India.

In 1990 the Bhutanese rural household population was estimated to be 67,400 rural households that comprised about 84 % of the total population (Kinlay Dorjee 1995). At the time, about one-third of the rural households lived in the eastern part of the country; in the years to follow that fraction must have increased. The rural economy is commonly regarded as a subsistence farming economy, although to me it seems that rural non-farming activities are more important than most literature on rural Bhutan suggests. Such activities include local administration, providing religious services, construction work, transport, handicraft production (weaving or manufacturing of musical instruments and utensils), these non-agricultural activities may altogether count for half of the labour performed in most villages. Thus, although subsistence agriculture is the primary and eye-catching activity in villages, many sidelines, including cash-cropping, form an important part of the economic activities in rural areas and the rural economy is better described as a semi-subsistence economy[1]. This is confirmed by various farming systems studies. For example, in semi-subsistence farming systems in central Bhutan, cash generating activities are carried out in addition to (rather than at the cost of) traditional subsistence farming activities. Even if the local cash crop, potato, is grown in traditional fields, their production does not affect the production of traditional crops because land use is intensified (Guenat 1991). For additional cash income through citrus this counts even stronger: most traditional citrus orchards occupy the poorer soil in villages and thus hardly affect traditional production. Competition between labour input for citrus and for subsistence crops is also limited because most labour in citrus is required during the harvesting season in autumn while labour for subsistence crops is mostly required during spring and summer.

In eastern Bhutan there are no taboos of men working on land (as is common in western Bhutan), yet, women carry out most of the agriculture work. This "feminisation of agriculture" is a result of out-migration of educated people from villages, and local division of labour. Men remaining in the village are often more involved in non-agriculture activities than women, although in some villages many women are skilled weavers (Schoubroeck *et al.* 1999).

The relative isolation of cash cropping from the subsistence functions in the farming system had important consequences for the development strategy the citrus programme adhered to. If citrus cultivation can be regarded as a more or less separate activity, programme implementing staff does not have to worry too much about repercussions of programme activities on other, non-commercial farming activities (apart from the fact that this is the farmers' rather than staff's domain of decision). Thus, one does not have to map and understand the farming system as a whole. On one hand, programme staff was aware of the socio-economics of communities

[1] Semi-subsistence households primarily live from their own production, but also interact with markets (Guenat, 1991, p.65).

through extensive interaction while staying in villages. On the other hand, the programme concentrated on the further development of one opportunity, i.e., cash crop development in the local (agricultural, social and economical) context. Farmers for themselves decided whether they make use of the developed opportunities or not.

1.5. In what types of crop can IPM contribute best to economic development?

When starting an IPM programme we wanted to work on the crops in which application of IPM technology bears the best potential for improving the life of the rural population, even if the national policy often stresses the importance of food crops, particularly rice. In eastern Bhutan the importance of food crops such as maize is compelling. A good maize harvest results in a relaxed year for farmers, but one should understand that the maize economy has some particular characteristics. Maize is hardly marketed, as the market price is often lower than the in-village price; the produce is used for food and for processing into local drinks. When the maize harvest is poor, people cut back on their consumption of drinks, so that their food supply is ensured. Excess produce can not be stored for over a year, and after a good harvest, people organise (religious) parties with plenty of eating and drinking. Thus, for maize it is more important to stabilise yields than to improve them. This leads to the paradox that, although farmers consider maize as their most important crop, they are unlikely to invest time and money to activities for further improvement of the average harvest. Thus, developing a monitoring system and a baiting method for cutworm in maize was not likely to be a wise investment, as farmers were not likely to adopt the method. This observation is applicable to pest management in which during the cropping season extra investments are needed, and less so for measures such as variety improvement; just changing a variety for a better yielding one might be rewarding to farmers.

Cash crops however play a different role in the rural economies. The better yields farmers get, the more money they make, and money can always be saved or flexibly used for immediate needs. More in general, the creation of tangible opportunities through technology development (in addition to mobilisation, organisation and training) is one of the options to alleviate rural poverty (Röling and de Zeeuw 1983). In eastern Bhutan, the most important cash crops are chilli, potato and mandarin. Potato is grown in a few clusters of high-altitude villages (over 1,800 m asl.), and mandarin in all mid and low-altitude villages (up to 1,600 m asl.). In potato, late blight is a problem that affects yields once every few years, while in mandarin, quite a few pests do considerable damage. It was concluded that plant protection research to improve yields of cash crops bore the best potential to have socio-economic impact. This notion was confirmed by a study in central Bhutan on traditional farming systems transforming to a semi-subsistence system. A survey in about 200 households showed that households with cash cropping entertained higher cash revenues, increased expenditures (mostly invested in rice), thus improved food security, and had a better human nutritional status. Growing cash crops did not result in the decrease of traditional crops, instead, more output was generated per unit land and labour (Guenat 1991). The study of Guenat dealt with households that planted potato as cash crop in an area far away from the market in India. This study deals with mandarin in an area relatively close to the market in Assam, in which the benefits of improved cash cropping may be even more pronounced. Other comparable studies were carried out on local cash crops such as potato (DoeDoe, Khangma, pers. comm.) and chilli (Marja Kool-de Rie, Khangma, pers. comm.).

1.6. Mandarin is the main cash crop in Bhutan with a vast potential for better profits.

Almost all cultivated citrus species can be found in Bhutan, although most of them are planted sparsely. The more common species are mandarin (*Citrus reticulata* Blanco), citron (*Citrus medica* L.) and a type of lime (possibly *Citrus aurantifolia* Swindle). Mandarin is widely planted for commercial purpose and is by far the most important species. Citron is indigenous to the area and it grows in the wild in the lower strata of mid and low-altitude forest. The life cycle timing of the chinese citrus fly is well adapted to the phenology of citron which might well be its original host (see Section 5). A local type of lime grows between 700 and 1,900 m altitude. Subba (1984) reports that its Nepali name is *kagsi nimboo*, which may be a variety of C. *aurantifolia*. The name of this lime in Sharchokpa is *nimba* fruit; however, the rough shape of the fruit's skin, the medium acid taste and its tolerance to frost make this identification uncertain. This local lime is well adapted to the local conditions and often grows wild. Indian and Nepalese people process its fruit into tasty pickles. In this study lime bears importance because it is the main host of the chinese citrus fly in the early oviposition season and may well be used as trap crop in that period.

This thesis deals mainly with mandarin because of its great economic importance in the region. The Bhutanese mandarin is classified in the C. *reticulata* group, which is a wide collection of varieties in itself. Like all citrus, its origin is believed to be in north-east India and south-west China, so Bhutan may be situated in the gene centre of the species. Mandarin has been cultivated in China since thousands of years, and since the early 19th century the species spread all over the tropical and subtropical world. Mandarin is generally seen as the most cold-resistant citrus variety (although we found that the local lime variety was more resistant to cold than mandarin), and the tree tends to be alternate bearing. The name "tangerine" is quite inconsistently tagged to a few mandarin varieties, particularly in the USA, and to complicate things further, in India and Bhutan the fruit is referred to as "orange". In this study the fruit will be called "mandarin" which seems the least confusing term for an international audience.

The Bhutanese mandarin variety.

The variety grown in Bhutan is probably close to *Nagpur suntara*, which is grown in China, Japan, the Philippines, Brazil and India under a variety of names. The variety grown in Bhutan is probably the same as the one grown in Darjeeling and Sikkim (that is locally called "Sikkim mandarin"), and in Nepal, Arunachal Pradesh and Meghalaya ("Khasi mandarin"). Unlike almost all commercially grown citrus world wide, the variety is seed-multiplied, and the fact that within orchards trees have fruits of varying quality suggest that the variety is a landrace implying that there are genetic differences between individual trees. Mandarin is grown between 300 and 1,600 m altitude. Trees perform best between 900 and 1,300 m altitude although varying microclimates result in vigorous orchards at other altitudes as well. At low altitude trees form a loose and open canopy and develop relatively few big and very sweet fruits. At higher altitudes fruits tend to be smaller, less sweet, and more in number. The skin is usually not puffed, although easy to peel off. Principal harvest time is November-January, although in places without a nearby market not all fruits will be harvested and some may be picked up to April.

Yield constraints.

In mid-altitude orchards, individual healthy trees bear between 150 and 400 kg per year (equivalent to 15-40 tonnes per hectare), although over larger areas this level of production is never reached. Orchards typically yield up to 6 tonnes per hectare (Fullerton 1988, confirmed by additional observations), although yields as low as 2 tonnes are common. The production of individual trees shows that the potential production of the local mandarin variety matches international standards, even if it is neither grafted nor bred in formal ways. Nutrient problems, water stress and damage by pests cause the sub-optimal production in most orchards. Thus, there is ample scope for production improvement with local varieties and it is unlikely that more profitable citrus varieties can be found, possibly except for some high value varieties of lime.

In my view, this means that for better mandarin production, it makes more sense to concentrate on improving management practices than to introduce new varieties. The market value (per kg) of oranges, grapefruits etc. is lower than of mandarin and lime. The local variety is well adapted to local conditions, and farmers themselves are capable to multiply and maintain trees. Moreover, by adhering to the local variety there is no risk to introduce virus diseases. So far, Bhutan has no major virus problems (Vincenot 1994). Elsewhere in the region there have been a few occasions in which great damage was done by introduction of virus pests. In Nepal, in Pokhara area and in various other places, the local citrus cultivation was wiped out after researchers introduced virus. Similarly, in the 1960s in Nongpoh area in Meghalaya, Tristeza and greening virus have been introduced and destroyed the entire citrus culture, resulting in the closing down of a fruit processing factory (Dr. K.M. Sohkhlet, Shillong, pers. comm.). So far, citrus farmers in Bhutan never witnessed such calamities, even if individual farmers occasionally bring in planting material from India. However, the risk of introducing virus is on the rise. In the mid-1990s Bhutan started a citrus germplasm testing programme, in which some individual researchers were neither aware of the risks, nor able to identify possible virus infection (own observation). This programme appeals to the mind of policy makers who think they could improve production through the famous "silver bullet", i.e., just a change of varieties (without change in management) would lead to a sizeable rise of profits. Thus, in my opinion, introduction of foreign germplasm is not likely to improve citrus profits, and jeopardises the citrus virus-free status of Bhutan.

Pest status.

Due to the diverse topography of Bhutan, citrus growing areas vary greatly in terms of climate and soil. Initial surveys revealed considerable regional shifts in the pest spectrum found in individual orchards. The chinese citrus fly *Bactrocera minax* (Enderlein) (Diptera, Tephritidae), causes 35 to 75 % fruit drop (in number of dropped fruits per total production) in mid and high-altitude orchards (>1,100 m asl.). The citrus shield bug (*Rhynchocoris poseidon* Kirkaldy) causes considerable early fruit-drop in low-altitude orchards (<1000 m asl.); and at times, possibly twice a decade, near complete losses occur. Another major insect pest is the citrus trunk borer (*Anoplophora versteegi*) which causes tree decline (die-back), particularly in neglected orchards and in dry areas. Other insect pests include the citrus leaf miner (*Phyllocnistes citricida*), and many small *Homoptera*. Mildew (*Acrosporium tingitaninum*) is a problem in nurseries and in low-altitude orchards, while scab (*Elsinoe fawcetii*) decreases the commercial value of fruits in some orchards. Citrus nematodes have been found but are of no economic importance (Maas 1994). Mistletoe (*Scurrula parasitica*) is a problem in poorly maintained orchards (Parker 1992). Monkeys, birds, and rats feeding on bark cause problems locally. For basic information on the four major citrus pests in eastern Bhutan, refer to Box 2.

Box 2. Life cycle and importance of citrus pests common in eastern Bhutan: mistletoe, trunkborer, shield bug and fruit fly.

Mistletoe (Loranthus spp.) *is a parasitic plant that grows in citrus (and other) trees. Seeds develop in August-October and fouraging birds spread the seeds. Tiny mistletoe plants then penetrate the bark and develop on branches. If left uncontrolled, mistletoe can take over the entire canopy and kill a tree in five years or so, particularly if it is not very vigorous. Control is done by pruning out infested branches and does not take much time if done regularly; it is best to control the pest on communal basis to prevent re-infestation from neighbouring orchards. In some villages, even the forest surrounding orchards is cleaned by farmers. Mistletoe leaves can be fed to cattle and make a fine tea, which may further stimulate farmers to carry out control of the pest.*

Citrus Trunk Borer (Anoplophora sp.) *is a long-horn beetle that causes die-back in mandarin trees. In April-July it lays eggs in the lower stem's bark; eggs hatch and tiny larvae feed on the bark for up to three weeks. Then, larvae bore into the wood, make holes and dispose of "sawdust". Larvae overwinter inside trunks; the following spring adult beetles emerge from freshly bored escape holes. In heavily attacked trees, branches display yellowing leaves, and in a few years (or even in one season) the entire tree may die; however, if properly cared for, it is possible to recover affected trees. Damage is more in trees with regular water stress. The pest is present in most orchards in eastern Bhutan, and damage is usually limited. Occasionally there are trunk borer outbreaks that result in fast decline of orchards over entire villages. Although such outbreaks do not occur very often and at limited scale (typically once in thirty years keeping confined to one village), they have a disastrous effect on the economy of affected villages. The pest used to be conrolled by pasting lower mandarin stems with persistent insecticides such as Aldrin. Nowadays such pesticides are banned and the beetle is controlled by regular checking trees and killing maggots in early phases of infestation.*

The chinese citrus fly (Bactrocera minax) *is a Tephritid citrus pest; it is locally called* ***fruit fly*** *or* ***citrus fly****. The female fly oviposits in summer in developing mandarin fruit. Eggs hatch in autumn and when maggots feed on fruit, it prematurely ripens and drops. In some orchards, the chinese citrus fly takes up to 75 % of fruits every year. In theory, control of the pest consists of luring female flies with proteinaceous bait, and killing them with an insecticide component. In the mid-90s, the here described citrus IPM programme developed practical application of this principle (cf. Chapter 3 and 6).*

Citrus green stink bug (Rhynchocoris humeralis) *sucks fluid from developing citrus fruits. After repeated sucking the fruit prematurely ripens and drops. Farmers and extension staff often do not distinguish between fruit drop by the citrus green stink bug and by fruit fly, so that sometimes the wrong control technology is applied. In the 1990s, the citrus IPM programme developed methods to tell dropped fruits apart with respect to the cause of fruit drop. Literature suggests that the bug can be controlled by keeping a predatory ant in the tree and by killing the bug's larvae that group together early morning on the upper stem. A research programme will be needed to develop this notion into a practical control method; Chapter 3 documents the working relations between stakeholders for such a programme.*

Economic aspects of mandarin cultivation.

Mandarin is by far the most profitable of cash crops grown in Bhutan (Kinlay Dorjee 1995, de Wit and Choeda 1996). Total area is around 8,000 hectare, the crop's export value is more than the value of all other cash crops (including apple and potato) together (derived from LUPP 1995) and is in the order of 5-15 million US$ a year. Between 1989 and 1993 official export data varied from 12,000 to 26,000 tonnes. This figure does not include the traditional trading through mule tracks straight to the Indian market, where no official (state-owned) auctions are established. In villages where mandarin can grow, almost all households maintain small orchards, even if they are situated many days walk from the market. It depends on the price of mandarins on the market whether in a particular year transporting mandarins from the particular villages is profitable or not. For improvement of production technique, specialised technical assistance is needed (de Wit and Choeda 1996). There is ample scope for increase of production and expansion of area (extrapolated from de Wit and Choeda 1996, and own observation). The market situation has improved significantly over the last decades. In the 1960's, road construction started in the country, so that most mandarins are now also transported by lorry. Many households close to the road started establishing orchards, and the crop has developed into their major source of cash income (typically 50 bearing trees per household). A few landowners maintain large holdings of up to 5,000 plants. Mandarins are transported to the border where auctioning takes place. Wholesale prices are Ngultrum 10-15 (US$ 0.35-0.50) per kg. Fruits are exported to Assam and Bengal with more than one hundred million potential consumers. The mandarins are marketed in December-February when other fruits are scarce, and the market can easily absorb many times the mandarin production of Bhutan. The most important threat to the market is trade barriers, monopolies and political unrest, which often have a negative impact on the price. For example, in the Guwahati and Shillong markets mandarins fetch up to Rs 5 per piece, while on the Bhutan-Indian border rarely more than Rs 1 per piece is paid, more so in the official auctions. Even then, the value of two trees' produce represents an unskilled labourer's monthly wage.

Villages situated further from the road maintain the traditional small-scale growing system (ten trees per household). Traditionally, growers traded mandarin fruit for salt, yarn and rice on the border of Assam. Even now, at harvesting time, people from northern districts come down to employ their horses for lucrative transport contracts. Thus, more than production, trading and transport of mandarins is an important economic activity. In fruit producing villages there is a complicated system of contractors and sub-contractors who take care of picking, grading and transporting produce. In this way, the fruits may change owner several times before they are transported down to the market. Households from mandarin producing villages have counterpart houses in the market area; such relationships between houses often go back for several generations.

Kinlay Dorjee (1995) studied the comparative advantages of various crops in Bhutan, with respect to trade to India and Bangladesh. He compared different crops in different agro-ecological zones, i.e., rice, maize, wheat, apples, cardamom and mandarins (named "oranges" by him). He used the Domestic Resource Cost (DRC) as a measure to compare opportunity costs of domestic production to the value it added, which is apparently a standard measure to analyse comparative advantages of different crops. With a DRC of 0.32 for the humid sub-tropical and 0.42 for the wet sub-tropical agro-ecological zones, the comparative advantages of mandarin are robust and can withstand substantial price fluctuations from current levels (p. 58). If political turmoil in Assam subsides and trade is liberalised prices will considerably increase. In addition to the economic benefits from orchard cultivation there are environmental advantages if mandarin is compared to cultivation of annual crops in the high rainfall zone.

1.7. Three phases of learning: appraisal, research and scaling-up.

The previous sections provided background information for the citrus IPM programme as the Regional Plant Protection Centre of Khangma, eastern Bhutan, and its local counterparts carried it out during the mid-1990s. The programme can be divided in three phases: an exploratory phase, a research phase and a scaling-up phase. The three phases are discussed separately, in the form of three more or less separate studies that try to explain out in what respect each phase was effective, and in what respect it was not.

In Chapter 2 the exploratory phase of the programme is discussed. It starts with an exposure on the technical definition of IPM and on learning theory utilised in Farmers Field Schools for IPM. It describes how the plant protection service and one district's extension service set up a citrus IPM programme based on existing technical and extension knowledge. While implementing the programme, a more participatory extension approach appeared to have important effects on the way different stakeholders perceived pests problems in citrus.

Even then, a few key pest problems could not be solved and further technical and organisational knowledge was to be developed to be able to control a few key pests. Chapter 3 further elaborates on learning, particularly in group settings. It briefs on social cognition theory and shows that the diffusion of innovations theory does not explain how innovations to be applied at group scale (such as village-wide IPM) spread. It questions how such technology can be developed and tested. It describes the dynamics of two village research programmes and tries to figure out how research can produce technology tailored to the application in villages. In-village research included technical research on the chinese citrus fly and the creation of social conditions for IPM application. On-station research complemented village research through the development of tools farmers and extension staff used to monitor the fly. It concludes that for the IPM of the citrus fly a type of "socio-technological knowledge" is needed that obviously includes technological and cognitive preconditions for a robust organisation of control.

Chapter 4 takes another step ahead and wonders whether, and if so, how the agriculture extension service can disseminate socio-technological knowledge over villages. It shows that, in the present set-up, district extension services are not well equipped to spread knowledge developed in villages. It uses social cognition theory and diffusion of innovations theory to explain why mainstream policies are not formulated in response to local problems, but as a result of international opinion making.

2. Learning phase I. Introducing experiential learning for citrus IPM.

IPM research and more successful orchard management in southern Bhutan suggested that citrus management in eastern Bhutan could be substantially improved. A citrus management extension programme was initiated with the objective to make farmers adopt recommended technology. Programme praxis showed that IPM technology developed on-station as well as some traditional extension recommendations lacked practicability. Knowledge in different social groups (farmers, extension staff and researchers) needed an empirical check, and elements of experiential learning were introduced in the extension methodology. So it appeared that some individual farmers had long been applying practicable technology, that hardly disseminated to other citrus growers and that was not known to researchers and extension staff. Exploration of such farmers' knowledge resulted in a substantially improved package of citrus IPM recommendations and some knowledge on the role of various players in the agriculture knowledge system.

2.1. Initiating a citrus IPM extension programme[2].

The previous sections sketched the situation in eastern Bhutan within which the plant protection service was to develop an IPM programme. Possibly increased citrus production could significantly add to economical development of small orchard holders (Section 1.5), and there were a few important pest problems (Section 1.6). The Pemagatshel district administration requested assistance in addressing citrus cultivation problems after orchards in a few villages seriously declined. We used farmer acceptance as the criterion of adequacy of technology (Ashby 1987). Pest control methods that were widely applied in parts of southern Bhutan were apparently adequate and yet often not practised in Pemagatshel district, resulting in sub-optimal mandarin production. Moreover, researchers had developed new ideas on pest management in citrus that were to be disseminated to farmers in the area. Thus, the plant protection service and Pemagatshel district initiated a joint extension programme on citrus. The programme started with the notion that IPM technology was available, and that current extension routines had the potential to disseminate knowledge on IPM. The task of the programme was to disseminate knowledge on IPM technology, to improve mandarin yields through better crop management practices by farmers.

The citrus management extension programme was carried out as follows. The programme area was Pemagatshel district, eastern Bhutan. The district administration and the regional plant protection service jointly implemented the citrus extension programme. One district staff, Mr. LN. Sharma, was designated as representative of the district in the programme. Mr Sharma had a thorough knowledge on the area and was fluent in the local language. During the first tours, programme villages were identified; selected villages were situated up to two days walk from the road near the district headquarter and in Assam, and belonged to the remotest and poorest places in the country (see Chapter 1). Activities were carried out in about 25 villages consisting of between six and 120 households each. During tours, the programme team consisted of Mr. Sharma and the present author and varying associated staff and students. The team walked to a village, organised training sessions, visited orchards and walked to the next village. The district extension service made use of a practical routine to carry out training activities: upon arrival in a village, staff contacted the village headman and a time for the training session was fixed. Each household was expected to send one representative, training meetings were held in quiet places such as in big houses or in temples. The citrus programme introduced two implicit innovations compared to previous extension practices. First, in stead of training on a variety of subjects, training concentrated on citrus alone.

[2] The programme was discribed in more practical terms in Schoubroeck and Sharma (1994) and video-filmed by Kleinheerenbrink and Schoubroeck 1993a.

Second, villages were visited repeatedly, so that feed-back on programme efforts could be sought and activities could be tailored towards the needs of the particular community. It was hoped that these two changes would make the programme more effective in improving farmers' know-how and yields. Initially, the programme drew on existing knowledge on citrus management available in the extension service. Confinement and repetition of training allowed for monitoring the effect of training on farmers' practices so that throughout the programme, feed-back was sought through informal interviews, group discussions, individual orchard visits, observation of people's practices, etc.

When I slowly started to understand the local language, it appeared to me that extension staff did not readily take over information on citrus that research staff was trying to introduce. Moreover, farmers did not always apply information extension staff had been lecturing for over a decade. The knowledge of farmers, extension and plant protection staff was not always compatible and needed reconstruction through an empirical check. For this, a few more changes were introduced in the mode of extension. We introduced a few experiential learning elements in the on-going programme. Before formulating research questions and describing the programme, I first want to present a few elements of experiential learning theory that played a key role in the difference the programme made compared to earlier extension practices.

2.2. Conventional learning and experiential learning theory.

In conventional Agricultural Knowledge Systems (AKS), learning is supposed to happen through a linear flow of information. Science is seen as the major source of new ideas and technologies and constitute a center-periphery process that does not allow for multiple sources of new ideas. Röling, 1992: "(...) *the model assumes that technology is applied science (...) A favourite metaphor is that of a commodity: technology is seen as a single, uniform product that is "delivered" to "users"*. One can imagine that learning in such a linear transfer-of-technology system takes the shape of scientists informing extension staff who in their turn inform farmers on technology developed by researchers. The vast majority of agriculture extension services are organised according to this model. Nevertheless, the "commodity" metaphor of knowledge appeared to have its shortcomings: *"The commodity metaphor ignores the fact that technology usually changes as knowledge products move through knowledge systems, and that farmers "reinvent" technologies before incorporating them into their production systems."* A well-known innovation in extension practice that took this transformation of knowledge into account is the Farmers Field Schools (FFS) for IPM in rice in Indonesia, that acknowledged the notion that knowledge had to be reconstructed in the mind of every trainee (van de Fliert 1993). FFS drew heavily on experiential learning theory, and thus, I briefly look at this theory as synthesised and further developed by Kolb (1984). Kolb shows that learning is best conceived as a continuous process rather than an activity with expected outcomes. Learning is holistic in character: *"To learn is not the special province of a single specialised realm of human functioning such as cognition or perception. It involves the integrated functioning of the total organism – thinking, feeling, perceiving, and behaving"* (p. 31). An individual's knowledge is adjusted and re-formulated based on personal experience, just like in the empirical cycle in natural sciences in which theories are continuously built and adapted or rejected through experimental evidence. Phases of the experiential learning cycle distinguished are *concrete experience, reflective observation, abstract conceptualisation and active experimentation* that follow each other in a circular pattern (Figure 1). For example, a farmer sees one of his mandarin trees displaying yellowing of leaves [concrete experience], he may attribute the symptoms to current drought [reflective observation] as all plants become yellow and wilt under dry conditions [abstract conceptualisation]. Thus, he irrigates the tree [active experimentation] and finds that the tree does not recover, he sees sawdust on the lower trunk [concrete experience], thinks for a while and attributes the yellowing to insects gnawing at the tree [reflective observation] ... etc. This process contrasts with traditional transfer of knowledge in which extension staff informs farmers that "Yellowing trees should be treated with insecticides on the lower stem..." or "IPM is the management of pests via the integration of chemical, biological and cultural methods ...". Thus, the nature of learning is interaction of apprehension of immediate concrete experience (observation) and comprehension of symbolic representations of experience (understanding). Transformation of knowledge from apprehension to comprehension takes place via intentional reflection (thinking), or the other way around via extensional action (experimenting). This is the way all people learn, although some individuals lay more stress on the comprehensive aspects of learning (conceptualists) and others more on the apprehensive aspects of learning (pragmatists). The structure of knowledge is thus a continuous dialectic process between apprehension and comprehension, equivalent to switching between practice and theory, observing and understanding, implementation and policy, to name a few common equivalent dialectic processes.

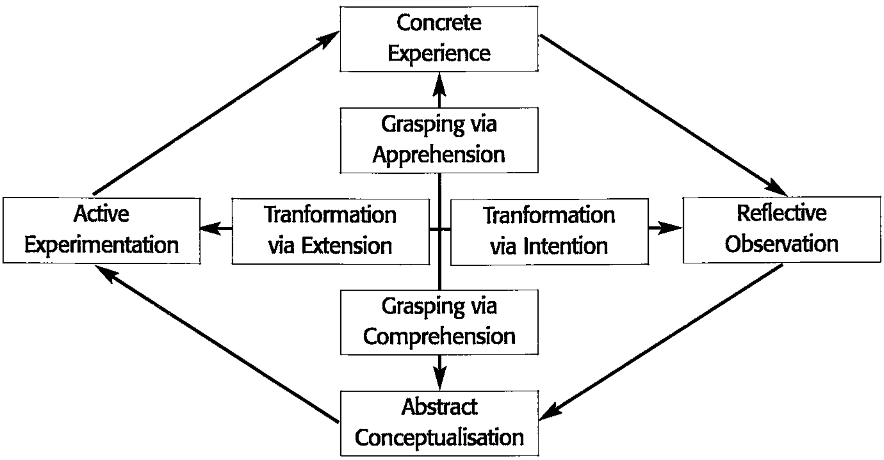


Figure 1. Structural dimensions underlying the process of experiential learning and the resulting basic knowledge forms. From: Kolb, 1984, p. 42.

Just as theories in natural sciences are being continuously verified and thus modified or replaced, the building of an individual's valid knowledge also needs continuous feedback – to place practical knowledge in a comprehensive framework, and to reframe comprehension through apprehensive experiences. I wish to take this dialectic process as a central concept in this study and will refer to it as searching for feedback. The word feedback is well understood by agronomists (usually with a natural sciences background), who often have a major say in the organisation of the knowledge flow in the agricultural system (that is governed by sociological processes). The term feedback is also acceptable to policy makers, even if they have a human sciences background.

The experiential learning theory has deeply influenced modern ways of looking at learning. In the field of agricultural extension, it is reflected in the changed role of extension agents: rather than bringers-of-new-information, they now become facilitators in the process of knowledge building. This new role is possibly best worked out in FFS-type of extension activities. We used some elements of experiential learning theory in the citrus extension programme (see Table 1), and consequences of this move are discussed in the following sections.

Table 1. The introduction of experiential learning elements into citrus IPM extension activities.

	Traditional pest management extension activities	*... including experiential learning elements*
Role of farmer	recipient of information as determined by extension and research staff	farmer is an experimenter playing with proposed control options
Role of extension staff	transferring information from research to farmers	bringer of control options from successful farmers and observant of farmer's experimenting activities
Role of researcher	producer of pest management options	combining farmers' practices and pest management theory
Programme characteristics	linear flow of information from research via extension to farmers in one-time classroom situated meetings	in-field evaluation of farmers' experiments during repeated visits; farmers and staff discuss and adjust proposed measures
Strength	fast diffusion of information over the farmers' population	research combines farmers' and extension staffs' knowledge into replicable pest control methods
Shortcomings	poor verification of measures' validity in field conditions; only measures working on individual basis may be adopted	fundamental technological innovation hardly takes place; only measures working on individual basis may be adopted; difficult to apply as isolated initiative in autocratic societies

2.3. Intervention and research question.

In the early stages of the citrus programme it was found that the body of knowledge of the different stakeholder groups was not always relevant or compatible with practice. Lectures were the main medium transfer of information (i.e., training concentrated on repeating comprehensive knowledge) and this information needed empirical checks for relevance, practicability and validity (i.e., it needed feedback through practical experience or apprehension). Prerequisite for such feedback was the presence of trees (experiential material). Therefore, the training site was shifted from in-door to the field, where contents of lectures could immediately be verified by observing live trees. Staff also got feedback on the practicability and validity of training contents by observing farmers dealing with real trees.

When we compare conventional extension practice with practice in the citrus extension programme, innovation can be summarised as changes in three interrelated fields. The programme featured *confinement of subject* so that stakeholder groups could monitor changes in practice. *Repetition of training* enabled stakeholders to adapt training methodology and contents based on earlier observed failures and successes. Without these two changes, *in-field experiential learning* could not be effective. After all, learning includes monitoring the results of earlier activities and adjust activities upon earlier experiences. If activities have too wide a scope (such as in general training) it is impossible to monitor the effect of the training, while at the same time training should be repeated to be able to adjust training to the monitored needs of farmers. The citrus IPM programme stuck to these principles in its programme design. The principles were nothing more than hypotheses that were tested in the field. It was supposed that enriching the extension methodology with experiential learning enabled staff to observe how farmers perceived training and adapt training contents and methods if deemed necessary. It was hoped that change resulted in a chain reaction of new learning experiences. The study tries to see whether the experiential learning elements in the training indeed effectuated changes in learning experiences of the three stakeholder groups. Thus, research questions were formulated as follows:

- *In the citrus extension programme, what were the consequences of confinement of subject, repetition of training and in-field experiential learning for learning experiences of different stakeholders?*

- *Does this change in learning suffice to make farmers adopt IPM practices?*

In the following sections, the shift in learning situation is described separately for each stakeholder group. In addition, the existing body of knowledge of each group is analysed through empirical check with criteria such as relevance, practicability and validity. In my opinion, the three stakeholder groups should at least agree on the technology proposed to farmers even if they may have a completely different view on the possible improvements of citrus cultivation. After all, the research and extension services' objectives are to technically inform farmers on better cultivation options and therefore these options should eventually be agreed upon. Finally, there is one more dimension in the programme that needs to be discussed. The continuity of the learning processes depends on the level of support of different actors to the programme, and thus the dynamics of programme support by various stakeholder groups is briefly discussed.

2.4. Stakeholder groups' learning experiences.

The previous section introduced the shift from learning in transfer-of-knowledge to experiential learning and the introduction of feed-back into the extension programme. This section discusses the consequences for knowledge of each stakeholder group.

Learning experiences by extension staff.
The task of the extension service was to spread existing knowledge on agronomical technology over farming communities. Extension staff appeared to have the most explicit body of knowledge on citrus management available, which the citrus extension programme used as a start. This section argues that the predominantly one-way communication during training had kept inconsistencies between extension staff's knowledge and farmers' practices unnoticed (to government officials). More participatory extension in orchards led to adaptation of extension staff's knowledge towards verifiable recommendations.

Extended information was practical but not always valid.

The change in extension practice (i.e., shifting the site of training towards orchards and discussing management practices with farmers in their orchard) led to occasional reconstruction of extension staff's recommendations. Here I want to give one example of how extension staff's knowledge was reviewed and adapted in an experiential learning environment. All over the country, extension staff promoted control of trunk borer (see Box 2) by plugging trunk borer larva holes with kerosene and cotton. The citrus programme initially promoted the same method, and farmers (even the ones who already used better control methods) never objected to the proposed method. When the training site was changed to orchards and it became common practice to discuss recommendations with farmers, some of them showed that the big holes usually treated during demonstration were larva escape holes rather than entry holes. Thus, the so far recommended treatment had no control effect (see Box 3). Some farmers checked their trees regularly for early infestation, and killed developing maggots before they damaged the bark, the most damaging effect of trunkborer infestation. Such information was then incorporated in the following lectures, and later in extension material. It should be noted that the few farmers who carried out this method by routine never explicitly talked about their management methods. Interviews did not suffice in teasing out innovations they made, even if they were explicitly asked for new ideas. It needed relations at trust and private orchard visits in which pest management of individual pests was discussed in detail. Loevinsohn et al. (1998) reports similar understatement of farmers about new options they developed during a FFS programme in Kenya, while Nonaka and Takeuchi (1995) report that Japanese companies explicitly address such "tacit knowledge" of their clients.

Box 3. The development of an extension message for the control of trunk borer.

The extension service had been training farmers on the control of citrus trunk borer for many years. The method proposed was simple: larvae made holes that should be plugged with cotton drenched in kerosene and closed with mud so that larvae suffocated. The method seemed so obvious that nobody ever doubted its validity. Plugging trunk borer holes was often demonstrated during practical sessions of training, and sometimes applied by farmers.

Some farmers argued that the holes in which we were plugging kerosene were in fact the larva escape hole rather than the entry hole (Sanjey c.s., Gomdar block, Am Shing village, pers. comm.). The actual entry holes were more numerous, smaller and difficult to find, and often occurred in the narrow space just above the trunk's splitting point. Once such holes were traced, it appeared difficult to plug them with cotton and kerosene; yet, a careful treating of such holes greatly reduced trunkborer damage in orchards. The control recommendation was further refined by a discussion with Mr Themphey (Shumar block, Darchung village) who had a vigorous orchard, while trees in neighbouring orchards all showed decline due to trunk borer damage. Mr Themphey did not plug kerosene in holes made by larvae; instead he regularly checked his trees for signs of infestation. Developing larvae induced a kind of swelling of the bark and excretion of fluid. When he traced infestation spots, he opened the bark with a sharp knife, to take out developing larvae before they further fed on the bark or entered the wood. It seemed obvious that the most damaging action by trunk borer was feeding on the bark rather than boring in the wood, and that control should take place before most damage was done rather than afterwards. Other control methods included catching adult trunk borers by giving children a sweet for each beetle they collected. Some farmers practised methods that seemed less rewarding in potential to reduce damage, such as putting up soil against infested trees in the hope roots would be formed from the upper stem. Such ideas were nice but were not convincingly effective. Also the usual praying

sessions to revive declining trees were not a very promising option for control.
The thus reconstructed recommendation for trunk borer control was the following one. The orchard should be kept clean of weeds, so that developing infestation in the bark could easily be spotted. At detection of infested spots, developing larvae should be destroyed. In addition, adult beetles should be caught by hand. When larvae had entered stems, the old kerosene/cotton method was still useful to kill developing larvae in order to reduce the following year's population.

Thus, technology development in the citrus IPM programme can be summarised as follows. The citrus programme was originally set up to enrich farmers' know-how with existing knowledge from the extension service and research. Experiential learning elements in extension made an interaction between farmers' know-how and extension and research know-how possible. Such practices appeared the main source of innovation in formulating better informed recommendations. This resulted in a well-informed IPM package for citrus. Later visits to Meghalaya and Sikkim revealed that the IPM package thus developed was the best informed one available in the region. The package was developed within two years of extension practice and at limited costs, because all actors in the programme played essential roles in technology development. In fact, technology development was unplanned and unexpected at the set-up of the citrus programme although it later became one of its major outcomes.

Extension staff's changing learning situation.
The citrus extension programme was initially based on the on-going extension routine, both in training contents and in extension methods. Extension staff could easily fill a few hours of lecturing with their extensive knowledge on citrus cultivation. I have tried to figure out where the knowledge lectured by the staff came from. The knowledge was not based on research in Bhutan, as formal research on citrus cultivation had hardly been carried out. When the programme started, there were a few booklets available with general information on citrus cultivation *("mandarin should be planted between 800 and 1500 m above sea level, preferably in good soil with few stones")* that added little to farmers' practices. The district staff recollected to have studied some Indian agriculture handbooks with sections on citrus cultivation during agriculture courses in the late 1970s. More recently, he had attended a few "refresher courses" for extension staff that had dealt with pests' scientific names and the definition of IPM rather than with practicable messages. Mr Sharma had a background as citrus grower, and possibly he incorporated part of his (and his colleague's) background knowledge into his lectures.

However, I suspect that in the course of time Mr Sharma had incorporated some untested intuitive knowledge in his vivid lectures. For example, he always stressed that cattle should not be tied in orchards, as this practice would invoke trunk borer attack (see Box 2), and he meant that trunk borer originated from cow dung. No farmer could confirm this, in fact, if asked privately, most farmers said that both urine and manure made trees more vigorous, although farmers avoided to tie cattle with particular ropes that could damage the bark. Possibly, staff associated cattle-infested orchards with negligence. Thus, it appeared that extension staff's and farmer's knowledge on citrus were not always consistent.

In the new training set-up, learning moments for extension staff occurred during discussion in orchards with individual farmers. During these discussions, earlier lectured recommendations were critically reviewed for validity and practicability. Staff readily incorporated new insights in subsequent lectures to farmers. But, extension staff had always been in a position to discuss and discover with farmers, so what did this programme do that the extension staff's view changed compared to earlier practices? Extension staff's strong point was delivering vivid lectures. So far, staff regarded discussions with farmers as a way to promote recommendations rather than to start two-way communication, witnesses a remark such as: *"You have to joke with farmers, otherwise they will not open their mind for you."* Extension staff's recommendations, although the most complete body of knowledge on pest control available, could not always withstand discussion by farmers because they were poorly founded in actual experience. The introduction of experiential extension challenged the supposed technical supremacy of extension staff. In training in which farmers had a say, most difficult moments were those when farmers came up with problems for which staff did not have ready-made solutions *("I already tried out this practice but it did not work")*. If staff controlled the agenda the risk that unanswerable questions were asked was contained. The presence of outside expertise made the shift from lecturing to more discussing and experiential extension easier: extension staff could afford to change views if research staff did so as well. This process was also possible because of the shift of training site. In orchards, real trees had the final say. Farmers, extension and plant protection staff spent a lot of time discussing phenomena on real trees [3]. Thus, in participatory extension practice the staff's original body of knowledge was discussed and refined.

The change in attitude of extension staff took a while to achieve and took place on request and in presence of the plant protection staff. After the extension staff's involvement in the programme was over, the particular person again practised the conventional autocratic extension methods. Apparently, a more participatory attitude in extension activities was difficult to maintain for the man in question.

Learning experiences by farmers.

Of course farmers formed the ultimate "client group" of the citrus programme. However fancy theories on citrus management were proposed, if farmers were not in a position to apply them, they had little value. The group of farmers was heterogeneous; some farmers applied innovative pest control methods (that they claimed to have developed on their own), others appeared not to be very interested in taking better care of their orchard or were absent orchard owners.

Relevant information hardly spread among farmers.

The previous section describes how extension staff's knowledge was often refined or made more practical although interaction with innovative farmers. For quite a few key pests, a few individual farmers applied successful management strategies. It surprised us that such information hardly disseminated within farming communities. It was well imaginable that individual farmers complained about trunk borer damage to staff, while their neighbour successfully applied control methods as discussed in Box 3. Apparently, farmers' knowledge did not always disseminate from household to household; although we came across occasions in which (particularly relatives) discussed technology with each other. The disseminating of materials (particularly seeds) went much easier than the diffusion of ideas.

Although farmers' practices added considerably to the growing information on practical pest management, it must be noted that not all knowledge in the citrus community was relevant to refinement of IPM packages. For example, priests sometimes carried out rituals ("poojas") with the objective to get a good crop. Sometimes one of the desired effects was to stop fruit drop or deterioration of mandarin trees, as part of the promotion of "general goodness". Effects of such rituals were difficult to verify. In fact, some priests themselves expressed their doubt on

[3] One such discussion was video-filmed, see Kleiheerenbrink and Schoubroeck, 1993a.

effectiveness of praying for better crops: *"Our rituals are not very effective, but they render peace of mind."* (noted down from various sources, including Pangthang lama, Kanglung block, 1996, pers. comm.). Staff decided that if working mechanisms could not be explained, measures were not incorporated in IPM packages for the programme. Farmers never expected the citrus programme to take over or advise to apply religious methods to increase production. Apparently, there was a clear distinction between magical methods to boost yields, and methods grounded in field experience. When the plant protection service once suggested rituals as an option to deal with a grasshopper outbreak, a high official from the Ministry (with a village background!) gave the service a serious reprimand. Most stakeholders apparently agree that religious rituals and technology are not to be mixed.

Changing learning situation.
Village-level training was the main forum of all extension activities in which farmers were supposed to learn about new technology. Extension staff was well skilled to make training sessions attractive to farmers. Staff prepared tree models from mandarin branches that formed the focal point of vivid and funny lectures (Figure 2a). One model showed the supposed local way of manuring: a clot of fresh cow-dung put around the stem of the model; while another model showed composted manure spread gently over the root area of the model. *"In this way village people manure mandarin trees"* (pointing at the model with fresh dung) *"so that stems will get infested with insects. The government way of manuring is this way"* (pointing at the model with composted dung) *"and your trees will grow much better."* Management of individual pests was covered in a similar way so that within two hours farmers were fully informed on state-of-the-art orchard management. After the lecture, there was time for discussion. Farmers often asked for "medicine" to treat their crop for any phenomenon they came across. Always a few farmers requested staff to visit their orchard, which was a nice opportunity to get an impression about major management problems. During such visits to individual households, usually diverse issues were discussed over a glass of local beer, including the socio-economics of citrus.

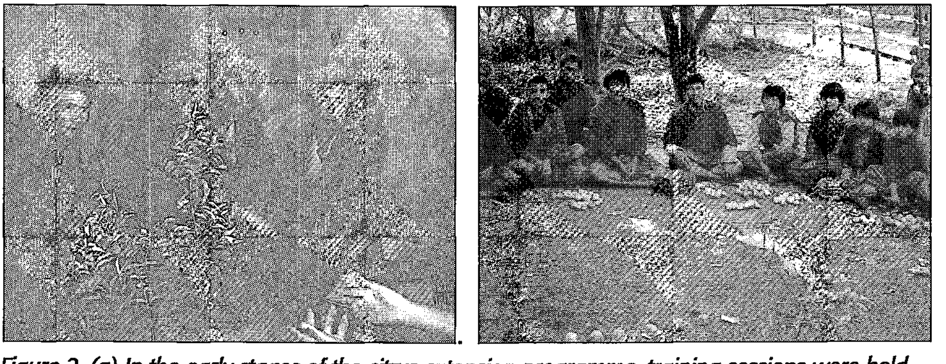


Figure 2. (a) In the early stages of the citrus extension programme, training sessions were held in-door and model citrus trees were the focus of training. (b) Later, training sessions were held in orchards and real trees were an added to the material used in training.

The existing extension system represented a typical conventional model of agricultural technology development and utilisation (Röling 1992). This transfer-of-technology routine worked well in some respects. All households were informed on issues felt relevant by the extension service. The numbers of households per extension staff were small (not more than 500) and most farmers knew staff personally. Yet, despite many years of extension programmes, the system had failed to make most Sharchop citrus growers apply IPM technology, even if it was successfully applied elsewhere or by individual farmers. Moreover, there was hardly any development in training content, present day training contents were basically the same as ten years ago, except from the non-availability of a few persistent insecticides. Extension staff often attributed the difficulties to spread technology to backwardness or even laziness of farmers: *"it will take another century to develop this district".* On the other hand, farmers often expected miracle solutions, they asked for chemicals that in their view had the potential to solve all problems, very much like religious rituals did.

In this situation the citrus programme introduced a few changes in training method. First, the site of training was changed from classroom-situation to orchards (Figure 2b). Regular training in orchards enabled showing proposed practices and their rationale directly in the field. For example, rather than showing the optimal place of manure deposition in models, farmers were asked to scratch the soil around trees and follow roots from the trunk, and found that roots extended many meters from trees. In this way, farmers could themselves figure out the optimal place of manuring. Pest problems that were locally important were now discussed more prominently. Farmers could immediately point out damage symptoms, and discussing the relative importance of different symptoms in relation to fruit production became possible. It also became easier to discuss common myths in the farmers community, such as the miracles farmers expected from application of "medicines". In orchards it was easy to point out (and occasionally show) how they worked and that their use was not feasible in the local conditions, also because there was no technical capacity in villages for maintenance of sprayers. After training, still individual farmers requested the team to visit their orchards and crop management issues were discussed with live samples as the final check. Farmers were often proud to show their management practices. Repetition of training allowed individual farmers to do experiments based on options coming up during such discussions and show the results to programme staff. The programme supported experimenting farmers by providing inputs for local experimentation (such as fertiliser, or water pipes for irrigation) to stimulate farmers experimentation. During follow-up visits, different treatments were jointly evaluated. It was noted that an "official" forum in which to discuss experiments was very stimulating to individual farmers. Experimenting farmers included quite a few of the female farmers that had participated in a district level training, and innovative farmers were invited to discuss their practices with colleagues during following training sessions. (Later, too open support for such farmers appeared to have its drawbacks. Often, the team was not aware of other farmers doing experiments, and the communities felt that the team only recognised efforts of close acquaintances. In a way, supporting farmers in public displays is a paternalistic attitude). However, to our knowledge, farmers hardly communicated about innovative recommendations. Without official reason farmers had only limited right to speak in public, and farmers were often hesitant to take a special role in the community. During social gatherings, technical matters were rarely an issue for discussion, unless the extension team set the agenda. Thus, it appeared impossible to establish a self-sustaining forum of knowledge exchange within the citrus growing community, at least on short term. We could not confirm the notion that more participatory extension methods may result in such informal institutions and lead to "empowerment" of farmers (e.g., Veldhuizen et al. 1997). Thus, farmer learning was basically an individual exercise, even if training took place in groups. It was the individual farmer or household who decided to apply newly learned technology or not.

Apart from the in-village training sessions, the programme used a few more information channels to reach farmers. Lessons on key citrus pests were given in schools. Pupils were to copy a chart of the life cycle of one pest to take home; often the chart was pasted on the wall and it was hoped that training contents were discussed in the family. Similarly, radio announcements were broadcasted in the local language, not only on technology, but also on individual farmers who had done something special. The radio announcements had noticeable impact, as farmers were proud to have their names or villages announced on the radio because it confirmed their role as "citrus innovator" in communities.

Staff monitored progress of farmers' knowledge through a few hundred individual interviews, that were unfortunately never processed quantitatively. Yet, the interviews yielded a general impression of the citrus programme's results in terms of technology adoption, including the following notions. Farmers memorised pest life cycles and control methods well and almost all farmers declared to have carried out proposed technology. Subsequent orchard visits showed that households varied in the accurateness in which new management options were carried out. Stubborn and silent innovators often carried out measures meticulously. Most common households tried out proposed pest control practices in a few trees, or carried out a particular activity once or twice; usually however such incidental activities did not control pests properly and pest population levels over the entire village did not noticeably reduce. When farmers were asked for the reason of this incomplete treatment, some farmers apparently lacked the urge to take citrus management seriously, even for clearly visible pests. This indifference contrasted with the care farmers took for their subsistence crops, even if the per hour production was much lower (if one calculates food grain in exchange for mandarin). A possible explanation is the historical place of citrus in household economics. Traditionally farmers just planted citrus and hardly cared for it, part of the poor harvest was taken to India and exchanged for a few necessary commodities. Even now, in particular villages making more money than strictly needed is not considered necessary, monetarily rich people were seen as greedy and boasting. Now that markets became better accessible, farmers were in the process of changing their concept of citrus as a serious cash crop rather than a semi-wild crop. Moreover, some farmers expected the government rather than themselves to carry out proposed measures (as a result of direct services the often offered in the past). This seemed the most plausible explanation for the apparent indifference towards citrus, even if such farmers often complained about pest problems and low yields of their orchards. Thus, there was some success although it was not overwhelming. In later Chapters the diffusion of innovations theory (Rogers 1995) is discussed that explains why adoption of practices did not go faster.

The extension method now applied was a mix between the earlier transfer-of-technology and FFS-type of extension. Elements inspired by FFS included in-field training, small scale farmers' experimenting, and farmers training farmers. Some aspects of FFS were not applicable in the eastern Bhutan conditions. We did not restrict training methods to experiential learning alone as we had no expertise on making farmers familiar with proposed technology without lecturing and discussing. Farmers expected government officials to instruct them, and requesting farmers to enter orchards and find out something for themselves was not an acceptable form of training. Similar difficulties with introducing experiential learning were found in Kenya (Loevinsohn et al. 1998). Repetition of training could not be planned as rigidly as in FFS: roadblocks or visits of high officials often came unexpected so that the programme had to be planned flexibly. Returning to villages three times a season was already way beyond the intensity of supervision farmers expected from extension programmes. Government officials were not expected to initiate group dynamics activities. In stead, staff respected and participated in local welcoming traditions.

Learning experiences by plant protection staff.
The initial responsibility of the plant protection staff was to make research findings available to extension staff and farmers. Knowledge of research may have been valid, it was not always practical. Apart from responsibility for validity of recommendations, plant protection staff also designed the citrus programme and translated in-field findings into research priorities. The official mandate foresaw only technological innovation. During programme implementation also the extension methodology was considered as it had relevance to achieving progress in technological terms.

Information was valid but not always relevant.
Before the citrus programme started, plant protection staff explained to extension staff that IPM was "the integration of cultural, hygienic, physical and chemical control methods to keep pests under economic threshold levels", and stressed that "damage does not automatically lead to losses". In the village programmes, extension staff occasionally translated this wisdom to farmers: *"Kepa chilo gi bu ga kaktap singmu chospa la, ming **IPM technology** rale"* [4]. Needless to say that such information is not of much help to farmers. Yet, the flair with which extension staff lectured such statements was admirable. Often, lectures were simple and vivid, although at times, they were like secret language to the audience. It appeared that theoretical notions so important at the level of research as such had no meaning in villages.

This is only one example of IPM technology that seemed sound in a research or extension environment, and appeared irrelevant in the village context. Some information from research however was well understood by farmers and extension staff and still did not contribute to better management practices. Consider the notion that most organisms in citrus trees are not damaging and some are even beneficial natural enemies. Although this notion made nice lectures about "good bugs" and "bad bugs", it had no practical consequences. Applying chemicals was not within the reach of farmers and the Buddhist farmers were not fond of killing living creatures in general.

A definite breakthrough in the field of citrus IPM was the research finding that fruit drop was caused by the chinese citrus fly. This finding was soon translated into a recommendation that potentially controlled the fly. Farmers were informed on the fly's life cycle and were instructed to dispose of dropped fruit in pits. Unfortunately, such initiatives did not result in noticeable reduction of fruit drop. At the time it was thought that measures were not done sufficiently rigorously: not all farmers collected dropped fruits and some collected fruits incompletely. Staff reacted by emphasising the need for hygiene even more. Such an IPM recommendation is valuable to extension staff, as staff can tell a plausible story and ascribe apparent failure to farmers carrying out the measure incompletely. However, the practice can never lead to improved yields. The accuracy with which such measures have to be carried out is not feasible in sloping villages like in eastern Bhutan (see Section 6.2).

Changing situation of learning.
The previous sections show how in the citrus programme, farmers' and extension staff's learning were enriched with experiential learning elements in orchards. For plant protection staff, practising extension as such was already a learning experience. The environment of villages, orchards and training sessions rather than offices, experimental fields and planning meetings put the theoretical concept of IPM in a different perspective. The theoretical knowledge as such was poorly applicable in village extension conditions, but connecting conceptual knowledge to discussions in orchards made research staff to learn a lot about pests in citrus. Extension staff and farmers often

[4] "High-level scientists have developed a new pest control method called IPM technology"

tagged pest names to particular phenomena, plant protection staff could then apply concepts to the symptoms under study. For example, research staff had often lectured threshold theory to extension staff. In orchards it appeared that most pests were present although usually in low densities. Most pests rarely exceeded (intuitive) economic thresholds: a few twig borer infested twigs were unlikely to seriously reduce tree vigour in the long term. The combination of concept and practice bore relevance in orchards, as extension staff and farmers often extensively discussed pest symptoms that could hardly be found in orchards. Discussion time could better be spent on the control of a few key pests that inflicted considerable damage like the ones listed in Box 2. As a result, many citrus pests (listed in Bigger et al. 1988) were scrapped from the research (and extension) agenda as in the local situation their control would hardly add to better yields.

Apart from considering contents of training, staff evaluated practicability of proposed technology in the farmers' hands. An important source of information was the observation of farmers' practices during practical training and orchard visits. One could immediately see whether or not proposed measures made sense to farmers. Farmers made pits and disposed some dropped fruit to reduce the following year's citrus fly population; farmers often carried out such measures incompletely so that the recommendation appeared not very useful in village conditions. Farmers very often displayed apparent indifference to systematically control pests in their orchards. In addition, staff interviewed farmers of all classes. Did they recapitulate training contents? Did the recommendations make sense to them? Did they apply them in practice? Did they, perhaps, carry out alternative practices, and why? How many trees did households have, and how much did they yield? Generation of data was the official pretext under which interviews were held, but well performed interviews induced closer rapport to some households, whom we could ask more sensitive questions such as: who does work in citrus, and is that person reached by the programme? Who uses generated money, and for what? And thus we could see whether the actual implementers of citrus cultivation were the same people as the farmers who were trained, whether recommendations were shared within families, and whether extra money was used for extra consumption or extra investments (Schoubroeck et al. 1999). After interviews, orchards were visited to observe actual management practices so that programme effects could also be evaluated in practice. Thus, also for plant protection staff the experiential learning routine strongly affected the body of knowledge it worked from. Observation of farmers and orchards effectively shed out irrelevant theorising and enabled research staff to formulate practical IPM recommendations. This uncovering of relevant technology is usually an important measure for performance of knowledge systems (Röling 1992, p. 53). In addition, the plant protection service had become well informed on current extension practices and field level extension problems. The original task of the service, i.e., instructing extension staff during district level workshops, had now become easy as far as citrus was concerned. For non-citrus crops still poorly verified information had to be lectured, although it appeared relatively easy to extend the practical view to other crops as well, even if there was little technological innovation for these other crops.

Shortcoming of technology: fruit drop control method needed.

For more than one reason technology development is a necessity for the optimal functioning of the extension service. Obviously, one wants to promote the most efficient production methods available. But also, in a transfer-of-technology environment, the only activity staff is expected to do is providing farmers with information. If information is not regularly refreshed, soon staff can only repeat already lectured information and the extension programme will become a dull and uninspired job. For example, in one cluster of villages (close to Mikuri), where citrus used to be a major source of income, about 90 % of trees had died after a trunk borer outbreak. Extension staff repeatedly visited the place to inform farmers on newly developed control methods, and after a few training sessions, farmers were fully informed. There was little extra the extension service could do. Orchard visits revealed that farmers still did not carry out proposed control methods, while farmers still reported problems with their orchards to district authorities. Extension messages were not developing and resulted in a blocked communication and learning on pest management. We often noticed that a new "trick", be it in the form of opening trunks to spot developing trunk borer adults, or attracting fruit flies through pheromones, appealed to curiosity of farmers and made particular training sessions lively and therefore useful. (Another way to break through a deadlock in programme development was the involvement of extension staff in organisation of concerted pest control over entire villages, as discussed in Chapter 3).

The extension programme revealed that there were a few pest control problems for which neither stakeholder had suggestions for practical solutions. For example, in October-November orchards were orange with maggot-loaded dropped fruit, and farmers often expressed frustration to see the best fruits being spoiled. Farmers guessed that the cause of fruit drop was excessive rain, or drought, or some spiritual power. Some maintained that presence of maggots in fruits was a *result* of fruit drop rather than the *cause* of it. Plant protection research had come up with the notion that one of the causes for fruit drop was a Tephritid fly, i.e., the chinese citrus fly *Bactrocera minax*. Theoretical options for control included destroying maggots in dropped fruit and employment of protein hydrolysate as a lure. The team showed different stages of the fruit fly life cycle to farmers, and thus farmers realised that fruit drop was not a supernatural phenomenon but a result of oviposition by a tangible fly. This resulted in the spirit of enthusiasm and action in some communities. If it would be possible to control the fly, then yields could stabilise or even double or triple. In many villages farmers started to experiment with citrus fly control based on theoretical control options: some farmers applied local beer (that contained yeast) in their orchards to lure and kill the fly. Such initiatives were observed in villages never visited before, as a result of radio messages alone, which showed how much farmers wanted fruit drop to reduce. Yet, proposed measures were never tested and did not noticeably reduce fruit drop. There was not enough information for the design a successful IPM strategy for the fly. The plant protection extension section requested colleagues in research to come up with practical solutions. Researchers had tried out controlling the fly for a few years in a row, without practical result. Basic biological knowledge on the fly was still lacking, even the number of generations was not known, and all tested control measures appeared ineffective (Hollands 1994). An additional problem was that there was no method to properly assess losses. Thus, farmers, extension staff and researchers stood powerless against the chinese citrus fly that took about half of all citrus fruits every year, a situation that forced itself dramatically upon people who worked in villages. Research and extension staff of the plant protection service had different expectations from research activities which resulted in structural tension within the regional plant protection service. Different individual representatives of stakeholder groups defined pest problems in their own terms, which hampered co-ordinated development of practical IPM. There were fora where the three groups exchanged ideas, but there were no fora in which each group could weigh, define and developed its capabilities and interests (as necessary for development of practical IPM) in relation to the other groups. This tension endured until a major policy change was effectuated so that all plant protection staff was expected to develop IPM technology in village programmes, as documented in Chapter 3. Developing IPM technology for farmers is more theoretically discussed in Section 3.1.

Extension methodology to initiate concerted action needed.
Most pest management measures have a population management component. For example for trunk borer and mistletoe control, population reduction over entire villages considerably increases effectiveness. This is a feature particular for IPM. To illustrate this point the following example can be given. In the 1980's, farmers successfully protected trees against trunk borer by pasting the lower stem with Aldrin, a potent (and now forbidden) insecticide. With such methods, concerted control is not necessary. The IPM alternative consists of regular monitoring trunks for infestation, and catching adults for village-wide reduction of population pressure. Thus, IPM of trunk borer made control at communal level necessary. Similarly, communal action made the control of mistletoe easier. A cleaned orchard is soon re-infested if neighbouring orchards were not yet cleaned, while it takes little effort to keep mistletoe under damaging levels once an entire village is clean.

This had consequences for the scale at which control should take place and thus for training methods. The on-going extension practice was disseminating information for voluntary change of individual farmers. With such extension methods, one cannot expect pest control measures to be carried out equally efficient all over the village. There are always households that do not spend time on pest control, and whose orchards form the source of infestation to neighbouring orchards. In one way or another, extension methods must address entire villages rather than individuals. This issue will be discussed more theoretically in Section 3.1, while Chapter 3 documents a programme designed to tackle this problem in IPM extension.

2.5. Evaluation and prospects.

Involvement and support by various stakeholder groups.

Involvement and support by direct stakeholders.
Even in a strongly hierarchical society like in Bhutan, support of higher level authorities does not automatically mean that low-level civil servants or farmers support programmes, even if they formally co-operate. Personal interest in programmes is of course an additional prerequisite for co-operation of stakeholders. For farmers, citrus cultivation, trade and transport was an important source of cash income for most households, in addition to remittances and handicraft production (De Wit and Choeda 1996, and own observation). Yet, most of farmers' attention and labour was invested in subsistence functions such as food grain cultivation and fuel and water collection. For example, in one village where the water supply system had broken down, farmers kept on requesting for support to fix it, which was out of the programme mandate (although such requests were always forwarded to relevant sector heads). In such a situation it was impossible to get farmers to become seriously involved in citrus activities. There were many more citrus villages than we could possibly cover and so staff decided to only work in villages where farmers were willing to invest time in citrus cultivation. It was sometimes noticed that not all farmers tried out recommendations the programme proposed, this was not regarded as problematic as long as individual farmers showed progress in experimenting with citrus management options.

Involvement and support by the district administration.
In Bhutan it is the district administration that decides whether activities can be organised in villages or not. Research institutions and district administration usually informally agree upon programmes initiated by one or the other. The district of Pemagatshel had requested for technical

assistance regarding citrus management. The district administrator regarded stimulating cash crops as a way to uplift the living conditions of the local people. He tried his best -and even used his formal power- to ensure full commitment of the plant protection service to the programme. Moreover, the district had assigned one staff to assist the programme when activities were organised. This genuine support caused the plant protection service to work more in Pemagatshel than in other districts with extensive citrus cultivation. For the district extension service the regular presence of a person from research in itself was already stimulating. However, support for the programme was based on personal relations and appreciation rather than formal agreement. Formal organisation of such a programme would entail its taking up in annual or five-year plans. For such a formalisation, much time was to be spent in planning meetings and the preparation time for programmes would take longer than the time research staff could possibly oversee. The citrus management programme was a pilot activity and in its early stages we never knew what adaptation would be made next. After two years or so the extension method and training contents stabilised, and ideally this new standardised extension work was to be carried out by the district. Technological innovations were readily incorporated in recommendations by individual extension staff. Although the district agriculture section was not very eager to carry out activities not taken up in the work plan, the district administrator instructed extension staff to extend new recommendations to all villages in the district. Such activities were one-time events. The extension service considered informing farmers their task, rather than making sure that farmers did indeed carry out better practices.

Adopting more a more experiential learning routine was more problematic. The district extension service never expected that the plant protection service would be involved in adapting the extension process itself. Moreover, to my knowledge, there was no national policy on extension methodology as such. The national extension service was in the process of relieving extension staff from input supply tasks, and institutionalising monthly agricultural workshops was a main (and important) innovation. Thus, the extension process itself was hardly an issue and nobody felt a direct need for change.

Involvement and support by the Ministry of Agriculture and donors.

Apart from the district, there were a few actors that formed the policy and administrative environment of the programme and determined its space for manoeuvring. Most important were the Ministry of Agriculture (MoA) and the (EC-funded) National Plant Protection Centre (NPPC) in Simtokha, the national co-ordinating institution. Other players were the Netherlands Development Organisation (SNV) and regional administration. The initiator of the citrus IPM programme, the Regional Plant Protection Centre (RPPC-Khangma) was a regional branch of the national service. NPPC left the regional services relatively free to design their own activities. RPPC-Khangma was thus ensured for its supply of logistics (transport, basic materials, office) and personnel. The citrus programme as such was welcome as an activity attracting publicity, even if it was not an official programme of the service. SNV supported the programme with personnel and particularly appreciated the programme for its support to local woman village leaders in taking a leading role to introduce IPM in villages (Schoubroeck et al. 1999). In December 1992 a video film on the programme (Kleinheerenbrink and Schoubroeck 1993a) was shown during a visit of the Dutch minister of development assistance and seen by most high officials. This made the programme known to quite a few influential policy makers, one of whom expressed his enthusiasm: *"In this programme, farmers are genuinely interested in extension activities, they are enthusiastic and responsive".* The video film and other publicity (radio announcements, exhibition in the office) resulted in high-level support for the citrus programme for the years to come. I am aware of occasional references to the programme when the Ministry was to show its commitment to improving citrus production in the country. Moreover, until the citrus programme started, the government considered citrus industry as flourishing by itself and not in need of extra research investments. Publicity on the citrus programme made high level officials aware of the potential to improve citrus production. Citrus was placed on the agenda of the Ministry of Agriculture, which in the second half of the decade led to the establishment of a horticulture sub-programme on citrus.

Problem statement regarding further development and application of citrus IPM.
The citrus extension programme had results in various domains. First, more participatory extension was introduced to the on-going extension routine. Second, a better informed IPM package for citrus was developed. Third, the programme had resulted in knowledge of the plant protection service on the area, and on the language and habits of farmers. And last but not least, the programme had created goodwill in the district and the Ministry with regard to developmental work on citrus. All this does not imply that the programme did not have its shortcomings. For example, the programme was not in a position to develop IPM for a few key pests. For a pest such as trunk borer control had been made explicit because farmers had already figured out how to control it. For other pest problems such as fruit drop, developing control appeared problematic in the present set-up. Fruit drop was an important problem in citrus cultivation. The government often received complaints from influential farmers, and there was a fair risk that the government would launch large-scale chemical control campaigns if no better solution would be available within a short period (Acting Director, Thimphu, pers. comm.). Although the research service had carried out some work on fruit drop, recommendations were so far not effective in reducing the problem, even not in experimental orchards. The extension section of the plant protection service became somewhat impatient, as its work did not bear much meaning if this key problem could not be addressed. Thus, a relevant research question emerged:

- *How can mandarin fruit drop be controlled?*

On-station research had so far generated quite a few fundamental ideas on fruit drop, such as the notion that a tephritid fly was its main cause and that mandarin trees teemed with all kinds of predators. However, these notions did not suffice in informing farmers on the control of the fly. The fact that in the near future research was not likely to develop a fruit drop control method put the plant protection service in an awkward position. What is the use of research if it can not contribute to the solution of one of the most important pests? After all, mandarin is the main cash crop in the country. It is the main source of cash for about one third of all Bhutanese rural households, many of them among the poorest in the country. Fruit drop results in irregular monetary returns and may, on average, reduce the mandarin yield by half. Thus, the control of fruit drop bears the potential to have one third of the Bhutanese rural households double their cash income. For such an overwhelmingly important problem, it was worth reconsidering the research strategy. Therefore, another research question is:

- *How can the research set-up be changed so that its outcomes are relevant to farmers?*

One reason for the poor relevance of on-station research was the fact that control that was to be carried out at communal level could not be introduced by the on-going extension routine. So far, extension activities addressed farmers as if they were to make their management choices individually. They never addressed communities to jointly clean their village of pests that otherwise spread from uncleaned to cleaned orchards. Thus, the final research question is:

- *How can pest control activities be promoted at community level?*

A follow-up programme should try to introduce fruit drop control at community level, and thus develop methods to have villages involved as a community rather than as individual households. This requires not only anthropological knowledge on citrus growing communities, but also know-how on ways to make farmers care as much for their cash crop as they did for their subsistence crops. In short, plant protection research needed to work on problems felt relevant in villages.

3. Learning phase II. Developing IPM in villages.

3.1. Theoretical considerations on the development of IPM strategies.

Previous sections showed that the different stakeholder groups' knowledge on citrus management was often of limited practical value and how practicability increased through joint experiential learning experiences. For some pests, practical recommendations were formulated, but as yet, for a few key pests applicable IPM technology was not available. This theoretical section looks at the type of technology that is needed for IPM to qualify for large scale application, and how such technology could be developed. Moreover, it discusses the diffusion of innovations within and among stakeholder groups as well as the difficulties expected when trying to introduce pest control activities over entire villages.

Technology needed for IPM: theory.

The IPM concept is of technical origin.
The term IPM (Integrated Pest Management, synonym to IPC: Integrated Pest Control) is now a few decades old. Its many definitions have in common that pest management should be based on a mix of methods to control pests. A classical definition is the one by FAO (1966): *"Integrated pest control is a pest population management system that utilizes all suitable techniques in a compatible manner so that damage is kept below economic levels. Integrated control achieves this ideal by harmonizing techniques in an organised way, by making control practices compatible, and by blending them into a multifaceted, evolving system."* Techniques referred to include quarantine, hygienic measures, crop management, trap cropping, mechanical control, physical control, and chemical control as a last resort. Moreover, as long as pests do not induce losses that justify investments in pest management (i.e., as long as pest populations are not likely to reach the "economic threshold"), no action needs to be taken. IPM and its inherent threshold level thinking have invoked the development of an extensive "tool box" for pest control, including introduction of natural enemies for pests, pheromone trapping, sterile male technique, development of threshold and warning systems. Such control methods are based on the population dynamics of the pest in relation to the host and to antagonists. A brief overview of the field IPM covered in the late 1980's is given by Gutierrez (1987), who described IPM as *"the management of pests via the integration of chemical, biological and cultural methods in an environmentally sound manner".* This was the dominant way of thinking on IPM in the national plant protection service of Bhutan when the regional service was set up in the eastern zone of the country in the early 1990's.

Station-led IPM development did not result in practical control methods.
In the first few years of plant protection research in eastern Bhutan, station-based staff researched quite a few pests. In the case of potato late blight, there was a risk of disease spreading during periods of high humidity, and the crop could be treated by preventive fungicide applications. During suspect periods experimental plots were monitored for signs of the disease that, once spotted, was prevented from spreading by spraying. Such treatments resulted in beautiful green canopies of treated plots; yet, during three years of experimenting, not even once treatments sorted significant yield improving effects. Soils were highly variable in the sloping experimental area and yields varied even without different treatments on the relatively small plots. Experimental control of cutworm in vegetables yielded similar experiences, although in this case it was the

irregular spreading of caterpillars over the experimental area that played a complicating role. Thus, it appeared difficult to get scientifically valid results on the station's premises, and evaluating different pest management options appeared impossible. Such experiments however did yield insight in the biology and potential control options, even if the results were not fit for presentation in scientific fora.

The station did not avail of experimental orchards and research on mandarin fruit drop had to be done in farmers' fields. Eight isolated orchards were identified in which different treatments of fruit fly control were applied. Three consecutive years of experimenting (two orchards untreated, two orchards baited, two orchards cleaned from infested fruits, two orchards both baited and cleaned) did not result in measurable reduction of fruit drop in the orchards. Again, experiments yielded valuable information on the biology and initial ideas about damage levels (Hollands 1994). Reason for the failure to get tangible control results are the high variation in both yields and losses, even without treatment. Moreover, it was not known how to actually measure yields and losses. How can one estimate fruit drop percentages in orchards with heavily bearing trees, and the soil orange with loads of spoiled fruit on the ground, while fruit was still dropping and rolling down the slope?

These experiences showed that on-station or station-controlled experimenting was not a very effective way to develop IPM technology. The programme needed to develop new ways to carry out research for practical IPM technology development. In the following section, it is considered how IPM technology had been developed in a reportedly successful IPM programme: in Farmers Field Schools in Indonesia.

How was rice IPM technology for FFS developed?

IPM for rice in Indonesia is based on a set of agronomic and ecological concepts that are presented to farmers as tools for their decision making. In FFS, an experiential learning approach is employed for farmers to understand and internalise these concepts and apply them in their fields. Concepts such as natural control and threshold level thinking originated from research institutions. Literature is not clear on how these concepts were actually transformed into a curriculum for discovery learning. An example is the use of economic threshold concept in an extension environment. Instead of presenting a precise but unworkable coefficient, the programme developed the concept of "experience threshold" which develops as farmers learn and experience, and which is applicable under specific farm conditions (Galagher 1990, in van de Fliert 1993). FFS used quite a few more of such educational tools, such as insect zoos and ecosystem analysis. Thus, technical as well as experiential learning expertise must have been employed to make agronomic, ecological and technical concepts fit for application in farmer training in FFS-format, although I am not aware of literature documenting how this was actually done. The rice ecosystem has been researched very well. In rice FFS, learning and technology (in the shape of general concepts) are inseparably intertwined. But what about ecosystems of other crops? Even if learning in FFS is based on general concepts, not all concepts will be applicable in every crop and occasionally new concepts will have to be made operational for use in a FFS-type of environment.

The FFS-extension model is now fast spreading and in some countries it is national policy to replace Training-and-Visit extension with FFS (Leeuwis et al. 1998). For many non-rice crop systems, the IPM "product" is not within reach of farmers. Farmers may perceive IPM as too complex or not appropriate to their farming system (Norton and Mumford 1993). Research in technical institutions will definitely be a rich source of the necessary concepts, but lack qualities essential for the extension environment. For concept level thinking to be relevant to farmers, farmers need to be able to monitor relevant processes in their crop. Further in this thesis I will refer to this monitoring quality as *visibility* of process. As a result of observations, farmers need management options to improve yields, which is the *manipulation of process*. *Visibility* and *manipulation* relate to each other like *apprehension* and *comprehension*. Farmers do observations in their crop, interpret and take control measures or not, of which the result should be visible in observation routines. Only through such an "empirical cycle" farmers are in a position to learn. Research that takes place in research institutions or on-station is geared towards manipulation of (pest dynamics) processes (i.e., pest control). Its taking place far away from farmers makes that it inherently lacks qualities that make processes visible to farmers and makes them understand dynamics on their crop. The type of adaptation Gallagher (1990) introduced to the threshold concept by his swapping from 'economic threshold' to 'experience threshold' is therefore an essential step that has to be made in order to make IPM applicable in farmers' conditions. Thus, IPM technology development differs from conventional pest control research in the explicit development of tools to make in-crop processes visible, in addition to methods to manipulate such processes. The case of IPM in rice is very special, as visibility of pest dynamics processes almost always results in the notion that (insect) pest control is not necessary. I am aware of a number of studies that did develop both monitoring routines and control options for IPM, for example in IPM for banana on Zanzibar (G. Bruin, Wageningen, pers. comm.); for IPM in cotton, vegetables and wheat in the Sudan (Dabrowski 1997); of course IPM in rice in Indonesia (van de Fliert 1993); and there are many more.

IPM technology development through PTD.

Having realised that for applicable IPM, one needs both feasible control options and visibility of processes, we should further consider the process of IPM technology development. In conventional technology development, researchers develop technology, that is to be transferred by extension services to farmers. Although technology is continuously adapted on the way (Röling 1992), there is no formal way in which processes (such as building up of pest populations or germination of fungal spores) are being made visible to farmers. Thus, farmers are not in a position to be aware of processes that may eventually lead to losses and have therefore a limited possibility for learning. Remains the question: how to develop routines to enhance visibility of process to farmers? And how can farmers learn to feed information from monitoring routines into relevant concepts so that they can take informed decisions? A few examples from literature are the following ones. In Zanzibar, Farmers Research Groups were supposed to develop a curriculum for FFS elsewhere, with some success (Leeuwis et al. 1998). This is possible, just like in FFS, if individual farmers or communities already practise a certain crop management regime. In more complicated situations this strategy will not work: farmers can not be expected to deal with subjects such as virus diseases and their transmission without a certain basic knowledge on processes governing virus infection. Such knowledge should come from formal research. Occasionally one might see farmers' practices evolved independently of such knowledge but still in accordance to it. Such empirical knowledge however does not result in flexible concepts, that form the technical base of FFS, even if it helps to form a link between formal research and farmer's practice.

Possibly, the PTD tradition may help to generate technical know-how for FFS-type of extension. In PTD, farmers and facilitators are supposed to jointly experiment with crop management options. Development of such options may result in monitoring routines that can be used later for monitoring pest population levels. However, literature on PTD is very broad, objectives are general and far-fetched. PTD starts with participatory appraisals to get an overview of the farming system and to identify relevant problems to work on. Then, farmers start experimenting assisted by facilitators. *"Most important of all, PTD should strengthen the capacity of farmers and rural communities to analyse ongoing processes and to develop relevant, feasible and useful innovations. (...) The method is designed to increase control of people over their own lives."* (Veldhuizen et al. 1997, p. 4). The PTD tradition thus leans on farming systems thinking (usually defined in hard systems with little scope for action) and rural appraisal techniques, and combines the two into practical experimentation. The "most important" goal, the empowerment of farmers, goes at the cost of technical focus, so that little innovative technology is developed for application elsewhere. No doubt, PTD has the potential to adapt well-known concepts to farmer's environments, but is not very strong in developing innovative technical concepts, as a thorough technology is not the primary focus. Yet, it is the PTD-tradition in which technology is regarded in its social context that is closest to developing the bridge between technical IPM and the intuitive knowledge of farmers. Possibly, a combination of PTD and IPM research of academic quality could bridge this gap.

It should be mentioned that efforts to help farmers get insight in underlying processes on their farm are not restricted to IPM alone. In integrated nutrient management (INM), the same dynamics have been recognised, and a new praxis of extension is in the making, in which observation aids and interpretation of principles and concepts by farmers play an essential role. More in general, in health education a parallel discourse is on-going.

Sociological aspects of IPM application: theory.

This study seeks to understand mechanisms that governed development and application citrus IPM technology as well as its dissemination within and among citrus growing communities. M. Keynes once remarked that people who declare to have no need for theories and claim to be "practical", usually operate on the basis of the theories of yesteryear (Röling 1992). The original citrus programme was practical in its set-up and objectives and not designed to expand theory towards new grounds. However, we realised that for the *technical* objectives to be fulfilled (i.e., the control of the citrus fly) we needed help of interpretation of various phenomena by *human science* theories. In order not to walk into the trap Keynes pointed out, we tried to apply a few innovative notions we were aware of when we assessed a need. An example of such an innovation is the (low-profile) introduction of experiential learning in extension on citrus. Moreover, in hindsight, theories developed elsewhere appeared to provide an understanding of phenomena not well understood during programme implementation. The transition from transfer-of-knowledge to experiential learning, and the introduction of feedback mechanisms in the extension routine was already dealt with in section 2.2. Further, knowledge in social groups (in this study: stakeholder groups) is discussed by a short introduction to social cognition theory, while for the diffusion of knowledge in a social context diffusion of innovations theory is briefly touched upon.

Experiential learning and self-referential knowledge in social groups: social cognition.

Section 2.2 discusses experiential learning theory, in which we have seen that knowledge for individual learners is generated by a dialectic process (feedback) between apprehension and comprehension. This knowledge building process however always takes place in a group setting that includes the values and language of that group. Social groups, or social institutions, have a reasoning of their own (Douglas 1986). Individuals live and communicate within a social institution: a farmer lives in a farmer community where he or she finds vocabulary and references for thinking, a scientist refers to peers in his or her scientific discipline. Through continuous communication, individuals conform to the group they belong to by sharing the same vocabulary, the same modes of thinking, and the comparable values. In some respects social cognition theory seems to contradict experiential learning theory, in which individual experiences determine the same individual's knowledge and vice versa. However, one can also see that within social groups, through social interactions, people share comprehensive knowledge that can overrule individual's experiences. Overruling individuals' observations through social interaction is in fact very common. Humans are good imitators, and they often imitate opinions and interpretations (such as the existence of Higher Powers that determine the course of affairs, without any empirical evidence). This often leads to self-referential comprehensive knowledge within social groups. Such knowledge is difficult to change, even if it is not valid, and often lacks feedback (validation) mechanisms, both towards other groups and towards the natural world. Thus, humanity is divided in social groups that share a belief system or a language that may go back many centuries in history, and that, despite extensive contact between groups, keep on existing separately.

For this study it is important to recognise the existence of self-referential knowledge in stakeholder groups in the agriculture knowledge system. Chapter 2 showed that different stakeholder groups had self-referential knowledge on citrus management: realities of researchers and extension staff often had little meaning in the farmer's environment if not exposed to and challenged by field level experiences. Hutchins (1995) gives a further, more practical proposal to consider the cognitive properties of human groups. He investigated the way in which the crew of a ship navigated; a process in which many individuals had complementing tasks. Although the role of each individual could be described in prescriptive terms (if we arrive at x, place the relevant map on the desk), each such prescription is "processed" through the particular human mind. Should the prescription not apply (for example, because the librarian locked the drawer and went asleep), the individual will go out of the way of the prescription to make sure that his task is performed well (he will try to wake up the librarian or break open the drawer, to avoid the ship entering unknown grounds). This property makes a more robust and flexible system, because if one task is not performed well, surrounding individuals will take it over. This is done without any individual having a complete overview over the process. Even if the captain is the chief commander, he will not be aware of the details each of his men deals with to have the ship navigate safely. Thus, the group as a whole has a "social cognition", in this case a dynamic and flexible property to navigate a ship, for which a certain common language, and shared worldview (at least with respect to the navigation) is needed.

For the case of technology to be carried out over entire villages I take this "social cognition" as a type of "intuition for acting" at community level. It differs from "village organisation" in the sense that the organisation covers the procedures that need to be followed by what particular person, more or less in a prescriptive way. "Social cognition" implies more than that. Individuals not only carry out the task they get in the community, they also keep an eye on tasks within their circle of influence, and put pressure or inform other people if some component of the communal task is not carried out as it should. This can be done by social control, or by sharing the task of one individual by others, etc. In fact, each individual in the community "monitors" the part of the task he can oversee and through feedback on its performance, makes sure that it is implemented the way it is needed for the purpose of the activity. Bhutanese communities are often excellent in performing such communal task in case of religious ceremonies and this is a typical case of a high level of "social cognition". The chief lama always gets his food, even if the head cook is sick for the day. The dances will be performed and the cloths will be in place, despite a thousand things that can go wrong. The community agrees on the objective of the activity and each individual looks around where he or she can fit in to contribute to the task to be fulfilled as per everybody's expectations. For citrus IPM, social cognition implies that the community agrees that the village should be cleaned of the pest at stake, and that each individual does whatever is in his or her power to makes sure that this indeed happens.

Diffusion of innovations and problems of scale.

Diffusion of innovations is a process governed by particular mechanisms. Rogers (1995) showed how adoption of innovations in social groups generally occurs gradually, by some individuals adopting it earlier than others. Innovativeness is the degree to which an individual is relatively earlier in adopting an innovation than other members of the group under study. Such innovativeness is a continuous characteristic of individuals within an adopter population, and the population can be classified accordingly. *Innovators* are risk takers, early adopters, *early majority, late majority and laggards* adopt innovations at later stages. The early adoption stage (when typically 10-20 % of potential users adopted the innovation) is critical, as once an innovation is beyond that stage, its diffusion becomes an autonomous process. This is the *social component of scale* needed for an innovation to be widely adopted. The process from introduction to full adoption of easy-to-apply innovations (such as hybrid maize varieties or a drug) within a relevant population usually takes between a few to nine years.

In pest management, particularly in IPM (cf. Section 2.5), there is often a minimum *natural scale* of control: suppression of pest populations often needs to be implemented at local or regional level. Thus, in IPM, *scale of experimentation* is essential: experiments have to be carried out at appropriate scale and this scale depends on the distance pests migrate between the control activity and the period damage may be inflicted. If we now consider Rogers' diffusion of innovations theory, we soon see that innovations in IPM need a minimum scale of application that can not work through usual adoption processes. If an innovator carries out hygienic measures to suppress pest populations and his neighbour does not so, the experiment does not give desirable results and the innovation is rejected. Thus, for introduction of IPM, usual mechanisms of innovations diffusion have to be overruled in one way or another. This has direct bearings on the role of the change agent, the person who introduces an innovation in a particular community. In the classic, linear flow of information, the change agent had to introduce innovations to innovators or early adopters, and could further lean back. For experimentation on IPM, each community that wants to apply IPM technology needs a leader who makes sure that innovative experimentation takes place at the right scale. Thus, the change agent should not only be involved in dissemination of information, but also in having all adopter categories involved in concerted action for experimentation, in order to enable farmers to experience positive results. Within the community a sizeable part of the farmer population then must experiment with an innovation much earlier than they would do according to their intuition or social situation. In fact, by experimenting at village scale, an entire village rather than an individual farmer becomes a unit of innovation. If one considers individual village communities as a social group, one can imagine that village communities can also be classified as innovator, early adopter etc. communities.

In the previous part I introduced Rogers' *change agent*, an individual who influences clients' innovation-decisions and who, in the Bhutanese context, is usually the agriculture extension staff. Another important role in diffusion of innovations is the *opinion leader*, a role that in traditional societies like in Bhutan is often fulfilled by the early adopters of innovations rather than by innovators. Opinion leaders are the people consulted by majority adopters when they consider adopting an innovation. Rogers describes characteristics of opinion leaders (p. 293 and onwards), for this study their relatively higher socio-economic status than their followers is of importance.

Summarising the theoretical framework.

The thus outlined theoretical framework is summarised in Table 2. The upper row represents the move from uniform pest control methods to technical IPM and IPM with feed-back options to farmers. The last column shows technological innovations needed under different situations in which IPM is to be applied. The left column shows different levels at which farmers are involved in the decision-making process on IPM application. In the green-revolution era, farmers were expected to follow recommendations; in IPM they work with a conceptual base for decision making, or have to be involved as an entire community to implement IPM at the right scale. The table cells then give the activities by the combination of different technological and social characteristics of IPM.

Table 2. Summary of the technical and social dimensions of the theoretical framework of this study, with references to chapters dealing with particular issues.

		Technical dimension			
		classical pest control	*"best mix" of measures for pest control … (Chapter 2)*	*…including pest status & effectiveness monitoring tools (Chapters 5 and 6)*	*technological innovation (Chapters 5 and 6)*
Social dimension	*recipe-like technology application*	chemical control	technical IPM (Chapter 2)		on-station development of control technology…
	Implementation measures when needed & evaluation - by individual		IPM through experiential learning (as in FFS) & PTD (Chapter 2)		…complemented with PTD and development of monitoring tools …(Chapter 3)
	Implementation measures when needed - by community (Chapter 3)		IPM at communal level…	…based on pest status monitoring and learning from previous experiences…	…and identification of minimum scale for control … (Section 6.2)
	Introduction of technology in farmers' communities (Chapter 3 and 4)	T and V type of extension	FFS-type of extension and change agent involving in community organisation …		… and a farmer's-research network developing organisational patterns for IPM at scale

3.2. Experimental set-up for IPM development and application.

The previous sections argued that farmers needed pest monitoring tools and control options as technological needs for IPM and the notion that experiments should be carried out at village scale. To build expertise on how to tackle such problems, this section identifies pest problems and stakeholders to work with.

Mistletoe control as a model to introduce concerted activities.
Staff and farmers have always known how to control mistletoe. Almost everywhere in southern Bhutan, the pest used to be controlled by pruning out the parasite over entire citrus growing patches. In eastern Bhutan, some villages indeed pruned the plant, although in most villages the parasitic plant was controlled only by individual farmers rather than over entire villages. The agriculture extension staff had been lecturing the control of the pest for decades, and yet, in many places farmers hardly controlled the pest. Thus, there must be mechanisms outside the information farmers availed of that made them to not control the pest. This made a nice case to experiment with more involvement in village organisational matters of extension staff. In villages with well-infested orchards, extension staff could carry out a communal programme to have the pest controlled. The spreading as well as the control of the pest could easily be explained (see Box 2), farmers were well aware of the damage and control of the pest, and apparently its control was hampered by an impossibility to introduce communal control activities in the village. This was a clear example of concerted action that could be introduced without any additional technology to be developed. The resulting mistletoe control programme was almost fully carried out by extension staff and farmers, with occasional support by research staff. The process of extension staff involving in organising in communal action is interesting and relevant for introduction of IPM in villages, so that it is briefly discussed in Section 3.4 and Box 10.

The chinese citrus fly as a model pest for IPM development.
We are aware of two causes for fruit drop, the citrus green stink bug and the chinese citrus fly. When sampling orchards in Tashigang and Pemagatshel districts, most dropped fruits contained maggots, and were thus attacked by the citrus fly. (Later it appeared that the citrus green stink bug is more important in lower altitude orchards that were mostly out of our reach.) Thus, the chinese citrus fly was chosen as a model pest to develop IPM for. However, the introduction of citrus fly control was far more complicated than the control of mistletoe, as apart from the concerted action to be introduced, also quite some technology was to be developed. There were theoretical options to control the fly through proteinaceous baiting and hygienic measures and thus practical IPM seemed to be within reach (see Box 4). Yet, quite a few characteristics of the pest remained to be explored. The possible control effect of hygienic measures was to be researched, the distance of fly population dispersion, and the period of attraction to protein bait and of oviposition were unknown, and the establishment of damage appeared problematic. The plant protection service conceived that IPM could better be developed by a closer co-operation between different stakeholders. Researchers were to develop a practical IPM method, farmers should develop a social configuration for implementation of the method, and extension staff was to eventually spread the technology over citrus growers' communities that ranked among the poorest communities in the country. Thus, development of IPM for the chinese citrus fly would serve major goals of most stakeholders in the AKS, including project donors, researchers, farmers and the government, even if the objectives of the different groups differed vastly.

Box 4. Fruit flies (Tephritidae) in general.

Fruit flies (Tephritidae) form one of the families of the true flies (Diptera). The family of Drosophilidae is often also referred to as "fruit flies", most of its species feed on decaying fruit, unlike Tephritid fruit flies that feed on fresh fruit, flower heads etc. or are gall-makers. A few thousand species of Tephritid flies have been described, of which about one third oviposits and feeds on soft fruit during the maggot stage. Various species of Tephritid flies attack economically important fruits, and make the family of enormous economical interest. Losses include reduced quantity and quality of fruits, but also the costs of quarantine restrictions imposed on fruit from infested areas. In India fruit flies are of immense importance, and yet, little research is being done about the group (Kapoor 1989). In Pakistan, Tephritidae cause losses of an estimated 200 million US$ annually, with added losses to traders and exporters (Stonehouse et al. 1998). There are initiatives for a regional fruit fly management programme in east-Africa to stimulate local fruit production for international markets. In the Pacific region similar programmes are being carried out (Allwood, A., Fiji, pers. comm.). In California (USA) alone eight species of fruit flies have the potential to inflict 900 million US$ losses annually, and in 1986 control measures amounted US$ 290 million to keep them out (Dowell and Wange 1986 in White and Elson-Harris 1992). These are just a few of many more initiatives that exist in the field of fruit fly control programmes, and it is no wonder that the biology of Tephritid flies in general is widely studied. Life cycles of fruit flies consist of an adult stage, egg stage, maggot stage and pupal stage; usually the egg and pupal stages take place in host fruit, and adult and pupal stage outside fruit. Fruit-attacking fruit flies oviposit in developing or ripe fruit, where eggs hatch and maggots feed. Maggots pupate and turn into adult flies. The most damaging species are polyphagous (feed on fruits of different species) and multivoltine (have more generations per year). Typical mating behaviour includes male flies attracting female flies with sex pheromones, which gives rise to possible control techniques through disturbance of such behaviour.

The species that was subject to this study is Bactrocera minax or the chinese citrus fly, and is somewhat exceptional. It has only one generation a year, it employs two rest periods during its life cycle (as puparium and as egg) and it reproduces exclusively on citrus. It is not known to be attracted to pheromones, but its behaviour suggests that male flies employ a female attracting substance. Other Tephritid flies in Bhutan include Bactrocera cucurbitae that restricts cultivation of susceptible cucurbits, and Bactrocera dorsalis in a variety of fruits including wild figs and mango. In view of extensive plantation of mango trees in some eastern Bhutanese districts in the mid-1990s, and the pest status of B. dorsalis in existing mango orchards, the pest is likely to become a major pest problem in the near future (M. Kool-de Rie, Khangma, pers. comm.).

The intention to develop IPM with stakeholder groups in villages.

Section 2.5 showed that a lack of compelling co-operation between farmers, extension staff and researchers hampered the development of practical IPM for the chinese citrus fly. In formal discussion fora, there was always a hierarchy between the different stakeholder groups, and it was easy not to incorporate knowledge presented by colleague groups in one's own working routine. Thus, a new research set-up would have to make sure that the three groups would take each other seriously, and reflect on each other's and one's own role to achieve a common goal: control of the chinese citrus fly. In 1993 a new plant protection project started, which in its the inception report proposed a new IPM development method that was described as follows: *"Main activity for the project is the development, implementation and verification of IPM packages in pilot project villages. This activity will be carried out by networks of farmers, extension and plant protection staff. A participatory approach will be used"* (Royal Government of Bhutan 1993).

This innovative research set-up coincided with the felt shortcomings of the contribution of research to better plant protection practices as described earlier in this book. Initially, the change in policy was not so much meant to involve farmers in research activities. The project management, notably the new project team leader, Dr. H.R. Feijen, regarded the availability of big experimental fields as the major advantage of pilot-village research: after all, years of on-station experimentation had hardly resulted in scientifically presentable results (H.R. Feijen, Simtokha, pers. comm.). However, as soon as research teams started to work in villages, social aspects of IPM application appeared to be an essential element in IPM development.

For the citrus IPM programme this meant that a combined social and technical experiment was initiated. The development of IPM for the chinese citrus fly was to be carried out in villages, in a co-operative structure of farmers, extension staff and a researcher. *Research staff* initiated the programme, had the general co-ordination towards outside institutions, and brought in basic knowledge on pest management technology. *Farmers* will eventually have to implement IPM without outside assistance, so that it was *their* learning capability that determined whether IPM can be successful or not, and thus farmers were important stakeholders in evaluating IPM technology. Farmers were responsible for carrying out control measures and organising IPM activities at village level, and developed community organisation patterns for pest management. *Extension staff* was responsible for the day-to-day co-ordinating task in the village and involved the farmers' community in the technology developing process. He kept contact with research staff about relevant developments in the village. Extension staff also pointed out if developed technology was fit for dissemination outside the research area and in what fields simplification or extra training was needed. Thus, for IPM technology development, farmers, researchers and extension staff worked together in their own function. In this set-up, each group had the "power of agency": if one of the groups did not take the programme seriously, the other groups would immediately notice it and discuss further action (as in Long and Long 1992, p. 24).

Yet, this co-operation did not cover necessary technical developments. Developing monitoring tools such as traps or damage assessment methods is better first carried out by researchers, and then applied and adapted in a village environment. Thus it was decided to continue station-led research activities; although the research agenda was now to support activities in the research villages rather than to recognise and confirm general scientific concepts. The continuation of on-station research even after in-village research was initiated was a particularity of the citrus programme. In other village research programmes[5], research was carried out in villages and not on-station, partly because of the nature of problems addressed in those programmes.

As a result of the then on-going citrus extension programme (cf. Chapter 2) the plant protection service was in a position to carefully select villages to work in; and the district authorities and farmers readily agreed to start a programme in the villages proposed. The bias of the plant protection service in favour of Pemagatshel district was not well received by neighbouring districts, and another district was included in the citrus programme. One village selected was Am Shing under Gomdar block, Samdrup Jongkhar district, situated at two hours walk (and a short drive) to the market. This village made a progressive impression. The other village selected was Dungmin under Dungmin block, Pemagatshel district, at two days walk from the road and market, which made a more conservative impression. Activities in each research village started in August 1993 with an RRA exercise that concentrated on citrus, even if other problems were discussed as well (reports can be found in Hartmann *et al.* 1993). During the RRA-exercise, training sessions such

[5] Nation wide about twelve pilot village programmes were initiated in 1993 -1996. Problems such as potato late blight, chilli wilt, vegetable pests, apple pests, rice blast and wild boar were addressed in such a set -up

as already developed in the earlier citrus programme were carried out as well. Through the combination of gathering information and organising training sessions, the RRA-team took up an accepted role in the village and people could already envisage what to expect from future programmes. The programme thus initiated continued for about three years.

3.3. Village research programme in an "innovative" village.

The community of Am Shing village is innovative and willing to experiment with new orchard management methods. Thus, the community is an ideal partner for the development of IPM for key pests. A research programme was set up that naturally embarked upon difficulties. Success of experiments is never ensured and farmers may invest time in management options they will not directly profit from. On the other hand, the community got access to government services and was skilful in changing the programme towards their objectives, which resulted in developing a new relationship pattern between government services and the people.

History and situation of Am Shing village.
Am Shing village under Gomdar block is a relatively new settlement. The story goes that Am Shing was founded in the 1920's by three households originating from three different villages in the neighbouring Pemagatshel district, i.e., from Yurung, Chemung and Dungmin, the latter being another village selected for the citrus IPM programme. A few older people remember to have come to Am Shing as a child. Even if descendants for the various settlers intermarried, even now most people are aware of their place of origin which gives rise to a joking animosity among households.

Am Shing village consists of about 33 households and is situated on the eastern slope of the Nyir-ama river valley at an altitude between 800 and 1200 m asl. Within 15 minutes walk one can find two or three more villages living from semi-subsistence farming with mandarin as their main cash crop. The climate of the area is hot and dry with occasional heavy showers in summer time. In 1994 there was no drinking water system in Am Shing, people had to take a fifteen minutes' walk for water. The block centre is situated at twenty minutes walk, down at the river and features a small bazar, a junior high school and a basic health unit. There are a few lay monks in the village, but religion is relatively unimportant compared to more traditional areas such as in most of Pemagatshel district. Each house has up to two hundred bearing mandarin trees, the average holding is about fifty trees while half of the orchards are yet to reach the bearing stage. Mandarin transport involves about two hours walk to the road from where mandarins are taken for two more hours ride by truck to the Indian border. An official auction yard was opened in 1990 but its functioning was not optimal; due to price agreements by traders prices were often 50-70% lower than in nearby Indian markets, while farmers were not allowed to take their produce over the border. Moreover, the bordering area in Assam was plagued with political unrest and at times prices collapsed in absence of transportation possibilities. Yet, the mandarin cultivation and trade was flourishing in Gomdar area, providing economic opportunities to a group of vocal and active farmers. Some farmers involved in the research programme were local contractors for whom better yields would result in higher turnover and better profits.

Changing learning situation.
The village research programme started with an RRA-exercise that was followed by training of the village like during the earlier citrus extension programme (cf. Chapter 2). As a follow-up staff

visited the village five times a season for a few days, and soon a new programme pattern emerged. "Official" meetings were held at the start of such visits, while later people came with local snacks and drinks and organised social parties. Both type of activities were of complementing importance to the programme. During official meetings, the programme contents were discussed. Informal gatherings helped to build a group spirit and to build commitment to realise the programme objectives. The informal gatherings resulted in a confidential atmosphere and both farmers and staff felt at ease to request for necessary assistance to solve problems felt by either side. Programme staff came to develop an IPM method for the citrus fly; the community carried out experiments and got access to technical information and specialised inputs (such as bait and pesticides) through the programme.

The Am Shing community mastered the skill to seize the initiative in the programme, which programme staff took as an opportunity to be explored. For example, during one of the sessions a control option for trunk borer was discussed, i.e., instruction of children to catch adult beetles to reduce the pest population. This measure was then implemented in-between subsequent programme team visits and programme staff was proudly shown its results. Such activities showed that the community was familiar with communal organisation. The citrus programme just brought in some new ideas that were easily implemented in a community with such a tradition. For the first time, programme staff worked with a village as an organisation rather than as a couple of individual households. But also for farmers the learning situation changed. In the citrus IPM programme the village developed a much closer rapport to researchers as compared to earlier development programmes. In the framework of the citrus programme, farmers came up with various management problems they wanted to be solved, such as pests related to fruit quality (i.e., small suckers and scab). Farmers carried out experiments with suggestions and materials provided by research staff, even if staff was not particularly knowledgeable about the problems. Later in the programme, the community regarded periodical drought as a management problem, and asked the research team for assistance by helping to get support for the construction of a small water supply system.

Community-implemented efforts to control the chinese citrus fly.

One can imagine that in an apparently well-organised community like Am Shing, experimenting with pest control measures is relatively easy. However, the programme was experimental of character, and, even if they represented the best informed ideas for control available, proposed measures had never been tested before. This testing now was a task of the programme. Theoretical options to control the chinese citrus fly included proteinaceous baiting and collecting and destroying maggot-loaded dropped fruit, both over the entire village.

Baiting the chinese citrus fly.

In the preceding season, on-station research had identified a proteinaceous substance that attracted individual flies. In May 1994, in Am Shing various bait monitoring traps (a 4 into 4 m cloth stretched under a bait-treated tree, cf. Section 6.1) were set up and caught quite a few flies. Then, the community carried out bait splashes over the entire village (see Box 5) every ten days or so until September. The local extension staff designed a fruit loss recording system for illiterate farmers, and in October-November five individuals volunteered to carefully record fruit drop and take record of the final harvest in two trees each. The same recording was carried out in a neighbouring untreated village[6]. Data thus collected were analysed by the research team, but appeared to poorly represent fruit drop percentages. Even if farmers of non-treated orchards claimed that one-third of fruits had dropped, the thus recorded percentages of fruit drop officially varied from 2 to 8%. As an experiment we once dropped 20 marked fruits from the canopy of one tree, and could recover only six from the ground: the rest disappeared in bushes or down the slope. Thus, the fruit drop records did not reflect actual losses and we were not able to present official records of its effects. Am Shing farmers themselves claimed that about 15% of all fruits had dropped after treatment, compared to one-third in the year before; however, fruit setting had been three times higher, so that in absolute terms, fruit drop had been higher. Moreover, the farmers' assessments may have been tainted by the wish not to disappoint the research team, and were therefore not very reliable. After all the efforts put in the experiment, the researcher then presented the relative reduction of fruit drop as a success (which, later, appeared a valid judgement in view of the fly's behaviour under varying levels of fruit setting). Yet, obviously the lack of presentable data was a serious drawback of the village experiment[7].

Box 5. Control of the chinese citrus fly through bait-splashing and related luring methods (see also Section 6.1).

Poisoned fly attracting substances can be used to lure and kill flies of the Tephritid family in general. In August 1993 a locally available proteinaceous substance was found to attract female chinese citrus flies. With bait it is possible to reduce the fly population with minimal insecticide requirement, so that also the effect on non-target insects is reduced. The bait-poison mixture is best applied spot-wise, and it can be applied by splashing into individual trees with a cup, brush or locally made water piston rather than by expensive and unreliable sprayers. Each bearing tree must be treated with 50 ml bait mixture, compared to the need of about five liters insecticide solution for a conventional cover spray. A disadvantage of fly baiting is its obligatory village-wide application. Bait attracts flies for about four consecutive days, and in treated orchards flies will reappear from adjacent non-treated areas and undo the fly control effect, and treatments need to be repeated if there is a risk for immigration from elsewhere.

During the 1994-97 research various refinements were made in the citrus fly luring technology. Male flies flock in the trees with the biggest fruits, particularly in the early oviposition season, and may be lured in earlier developing lime before oviposition in mandarin starts. Similarly, flies gather in upper canopies (where fruits are bigger) and application of bait in the upper canopy enhances its effectiveness. In 1996 it was found that both male and female flies are best attracted during emergence rather than just before oviposition, so that baiting in that period may be most effective. This observation may allow for a reduction in number of bait splashes to be carried out from twelve to four or so. Twelve bait splashes in one season appeared impractical in most villages.

Further problems of bait-splashing include the unclear "ownership" of chemicals bought by an entire village and applied on communal basis. The research programme developed a bait-soaked wick that would be effective if once placed during the fly emergence period in bearing mandarin trees. This wick could be bought by individual farmers for whatever number of trees they had. Even if the costs of such wick may be double the costs of splash application of bait, the fact that each farmer would get one such wick in hand appeared to appeal to the feeling of individual ownership and farmers were ready to pay for it. However, this bait-soaked wick was not tested for its effectiveness ***ad finitum****.*

[6] Another problem with in-village of experimenting is the difficulty to collect "pre-traetment" data: at recording loss data, farmers immediately want to get access to possible control options and it is difficult to deny such requests. Am Shing and its neighbouring village appeared similar except for the fly control treatment.

[7] Luckily, a parallel experiment in station-led experimental orchards in the same season showed a decrease in fruit drop percentages from 54% to 17%, which indicated that fruit drop reduction as a result of baiting was not to be ruled out.

Hygienic measures to control the chinese citrus fly.
Another control option was the destruction of maggot-loaded dropped fruit. For this, the community made 8 feet (!) deep pits for fruit disposal in every orchard. During the fruit drop period Am Shing community collected dropped fruits and disposed them in pits. An experiment was carried out to establish the emergence of flies from such pits (as illustrated in Box 6 and Figure 3). It appeared that natural control mechanisms in the pits killed as good as all pupae and that no additional control measures were required.

Box 6. In-village experimenting for better pest management options .
One proposed measure for citrus fly control was the application of hygienic measures. Farmers disposed maggot-loaded dropped fruits in pits to avoid maggots pupating in the soil. The community carried out the measure beyond expectation, and during the following meeting farmers requested for chemicals to kill citrus fly larvae in pits. Researchers however maintained that deep burying fruits as such would kill flies emerging from pits. The debate could not be settled and it was decided to do an experiment. Pits were filled with thousands of dropped fruits, some pits were treated with chemicals and some were not; for the sake of the experiment fruits were covered with only a thin layer of soil. Emerging flies would be caught in mosquito nets suspended over the pits (Figure 3). In spring, from pits under both treatments only few flies emerged whereas thousands of maggots had been disposed in the pit (by disposing dropped fruit). Maggots had died through the incapability to reach soil fit for pupation, while a variety of natural enemies were collected from the pits. This not only convinced farmers, but also extension staff and researchers, that natural control in pits worked well to kill maggots and pupae. The results were incorporated in the on-going extension-programme in other areas. Experiments thus developed were in fact modules that could be used in FFS-type of extension programmes.

Figure 3. Am Shing farmer observing the survival of fly pupae in a pit with disposed dropped fruit.

One remark must be made to underline the experimental character of the programme and the possible investments of farmers in technology that does not automatically work. Later research revealed that hygienic measures hardly bore the potential to reduce the citrus fly population, as it was quite impossible to reduce the number of pupae in the soil below the numbers natural enemies achieved through their grazing of the soil (cf. Section 6.2). Thus, the community's efforts to dig the 8-feet pits in stony soil probably never contributed to a better citrus production in the village. This underlines that theoretical control options are not necessary practical ones, and that one must be very careful with proposing such measures without reviewing their effectiveness.

Technological shortcomings for applicable citrus fly IPM.
All over, the experiment showed the lack of a few essential technological components for the development of reliable fly control methods. For example, the community had carried out about twelve bait-splashes over the adult-flying season, while it was quite likely that the fly could be controlled with fewer treatments. In fact, the applied control method could only be characterised as "IPM" rather than "chemical control" because of its low pesticide use (1% of the amount needed for cover spraying); otherwise the method was applied recipe-like and determined by the instruction of the research team rather than based on a fly population monitoring system. Farmers were not yet in a position to develop an intuition on fruit fly control in absence of easy-to-use population monitoring devices. In the long run the community was never going to carry out twelve bait-splashes per season; possibly four or five was the maximum. Thus, a fly population monitoring method was to be developed to base the time and number of bait applications on. The incapability to reliably establish fruit drop percentages made that researchers just guessed about the effect of the experiments. A more reliable method to establish fruit drop was necessary, preferably one that could distinguish between fruit drop caused by the citrus fly and by the citrus green stink bug.

Monitoring infestation level routines.
Monitoring losses by the citrus fly may seem simple at first sight; it appeared to be one of the most difficult components of the research programme. Difficulties were caused by a combination of factors. The relation between the fly activity and the fruit drop levels was not known. How do flies select fruits for oviposition and what types of fruits do then drop? What is the in-fruit mortality of posited egg clutches? What is the relation between oviposition and fruit drop, in view of possible other drop causing factors? Another problem was the quantification of fruit drop. On-station research revealed that fruit drop percentages within orchards varied among trees: in the same orchard, one tree shed 20% of its fruits, and another 70%, while fruit drop in both trees lasted for two months. In addition, it appeared difficult to estimate the final harvest of individual trees. Thus, a pre-drop observation routine was developed based on the finding that flies, during their oviposition act, leave scars in the skin of individual fruit (Box 7).

Box 7. Development of a protocol to establish damage by the chinese citrus fly.
An important difficulty in establishing effectiveness of treatments was the absence of methods to reliably estimate yields and damage. At first, drop percentages were established through collecting dropped fruit and estimating fruit remaining in the tree. This method was carried out through weekly collecting and counting of dropped fruits from under selected trees for ten weeks in a row. In relatively flat experimental orchards where staff and students carried out observations, this method worked reasonably well; in villages however it appeared impossible to get reliable drop data. During local festivals farmers failed to do observations and dropped fruit rolled down the slope to disappear into bushes. Thus, more reliable fly activity observation methods were to be developed. Among other methods, it was tried to estimate percentages of discoloured fruits in trees during the dropping period and examining fruits for signs of oviposition. The latter method appeared most promising. When fruits

were superficially peeled, the place where flies inserted eggs into fruits was visible as a black spot. This principle of observation resulted in insight of the fly oviposition behaviour. Flies first oviposit in the biggest citrus fruits in the tree or orchard, irrespective of fruit species and position. Thus, more vigorous trees (in which fruits are slightly bigger) attract more oviposition activity than declining trees. The main oviposition season is during the period that fruits are between 15 and 22 mm diameter; i.e., for mandarin usually between mid-June and August (depending on the local climate). It took several years to develop these findings into a reliable infestation monitoring routine. After the main oviposition season, sampling and checking the biggest, medium and small fruits in the orchard allows for the comparison of fruit fly activity between years or between villages. Comparing oviposition density in samples from the tree and from the ground allows for establishing the relative importance of the citrus fly as a cause for fruit drop. (For a further elaboration of the method to establish citrus fly infestation levels, please refer to Chapter 5). During training, this method was explained to and used by farmers, in particular to establish the cause of fruit drop in their respective orchards (Figure 4).

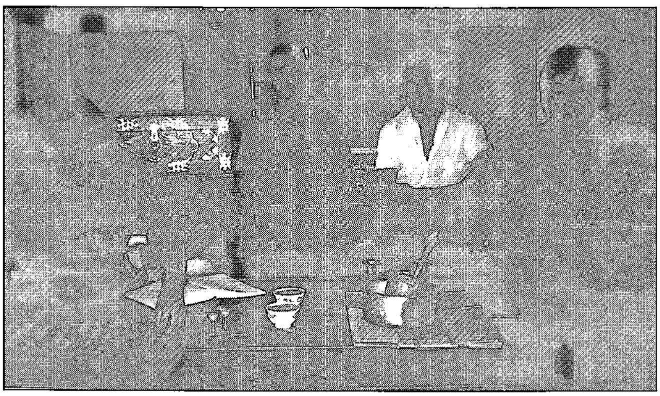


Figure 4. Establishing the chinese citrus fly infestation level of a particular fruit population in a village.

An early version of the fly monitoring routine revealed that after two years the Am Shing community had succeeded to considerably reduce fruit fly damage. In 1996 less than 5% of fruits was infested by fruit fly (against about 35% in nearby non-treated villages) which meant that the fruit fly population in Am Shing was near extinct. However, still some fruit drop by the citrus green stink bug remained. Through the fly activity monitoring routine the most active group of farmers could see that one of the two major causes of fruit drop was checked; however, for most farmers bug-caused fruit drop blurred the evidence for effectiveness of the fly control method to some extent. This feature also resulted in the invalidity of the apprehension of farmers regarding the effectiveness of the fly control programme.

Farmers' poorly grounded use of monitoring tools influenced the research agenda.

Pest monitoring routines allowed for building intuition on control activities.
So far, the Am Shing community carried out measures following technological developments by the research team. The development of traps however enabled the community to carry out measures tailored to the needs they felt, so that the community began to behave like an independent actor. In the second village research season, on-station research had come up with a

few fly traps (Section 6.1), i.e. the dry-lure trap (based on attraction by smell and an indication that flies could be baited) and the fruit-mimic trap (based on attraction to fruit shapes and an indication that oviposition activity was on-going). Another useful tool was the fly-emergence bottle in which pupae could be kept to establish the fly's emergence period. Although the tools worked in experimental orchards, we did not yet know what device worked best in what period, and how the devices could be used as indicators for possible action to be taken. The fruit-mimic trap attracted flies in June. The Am Shing farmers were provided some traps and baiting materials to carry out a baiting treatment so that they could figure out how to use them. If fly baiting worked this year, the following year they would have to pay for the materials. The village baiting committee then placed the traps in various orchards. It regularly monitored the traps and baited only after trapping flies; this resulted in farmers carrying out only two bait splashing treatments that year. This, while the researcher would have preferred to play safe and carry out calendar-based treatments; as at the time it was not yet known whether bait-splashing was effective at all. When such was discussed during a research team visit, farmers expressed that they had wanted to cut down on baiting material's use in order not to have to buy them in the following year. Thus, farmers used the fly catching devices as population monitoring devices; even if the relation between low fly catches and a low population had not yet been formally made so that the research team felt uneasy about the farmer's decisions. In this, the farmers showed how they used the monitoring tools independently for their objectives rather than following staff's guidelines. This both showed the intentions of the community as a whole and the fact that they could act upon these intentions in an organised way.

Further experiments carried out by farmers included the keeping of pupae in jars, some in the upper village and some down; some in the open and some near the fire; to determine the timing of emergence under various conditions. Farmers concluded that the warmer the place where the pupae were kept, the earlier the flies emerged. Thus, when again one year later research showed that the best time to attract flies was the fly emergence period (rather than the oviposition period), a brief discussion with the Am Shing community sufficed to make farmers adjust the timing of their bait splashing activities to the optimal attraction period. In this way no extensive experiential learning exercises were needed for farmers to make full use of this finding, because most of them had already constructed a broad concept of the fly's life cycle and could link on-station experimental findings to this concept. The initial investment in the farmer's understanding of the problem resulted in later flexibility and effectiveness of their activities.

The Am Shing community was able to act upon communal intentions.

For the proposed citrus fly control method concerted baiting (and hygienic) measures over the entire village were necessary, and later programmes elsewhere showed that this communal organisation often was a major constraint in achieving proper citrus fly control. This justifies a closer look at the internal organisation of the Am Shing community that was so successful in their approach of the programme as a community rather than of individually interested households. First it should be noted that in Am Shing quite a few enterprising people were still living in the village, while elsewhere such a group was often absent. The main cause of this group remaining in the village was the presence of economic opportunities by mandarin cultivation and trade. Secondly it should be noted that the initiative of the technical programme was in the hands of about ten individuals, mainly male farmers, even if their wives and most other households involved in the social gatherings during staff's visits. Thus, two-third of the households, even if they were aware of the programme, did not participate in the innovating activities even if they assented to carrying out measures as proposed by the leading individuals. A few absentee landowners' orchards were treated by the baiting committee, even if they did not participate in the programme.

This smooth programme implementation was rooted in an older tradition of organisation in the village, and in fact, over the entire block. The community organised pre-meetings in which a univocal standpoint was formulated, which explained the apparent consensus within the community on programme implementation. An assistant of the block's major who acted as a facilitator chaired this type of meetings throughout the programme period. He attended programme meetings and played a role in organising activities as recommended by programme staff. Soon this alderman made individual households responsible for certain tasks. Some were responsible for receiving and feeding the research team at visits, others for technical co-operation with the programme or keeping experimental materials. When one person could not perform the village co-ordinating task, this was discussed in village meetings and another person was nominated to do the job. All households were instructed to contribute to the social sessions organised whenever the research team visited the place. The alderman discussed activities with the community even in absence of the research team. The fact that the community was well-organised resulted in a reduced role of extension staff. Most of the programme transactions were done directly between research staff and the farmers' community, even if the extension staff was mostly present during meetings. Later, the extension staff took up a role as spreader of the fly control technology, although the extension strategy he chose followed mainly the earlier transfer-of-technology routine.

Follow-up of the citrus IPM programme.

The Am Shing community showed itself as an interesting actor as it pulled the programme way beyond its original objective. The village had been selected for the development of IPM for the citrus fly at a time when it was still thought that this pest was equally important in all citrus growing areas and inflicting 35-75% damage to the mandarin harvest. In Am Shing this appeared not the case. Fruit drop was a 35-50% "low"; the citrus fly was responsible for possibly two-thirds of all fruit drop; the remaining one-third was probably caused by the citrus green stink bug. Thus, other than in higher situated villages the control of the citrus fly did not lead to double or even triple yields (such as in Dungmin village, next Section); the increase in yield was possibly "only" 50% or so. Yet, the community was always eager to receive research staff and attract their attention. Reason was that the village community regarded the programme staff as representatives of the government, and that the village had other points on the agenda. It soon appeared that the people wanted the programme to assist in lobbying for the construction of a feeder road, an idea that staff soon denied as completely out of reach of the programme. Yet, the IPM programme, as a part of the Ministry of Agriculture's activities, did have access to the decision making process in that Ministry. For citrus production, a next production constraint was the periodic drought in the village. The community was eager to have a water supply system constructed. During a joint training activity with the then active Farmers Associations Support Unit the community exercised to develop claim making capabilities. This resulted in the programme assisting the Am Shing community for lobbying for their cause (Box 8). During a farmers' group training Am Shing farmers were to present their wish for the construction of a water supply system that was presented as an idea to experiment with orchard irrigation. The regional irrigation section appeared willing to invest time and money in a small water supply scheme that could be used for various purposes, including the irrigation of orchards.

Box 8. Initiating citrus irrigation experiment cum drinking water system.
Farmers requested programme staff to organise a follow-up programme of the citrus IPM activities and identified tree irrigation as the next production constraint . In spring there was little rainfall and trees often made a wilted impression, while there was a small source of water at 1.5 km from the central village. Irrigation staff was invited to the village. Now, plant protection staff was requested to attend the pre-meeting to discuss the strategy for getting access to assistance for the construction of a small water supply scheme. The community discussed the construction of a citrus irrigation facility, which was a novel idea for the irrigation section. The latter was interested in carrying out the idea if the Am Shing community was ready to pay part of the construction costs. After all, water would be used for orchards that produced mandarins for sale. Various government officials (such as officials from the irrigation section and the regional project facilitation officer) visited Am Shing and discussed options for development they could possibly arrange for. Even if, at times, individual civil servants approached the village in the traditional (autocratic) way, villagers learned to get the best out of available government services. The programme regarded this as a type of "experiential learning" with respect to claim-making processes; a subject that was way beyond the initial objective of the programme. Quite a few government officials declared to be positively impressed by the awareness and the responsibility of the Am Shing community during the citrus management programme and later activities. When the community agreed to pay part of the construction sum and completely carry out construction, the case invoked heavy discussions in MOA. Some officers felt that the government was giving away part of the decision making power to farmers' communities. After a year of deliberations the Ministry decided to support the construction of a citrus irrigation facility at shared cost basis. Farmers agreed to pay Nu 40,000 for the scheme, which was about half of the cost, and the labour for construction. The facility was then to be used to carry out citrus irrigation experiments. This arrangement had no precedent in Bhutan; so far farmers only contributed in labour to the construction of such schemes. The irrigation facility was built early 1998 (H. Kool, pers. comm.). Unfortunately, circumstances brought the experimentation with orchard irrigation to an end, although experimentation may have resumed later.

This is where the involvement of the plant protection service ended. By constructing a joint experimental orchard irrigation facility, the Am Shing community and the irrigation section developed a new type of partnership between the government and farmer communities in Bhutan. With the community's monetary contribution to the scheme, it got more power and ownership over the scheme. This type of developments may be labelled the development of claim-making power, or "empowerment", as it is often mentioned in PTD-literature (e.g., Veldhuizen et al. 1997). One could see this development as "experiential learning" with respect to social and political processes, although some actors in Bhutan would disapprove of this view. If the community was ready to negotiate a more equal relationship with the government, it may be doubted whether the government services were ready to change their ways of working with farmer communities. Negotiating programme contents is not always well-received in autocratically organised societies. Unfortunately, Gomdar block as a whole became involved in some local political tension, so that the programme was interrupted late 1997; we are not aware of the fate of the citrus irrigation experiment afterwards.

Retrospective remarks.

The Am Shing story shows what possibilities are created and what dilemmas occur when implementing in-village experimenting with farmers and extension staff as vocal stakeholders. First it should be noted that the community was capable of putting a flexible and robust organisation in place, or in more theoretical terms, the soon developed a "social cognition" just as described by Hutchins (1995). If a task could not be performed by one person, soon another person would take up his job for the common purpose of citrus fly control. This capability of the village was one of the main reasons why the programme went smoothly and why I tagged this village as "innovative". The story shows how on-station research was determined by the needs of a practical IPM experiment by farmers, and how research outcomes were immediately applied in the village. On the other hand, throughout the programme, the three stakeholder groups – farmers, extension staff and research staff – had different interests. Researchers wanted to develop a citrus IPM strategy that could be applied all over the place, and used the initiatives of the Am Shing community to identify shortcomings in the control and pest monitoring tools available. The development of tools then took one or two seasons, and by the time they became operational the village programme was coming to an end (two or three years is a maximum for such programmes). For the research staff, control of fruit drop was important as an indicator for success of the programme and for the continued support of the farmers (and, through them, of village and district authorities). For farmers, citrus pests represented only one of the many constraints for a better living. They carried out the fruit drop control experiments in order to get further access to government services – a service that the researcher could not deny after the farmers' overwhelming support to the IPM experimenting programme. In fact, the programme could be analysed through the perspective of the various actors, how they reacted and interfered with each other; a perspective that was not chosen for this study.

In the next section a more complex situation is discussed. In Dungmin village, apart from the technical issues, also problems in the domain of community organisation hampered the development of citrus fly IPM.

3.4. Village research programme in a "conservative" village [8].

In the previous section it was shown how an innovative community like Am Shing was able to utilise technological tools for the control of mandarin fruit drop. A parallel fruit drop control programme was carried out in a more conservative community, i.e., in Dungmin village of Pemagatshel district. Fruit drop was high (50-75%) and exclusively caused by the chinese citrus fly rather than by a combination of pests, which suggests that the control of fruit drop is relatively easy. On the other hand, the community was less well organised than Am Shing, at least for the IPM programme purposes. This section describes the social processes governing a technical experimentation programme in such a village.

History and situation of Dungmin village.

Proper Dungmin village is situated on a North-facing slope and may be 1 km wide and 1.5 km long. It takes a full day to walk from the road head near Pemagatshel Dzong to Dungmin village; the market in Assam is some ten hours walk away to the south. The proper village consists of 75 households, but within fifteen minutes walk neighbouring villages may account for some 45 more households. There are various religious buildings: an old temple and a monk school; the village functions as a religious centre to the area. The village serves also as a block centre with a Basic Health Unit, a service centre for livestock, forestry and agricultural services, and a block administrative unit. The story goes that the village population originated from Yurung, a main

[8] The Dungmin village programme has been video-filmed; Kleinheerenbrink and Schoubroeck (1993b and 1994) and Kleinheerenbrink (1996) show discussions, interviews with farmers and experimenting activities in various phases of the programme.

centre about five hours walk to the North, from where they were once chased out by the forefathers of the present inhabitants who invaded the area from Kurte area. Even now a (low-profile) animosity between Dungmin and Yurung people can be felt. Marriages between the two groups are not very common, while disputes on land arise every few decades or so, mainly because the Dungmin community is short in arable land while the Yurung people leave part of the land fallow on their side of the area separating stream. In the late 1980's the government had assisted the community to construct an irrigation channel. It led water for a few hundred meters onto the village's plateau to irrigate a few hectares. The story goes that during two seasons the community tried to cultivate rice; however, there was no traditional system of water distribution and both rice crops failed in view of water disputes. The community decided to block the channel and continued to cultivate the traditional upland crops.

Around ten citrus growing villages lay within two hours walk from Dungmin and all those villages produce for the Assam market in Subankatta, at up to three day's walk just over the border. Marketing is hampered by the absence of a motorable road; on the other hand the market outlet straight to Assam (rather than within the Bhutan territory) ensures that the buyer's competition is high, and that mandarins fetch double the price offered in the nearby Samdrup Jongkhar auction yard. The distance to the market explains why most money is made in transporting mandarins rather than producing them, which gives rise to an extensive system of local contractors and sub-contractors led by the local lama family.

Changing learning situation.

During the earlier citrus extension programme (cf. Chapter 2), staff visited about fifteen different Pemagatshel villages two to three times a season. Dungmin village had been visited twice and thus two training sessions and several household interviews had been held. Now that the IPM village programme was initiated, staff worked with one community rather than briefly visiting and training many villages. The new stakeholders in the citrus IPM development programme consisted of the Dungmin community, the plant protection staff and the local extension staff, Mr B.B. Acharya, a fresh graduate from the National Agriculture Training Institute. The village research programme was initiated through a four day's RRA-exercise in August 1993, which started with a plenary training session on citrus management and a discussion on the programme-to-come. Earlier that month, on-station research had managed to lure a few chinese citrus flies in provisory traps, and in Dungmin village some flies were caught accordingly. The presence of a tangible fly that apparently caused fruit drop raised a will to act in the village. Quite a few people expressed that the community was highly interested in controlling the fly, which staff took as a sound starting point for co-operation with the community. Other activities carried out as part of the RRA included the interviewing of individual households on their knowledge concerning citrus management. This exercise yielded a general overview of existing knowledge and practices on the citrus fly, of which a few examples are presented in Box 9. The interviews revealed that providing farmers with information alone, like in the earlier citrus extension programme, did not necessarily lead to successful pest control activities. The "body of knowledge" of farmers and staff was too far apart so that even repeated training sessions did not result in farmers' ability to utilise proposed measures. It must be noted however that the citrus fly biology and control are relatively complicated (cf. Section 6.1) and that in more transparent pests individual farmers are likely to successfully adopt and apply control measures.

Box 9. The knowledge of Dungmin village farmers on the biology and control of the chinese citrus fly (from: Hartmann et al. 1993).

During an RRA-exercise in Dungmin, a survey of the Knowledge, Attitude and Practices (KAP) was carried out, in particular regarding mandarin fruit drop. The following anecdotes were noted down:

Knowledge: Life cycle of fruit fly. *Rinzin Wangmo was the village headman's wife, and often in function herself. She attended training on citrus fly biology and control. Two days later, during a religious ceremony for which many people were invited, she explained the life cycle of fruit fly: "There is a kind of wasp, and, as my parents told me (and who else should I thrust?) those wasps turn into flies. Those flies (was told to me during the training) lay eggs in mandarin fruits, which then turn yellow and drop. From the eggs maggots appear that eat the fruit from inside so that it gets rotten. I do not think maggots can fly and I have never seen any maggot creeping up in the tree, so without food left they are bound to die in the rotten fruit. Maggots are maggots, they can not change. Where the wasps come from? I have no idea, they are just there..." Then Mrs Rinzin Wangmo's friend, Mrs Ugyen Wangmo said: "Maybe maggots become the seeds of wasps. But no, that can not be, that is just impossible."*

Attitude: The sin of killing. *In the village, a religious ceremony is done off-season in order to purify the sins related to the cultivation of crops, such as the killing of insects during hoeing, while some lama's meditate for months in the same end. Sometimes farmers adjust their sowing time according to a special date or month specified by the lama to reduce the killing of insects. During auspicious days (3 or 4 each month) farmers do not work on the field as killing during that day counts extra heavily on each individual's record of sins. The team asked farmers whether killing insects in the framework of pest control is acceptable. Farmers invariably declared that it is better that the insects die than that people die. The fact that sometimes pests are killed on purpose is simply not told to any religious official in the village. Mr. Wangda, a religious official and enterprising farmer, was asked whether he minds to kill insects or not. "Of course I will not control pests as a monk, but when pests occur in my crops I have to ask others to control them so that the sin does not come on my account."*

Practices: Control of fruit fly – the ritual way. *For damage of unknown cause (like diseases and non-transparent pests such as the citrus fly) all households in the community contributes to a religious ceremony. This ceremony is not designed for a particular problem or crop, but to effectuate reduced damage (or a good yield) in general. To cure pest outbreaks a ceremony called Yiwezingse is performed, this ceremony however is near identical for all kinds of outbreaks. People seem not to believe the ceremony reduces losses ("... the monks get food and make money, but the pests remain ...") but people claim that the ceremony renders peace of mind, which in its turn contributes to a better working capability. Monks themselves state that the ceremonies are sometimes effective, and sometimes not. The monks have difficulties to explain the causal relationship between the act of the ritual and the control of damage. When the team asked a monk whether he could prevent outbreak of pests like citrus fly, he answered he could influence the weather, and through the weather the outbreak of pests. So, the team asked what kind of weather then would prevent high damage by fruit fly, the monk said that he had no idea. Such questions however seemed irrelevant to the monks; the fact that the right ritual was performed seemed to do any job.*

Practices: Control of fruit fly – the scientific way I. *Mr Wangda (a monk himself) had about fifty mandarin trees. Once he attended training on the control of fruit fly, and was advised to collect dropped* *fruits and dispose them in the river. He collected dropped fruits and carried them fifteen minutes walk down the steep slope below his field. The following week, however, fruits kept on dropping. Mr. Wangda found that the measures did not work and left this practice (Mr. Wangda had apparently not understood that hygienic measures should be carried out on communal basis, and that they worked through reducing the next year's population size).*

Practices: Control of fruit fly – the scientific way II. *In a nearby village, Mr Themphey had heard a radio broadcast that the cause for fruit drop was citrus fly and that it could be lured by fermenting local beer. When the first fruits dropped, he made a mix of local beer and water, which he splashed in the affected trees. The method did not result in reduced fruit drop and he left the practice. (Mr Themphey had apparently not understood that the fly should not only be lured by bait, but also killed by an insecticide component (which he did not avail of). Moreover, the luring of flies should take place before the oviposition period rather than when fruit drop starts).*

This aspect of IPM, i.e., keeping track of sentiments on the programme and gaining support for experimental activities, took up most of the time of both extension and research staff. Monitoring tools such as described in Box 7 appeared useful to introduce individual farmers to the logic of IPM experimentation. Such tools were the initial focal point of repeated training sessions in which the progress of the programme was discussed with representatives of all households. From the technological needs, soon the social consequences for control measures were discussed with the community. At the start of the programme, the overwhelming importance of social aspects governing technological experiments in villages had never been foreseen. The following section gives an example of the implementation of communal action for the control of mistletoe, with featured few technical secrets but many social ones.

Introducing a group morale for the control of mistletoe.

Mistletoe (Box 2) used to do considerable damage in Dungmin orchards. Most orchards, notably the ones owned by people who did not live in the village, were heavily infested with the parasitic plant resulting in reduced vigour an poor fruit development. A village-wide mistletoe control activity would increase tree vigour and reduce the infestation pressure on orchards kept relatively clean. This awareness has a social component; if most households clean their orchards, a laggard household is more likely to feel embarrassed to leave its orchard neglected. This notion led to the involvement of extension staff in organising the control of mistletoe (Box 10). The programme was a real tug-of-war and at moments, staff was about to give up and leave the programme for what it was. Once it was successful, the Dungmin programme served as an example to other communities in the district.

Box 10. Introducing control of mistletoe on communal basis.

In 1991, orchards in Dungmin village made a neglected impression. Most bearing trees were heavily infested with mistletoe, and roughly estimated, over the entire village this reduced the fruit bearing capacity by 50%. The then new agriculture extension staff, Mr. B.B. Acharya, was a fresh graduate who originated from a citrus producing area and was well acquainted with citrus cultivation. In his place of origin citrus growers carefully pruned out mistletoe from their trees and even forest surrounding orchards was kept free of the parasitic plant. Mistletoe was good fodder, and certain species' leaves made a tasty tea. Mr. Acharya did not entertain a good credibility in the village. He was young, and his predecessor's poor performance had left farmers skeptic on possible assistance by the agriculture extension service.

In early 1992 during village training sessions covered mistletoe control. Farmers were explained the pests' life cycle (the fact that the pest spreads from infested trees all over the village) and control methods (pruning out of infested branches, see Box 2). A few farmers indeed started to prune out mistletoe. However, in autumn, treated trees did not yield better and farmers lost their enthusiasm to carry out the job. The extension staff stressed during every training session the importance of pruning out the parasite and the long-term effect of the activity. More and more people indeed treated infested trees, although some households explicitly refused to carry out control measures, and a struggle between the community and the extension staff started. Plant protection staff visiting the place and supported the extension staff during village level training sessions. At some point, a list of mistletoe-control defaulters was prepared. Defaulters were mainly old people with little labour at home; people owning orchards but not living in the village; and people who had ownership problems over orchards. Interviews with such people revealed that they regarded the cleaning of their trees as their own business, on which neither staff, nor the community had any say.

The turning point in the programme came in autumn 1993 when the few trees that were cleaned in the very beginning yielded fruit in abundance. This made the case of the extension staff much stronger. Early mistletoe adopters now felt that their trees could be re-infested from non-cleaned orchards. The staff called a meeting where the issue of mistletoe control defaulter was discussed with the community. The community was given a choice: should staff help defaulters taking up their task by reporting the names of defaulters to the district administration for a reprimand, or should the community organise mistletoe control by itself? The community left no doubt. Not a single farmer was in favour of the district exercising administrative pressure on the community. The village headman took up citrus cultivation in various local administrative fora, such as the block development committee, and fines were established for defaulters; the collected money was then used to pay a labourer to carry out the pruning work. Even at that stage the extension staff was still involved in the programme. Once, two neighbours that had property dispute over one orchard came to see the extension staff. The one neighbour had controlled mistletoe in half of the orchard and the other refused to do his part of the job. The extension staff had to settle the dispute between the two in favour of proper mistletoe control.

Early 1994, almost all citrus trees in Dungmin and surrounding villages were clean from mistletoe. Trees recovered in a year, and in 1995 the orchards were the most vigorous in the area. In the course of the activity, the extension staff had gained some credibility to further address citrus management issues. Control of fruit fly added to the already high yields, trees had to be supported not to collapse under the load of developing fruit. For a few years in a row, the community entertained the best mandarin yields in history, in 1995 and 1996 trees yielded more than double the usual average harvest.

Although mistletoe control had a communal component, pruning the plant out of individual trees still had positive effects on tree vigour and yields. This made that the activity was still governed by a regular diffusion-of-innovation process with a change agent, opinion makers, early and late adopters etc. (Rogers 1995). Only during the last stage, adoption was speeded up in order to have the control efforts of the majority of farmers not being undone by re-infestation from a few non-cleaned orchards. Thus, laggard households were to clean their orchards before their "natural adoption time" came. The change agent and community went through a difficult process to have those "laggard" households clean their orchards. This showed that introducing IPM over the entire community was no sinecure, even for a relatively simple and transparent measure like mistletoe control. Extension staff had to use his full commitment, and at times he was regarded a meddler in other people's business. It was the support of a few early adopter farmers and back up by the plant protection staff that enabled him to complete his job. One can imagine that the introduction of citrus fly control is even more difficult to achieve. Control measures were still under development and were to be tried out by the community as a whole rather than by a few innovative farmers as a start.

Community-implemented efforts to control the chinese citrus fly.
In the parallel Am Shing programme, the farmers' community took care of the organisation for citrus fly control. The previous section shows how even in Am Shing fly monitoring routines were essential for building intuition on pest management options. Unlike in Am Shing, in Dungmin the community was initially not in a position to carry out proposed fly control measures. Therefore the extension staff had to involve in internal organisation of the village, so that the citrus IPM programme was not only a technical experiment, but also a social experiment. In the following section, first I will describe the programme from a technological perspective, in which the development of a feasible control technology is the central theme. Next I will cover developments in the social domain as related to fly control activities, in which the community's organisation and the relations between relevant stakeholders are key issues.

The development of a fly baiting method in a poorly organised village.
In technical terms, Dungmin is an ideal place for experimenting with citrus fly control. The village has about 1,200 bearing trees, it is isolated and situated on a north-facing slope which makes that fruit drop is heavy (50-75%) and exclusively caused by the chinese citrus fly rather than a mix of two pests. This means that in October-November orchard soils are orange with dropped fruit and that farmers look at their trees with fear: how much fruit will be left for sale this year? On-station citrus fly research had been carried out from 1991 onwards and continued even if research in villages was initiated. However, unlike during the training-and-visit period, the co-ordination of in-village and on-station research was in the hands of the same team. On-station research "fed" the village research programmes with technological innovations that could immediately be tried out in practice, and technological needs found in villages were worked on in experimental orchards close to the research station. Research efforts were now geared towards a practicable control method of the fly rather than the confirmation of notions from general IPM theory (such as the inventory of natural enemies and non-target insect groups). Theoretical options were the luring of flies through proteinaceous baiting, and the cleaning of orchards from dropped fruit as to reduce the following year's fly population. In August 1993, just before the village research activities started, a proteinaceous bait had been identified, that was provided in September 1993 to the Dungmin community to carry out three bait-splash treatments in all orchards in the village. This was the first of a series of activities to control the fly, as illustrated in Box 11.

Box 11. The interaction between developments in pest control technology and pest control organisation.
In the late 1980's the National Plant Protection Service identified the chinese citrus fly or ***Bactrocera minax*** *as a major cause for fruit drop in mandarin orchards (Bigger et al. 1988). There was little information available on this specific fly, although it was a member of a group of fruit attacking flies, the family of* ***Tephritidae*** *or true fruit flies (Box 4). In literature it was found that this group of flies was attracted to protein lures, and August 1993 a protein type of substance from India appeared to attract this particular fly. When the attraction of the fly was demonstrated in Dungmin village farmers immediately requested for a programme to control the fly. In most fruit flies, eggs hatch and damage*

fruits within weeks after oviposition. Thus the timing of the fly luring strategy first proposed was linked to the ***fruit drop period****. Extension staff organised fly baiting activities (Box 5). Such activity consisted of mixing lure and insecticide in water; and splashing this solution in every bearing tree all over the village. Farmers carried out three splash treatments in September; yet, fruit drop was heavy in 1993, and obviously the control method was ineffective.*
So, in 1994 it was decided to link the baiting activity to ***the oviposition*** *period that was yet to be identified. The Dungmin extension staff kept bait-monitoring traps in the village from late May onwards, and when he caught flies, he checked them for eggs. Late June the first gravid flies were spotted. However, in that year the Dungmin community did not manage to carry out a complete fly baiting schedule, and fly control failed. In a few experimental orchards near the plant protection station a parallel experiment was carried out, and fruit drop reduced from 54% in an untreated orchard, to 17% in a treated orchard (cf. Section 6.1). In the following year it was tried to replicate the on-station success in Dungmin village by setting up a fly control organising structure that managed to carry out eleven bait splash treatments to cover the entire oviposition period. Fruit drop reduced and some 80% of fruits remained in the tree compared to only 65-25% in other years (i.e., fruit drop reduced from maximum 75% to about 20%). Thus, citrus fly baiting (combined with the control of mistletoe (Box 10)) resulted in a production volume double the level of earlier pinnacle harvests (as measured by the volume and duration of transport in that year).*

In 1996 I had taken up the plan to prepare a scientific publication on citrus fly control for which quantitative data to show the attraction pattern of the fly over time were needed. By that time dry lure traps had been developed that worked throughout the adult flying season (cf. Section 6.1). This research revealed that fly control as achieved in 1994 and 1995 could not exclusively be attributed to the attraction properties of the bait. Attraction to bait during the oviposition period (in June-August) appeared to be weak, and was many times stronger during the fly emergence period, in April-May. Control so far achieved was probably not by attraction, but by random touching of flies flying about in the upper canopy of treated trees.

Moreover, in 1996 it appeared again that the Dungmin community had difficulties organising baiting activities. The implementation of twelve bait splashes in a season appeared to be problematic (baiting had again been carried out incompletely) and even extensively trained people never mixed different components in the proposed ratios. One line of research was to find out if pre-mixed quantities of chemicals (bait, insecticide and sticker to be solved in one bucket of water) worked equally well as loose components. They did. Once houses had to pay for the baiting materials, another problem emerged. People felt uncomfortable to contribute money for baiting materials that were community-owned and that they never got in hand. Research geared towards developing individual-owned baiting materials, preferably applied in a single treatment. As the fly emergence season attraction to protein soaked wicks in dry lure traps was very good, in the following season we tried to find out whether rain-protected protein soaked wick in trees were effective in controlling the fly. Such wicks could be produced at 4 Nu (about 0.10 US$) for one tree. This was a few times the price of community-owned splashes but still valued only a small fraction of potential profits. Yet, farmers were much more willing to pay for such things than to pay for materials to be applied on communal basis. Such fly luring devices were placed all over Dungmin in 1997, but that year the fly emergence period was rainy and cold so that we could not collect evidence on the working of the fly control method. Still another option to control the fly remains unexplored. During later processing of fruit colonisation data (cf. Section 5) and fruit-mimic trap catch data it appeared that early developing citrus species (such as lime) attract flies about three weeks earlier than mandarin, and could serve as a catch crop for the citrus fly. The combination of early baiting and applying a catch crop should be further tested for the combined potential to control the fly in ever easier (so, more feasible) ways.

Box 11 shows how in village research, *social* aspects of the control programme to some extent directed the *technical* subject for research. In theory this would mean that variable social settings would lead to a differentiated technical research. An example of this notion is the development of methods to control the fly. The innovative Am Shing community took the responsibility for a rather clumsy control method, i.e., to carry out twelve bait splashing during the fly's oviposition period, including mixing of various chemical components into the proper solution. In Dungmin this method never worked unless extension staff kept a role in organising it. The village was organisationally divided, people had a hard time properly mixing the bait solution (insecticide once finished in three splashes rather than in the 12 splashes provided for) and people quarrelled over the responsibility to carry out control measures. Thus it was the unfavourable Dungmin social setting that highlighted the need for simpler bait application methods (such as illustrated in Box 11). This gave rise to technological innovations we never would have thought of based on the Am Shing programme alone. This illustrates that in different communities, different priorities for research will emerge. However, should an easy control method have been developed up to conclusion, surely the Am Shing community would prefer it over the more complicated method used so far.

The use of monitoring tools as such does not lead to the building of intuition in a farmers' community.
The character of the Dungmin community and its unstable support for the citrus IPM programme led to a particular use of fly monitoring tools. A programme that demands strong commitment from a community is barely welcome if it does not soon lead to tangible results, be it in the shape of better yields, or as "mirrors and buds". Whenever on-station research had developed a monitoring tool, it was taken to farmers in villages and tested for its practical value. In Am Shing these devices were immediately used to adjust the community's investments in fly control to a minimum. The use in the Dungmin community differed vastly. The continuous flow of new tricks appealed to a few innovative farmers and, as long as improved yields had not been achieved, justified the activities of the research team in the village. One must realise that for over two years neither the team, nor the community, knew for sure whether the programme would indeed result in reduced fruit drop. Fly monitoring tools helped not only to show interested individuals the dynamics of fly behaviour, but also to motivate programme staff. For example, mid July 1995 the community felt it had done a great job carrying out two bait splashes (rather than the five required by that time). When just developed traps caught quite a few flies, staff re-gained the courage to instruct the citrus committee to carry out splashes as per the proposal. Staff badly needed such "support from facts" as to stimulate the community not to stop baiting after and incomplete treatment. Monitoring tools in the Dungmin programme enabled staff rather than the farmers' community to know what direction the programme went and what problems to anticipate. Only a few individual farmers put in enough effort to be able to build a complete picture of the fly biology and the relation between "catches" and eventual losses.

One of the main reasons for the difficulties in having farmers understand the dynamics of fly control is the different meaning of "economic threshold" or "action threshold" for a pest such as fruit drop by the chinese citrus fly. Fruit drop occurs in October-November, but is in fact caused by oviposition activity two to four months earlier, in June-August. Even if oviposition is noticed and farmers would employ an "action threshold" based on such observations, control is to be carried out during oviposition in April-May. Thus, in the chinese citrus fly IPM concepts such as economic and action thresholds do not apply, and other mechanisms are necessary for farmers to build an intuition on whether and when to apply control measures.

Thus, for most people in the community the success of the programme was best expressed in terms of harvest volumes. Most farmers seemed hardly interested in actual losses, nor in a better understanding of the crop ecosystem or the community's organisation capability. Unlike in Am Shing, the community did not intend to pull the programme beyond its original objective. People were just interested in better yields, and staff did considerable efforts to collect relevant data. Table 3 gives the development of harvest volumes and fruit drop during the programme period (1993-1995) and the years to follow (1996-1997). Fruit drop and harvest were broadly a function of citrus fly control and fruit setting. In general, the natural variation in fruit setting is around 300%; the programme started in a year with low fruit setting which increased possibly by 50% through mistletoe control. Tree vigour hardly influences fruit drop percentages varying naturally from 35 to 75%; fruit drop reduced after controlling the citrus fly in 1994 and 1995. The 1994 fruit drop percentage was just below the lower end of the natural fluctuation level, although farmers did not attribute the relatively low fruit drop to their baiting efforts. Mistletoe and fruit drop control resulted in ever-high harvests in 1995 and 1996 (Figure 5); the regular fruit transporting season was extended by weeks and in the late marketing season Dungmin was the only supplier of mandarins on the market. After the responsibility of the programme was handed over to the Dungmin community, early 1996, farmers baited less and fruit drop again increased.

Table 3. Development of fruit drop percentages and harvest volumes during the programme period. For further explanation, see text.

	1993	1994	1995	1996	1997
mistletoe control	-	+	++	++	++
relative fruit setting (avg = 1)	0.4	0.8	1.4	1.4	1.0?
citrus fly control (# bait treatments out of max. 12)	0 (3 too late)	3-5	8-11	1-4	0
estimated fruit drop[1]	72%	26-31%	5-15%	35-40%	33-75%
estimated total harvest (tonnes)[2]	13	35	80	60	25?

[1] In 1993 and 1994 fruit drop percentages were recorded by counting dropped fruit; in 1995-1997 they were derived from fruit samples' infestation. 1994-1997 figures are based on data from three sub-villages.
[2] Derived from the duration of transport (in weeks) and the estimated number of horses and people carrying mandarins to the Assam market.

Figure 5. The 1995 harvest was the most voluminous one in the history of Dungmin village. Farmers had to support their trees to prevent branches from breaking.

Citrus fly control is not compatible with the worldview of most farmers.
When late 1993 we initiated the Dungmin village research programme, we hardly anticipated that social dynamics would be so important in in-village experimentation activities. In hindsight, we were quite naïve by thinking that the community would carry out the measures we proposed, thus enabling us to evaluate the technology we had designed. Soon it appeared that in-village experimentation has a dynamics that differs vastly from the earlier training-and-visit and even experiential learning routines. During the earlier extension programme, the majority of farmers was informed through village level training, while experimentation was mostly carried out in co-operation with relatively innovative farmers. In contrast, in the village research programme, the obligatorily communal character of citrus fly control made active participation of all farmer groups necessary. Thus, also more conservative farmers had to participate in the programme. So the question arose, how do you involve late adopter farmers in experiments for which their co-operation is mandatory? One option is to have the farmers' community figure this out by itself, i.e., making an alliance with innovative farmers, who then overrule the doubts by late adopter farmers. This was (in hindsight) how the programme in Am Shing village developed (cf. Section 3.3). Another option is the use of administrative force, as it is common with the construction of hardware such as drinking water or irrigation schemes. However, construction of such schemes is not an experimental programme like the plan to experiment with citrus IPM, so that using administrative force (if it would work at all) was a risky option. Should the experiment not result in better yields, the community and district administration would have every reason not to allow further experimenting in their area. Thus, a more participatory (and time-consuming) approach was adopted. In one way or another, the entire community had to support the carrying out of an experiment. For this staff had to get acquainted to the community and started visiting religious ceremonies in individual houses during which informal contacts were laid and maintained. When station-based plant protection staff visited the village (every two moths or so), quite a few villagers used to come to the extension staff's residence to prepare and share food and discuss issues relevant to the programme. This allowed staff to keep track of sentiments regarding the programme in the village. When at times individual villagers developed adverse sentiments on the programme, staff visited them to discussed problems in a confidential atmosphere (i.e., over a glass of local beer). Thus, staff initiated experimental activities and simultaneously tried to create

an atmosphere conducive to carrying out experiments.

A closer look at the interests of the involved stakeholder groups may be clarifying. The plant protection staff wanted to carry out an experiment and needed success within one or two years. For this staff had to invoke the interest of extension staff and farmers in one way or the other. Raising the interest of the extension staff was relatively easy: he was, just like the plant protection staff, an outsider to the community, he understood the experimental character of the programme and received intensive supervision and recognition from a person higher in hierarchy. Thus, extension staff took the responsibility of day-to-day programme co-ordination and gathered information on social aspects of the programme. The position of farmers was more problematic. They were to invest time to treat their orchards, although experimental materials were provided for free. To some extent they had to violate a religious value forbidding killing. Their reward would be a possibility to obtain better yields, that could however not be guaranteed as the programme was experimental in character. When the programme failed to achieve instant-miracle results (like often provided by local lamas), a play of influence and networking emerged. A few notions on the field of powers governing the in-village experimenting programme are presented in Box 12.

Box 12. The delicate play of relations, influence and support between stakeholder groups in the citrus fly control experiment.

One of the most influential people in Dungmin village was the local lama, who, through his religious position, could impossibly support a programme in which the killing of citrus flies was an essential component. His family was one of the wealthier families in the village with vast interests in the trade of mandarin. Until the RRA-exercise, for most people fruit drop was a phenomenon apparently steered by supernatural powers, against which the lama and his helpers performed general religious ceremonies that ***"sometimes work, sometimes don't work, but in any case render peace of mind."*** *The catching of a few citrus flies during training sessions and demonstration of their role in invoking fruit drop took this phenomenon out of the realm of religious mystery and placed it, for many farmers, in the domain of comprehensible phenomena. The lama probably did not view this move as a threat to his position (there were enough unexplained phenomena left), although the following fly control activities were against the values he was expected to defend. The programme staff thought it necessary to discuss the inherent sinful component of the IPM programme with the lama and farmers. A meeting was organised in which several leading farmers and the lama were invited. The lama delegated his son who also held an important religious position and who was more in touch with modern developments. During the meeting, staff explained that through fly baiting and hygienic measures, only damaging insects were killed, and that cover sprays would kill many more and also beneficial insects (a general notion from IPM theory!). After some arguing up and down the lama's son grudgingly agreed not to oppose the programme, although he declared that he himself would not actively participate in it either.*

This meant that for that particular year, the religious establishment would not oppose the programme. Yet the bait-treatment was not carried out too well: the community managed to carry out only 3-5 bait treatments against the 12 proposed, which resulted in incomplete fly control. The following year one incident showed that not all community members were convinced the programme was beneficial to the village. After a new citrus committee was installed with some young and enthusiastic members, soon one enterprising chap returned to programme staff to lay down his function. He appeared to be a lay monk, and after his arriving home in his new shape, his parents seriously reprimanded him for taking up such a sinful task. This showed that still some households opposed to the programme for its killing insects, even if this had gone unnoticed to staff. Possibly low-profile opposition played a role in poor programme support. Another incident showed that not all indifference *or opposition could be traced back to religious sentiments alone, but more to a general thinking in mystical relationships between phenomena. In the hot and humid summer of 1995 an unidentified branch-dying disease broke out in Dungmin. Soon rumour spread that the bait treatments caused this disease, and some farmers wanted to suspend baiting activities and ban the entire programme from the village. (Note the similarity with an earlier innovation that failed: a the community had blocked a new irrigation channel after water distribution problems resulted in a few crop failures.) This time the good relations between staff and villagers paid off. Research staff came to discuss the issue, and at the appearance of programme staff in individual houses, opinion makers told they had reconsidered their judgement. Apart from treated trees, also some untreated trees showed the same symptoms, and they concluded that there was no causal relationship between splashing and tree deterioration. Staff was proud to notice that causal thinking was sneaking into the opinion making process in the community. When later that year the village entertained an ever-high harvest, adverse sentiments were stifled in enthusiasm over the programme. Yet once more, most farmers did not regard reduced fruit drop as the measure for programme success, but only its derivative, i.e., the good harvest. Thus, also the enthusiasm of Dungmin farmers was to some extent a dogmatic sentiment.*

The Dungmin experimental programme could be described as an encounter between mystical thinking and thinking in causal relations, an interaction of value systems of different stakeholders complemented with a cat-and-mouse play of attribution of failure and success. Programme staff needed outside support not only to keep their position in the village acceptable, but also to keep a core of causal thinking alive. During the disease outbreak as illustrated in Box 12, also the extension staff seriously doubted whether the disease could have been caused by the bait splash treatment. Similarly, the research staff sometimes needed backup from supervisors, in order not to get lost in social tinkering that governed the village programme. In this, I do not want to pretend that the core input from the programme was free of poorly defendable relationships and values. The believe that flies could be controlled by baiting in itself had never been proved, and later it appeared that the control effect of baiting during oviposition was to be attributed to random touching of flies to insecticide rather than to baiting effects. Similarly, hygienic measures appeared not to be a measure capable of controlling the fly. In such an environment we sometimes wondered with what right we were introducing so-called causal thinking in the community. Let us first notice that the conflict between the so-called traditional system and causal thinking was already on-going, and the programme supported one faction in the community that was however not dominant in Dungmin. The Dungmin community could be understood as governed by a dominant group of mystical thinkers, and a continuous drain of people in for more modern values. An early example of this drain is the emigration of people from Dungmin to Am Shing, early this century, but even now we could see enterprising young people leaving the place for better opportunities elsewhere. Programme staff thought that creating economic opportunities in the village could be a reason for more enterprising farmers to stay in the village. It must be clear that these dynamics forced programme staff to combine technical thinking with an understanding of social processes.

So, the Dungmin programme showed that experimenting with the community as a counterpart was a socially complicated process. A raised awareness of technical aspects of IPM appeared to be only one of many more factors for the community to accept particular innovations or not. Positive and negative sentiments on the programme came up as a result of social dynamics rather than its technical soundness, particularly before the community had seen control activities result in better yields. The community was, in practice, still deliberating whether they wanted to innovate their citrus cultivation or not, and staff had to take up a social role and discuss the pros and cons of innovations. For this, on one hand, staff had to put efforts in becoming an acceptable partner in the opinion making process. On the other hand, in order not to end up in an ordinary power game with established opinion makers, staff had to keep a narrowly defined goal in mind: the programme was to improve citrus yields through IPM. This made that discussions were confined to overseeable social dilemmas with clear practical consequences. In technical terms, not only farmers, but also staff itself had to be fully aware of the validity of the claims made about the beneficial effects orchard treatments could have. The success of on-station fly control in 1994 morally supported staff in the conviction that fly control could be effectuated in the village as well. Still, as long as farmers had not experienced themselves that yields were improved, support from the community was hardly ensured. Some farmers were stable programme supporters, mainly because of their close relations with staff and because of the sentiment that *"something should be done to develop this village"*. Programme staff tried to provide these individuals with reasonable arguments as an alternative to mystical relationships that occasionally undermined public support for the programme.

When in 1994 again fruit drop was substantial (even if fruit drop was quite low and the harvest was above average, see Table 3), a few farmers complained to the district administrator that the programme did not benefit the community. The district administrator informed researchers that the following season was the last chance: should control fail, their work in the district would be discontinued. This resulted in a tense programme in summer 1995, and staff made sure that farmers carried out baiting activities meticulously. This time the work was not in vain. That autumn farmers could see that yields improved; the harvest had never been as good as this particular year, and farmers attributed this improvement to the programme. Looking back, this improvement was in fact a matter of luck rather than a result of the working mechanisms we were targeting. The mistletoe-control activities started to bear fruits, and also citrus fly damage was lower than ever. Later it appeared that control must have been the result of flies randomly touching poison rather than flies being attracted to the bait. Apparently, random touching of flies flying about also reduced fruit infestation to a detectable extent.

This success however did not result in a more dominant position of causal thinking regarding citrus production in the village. Most people however never had the ambition to become experts in their crops. They expected that a "ritual" (= "incomplete" in technical terms) way of carrying out measures would lead to the control of fruit drop. The bait-splashing looked remarkably much like religious rituals, sprinkling about holy water, which occasionally helped as in some years more fruit remained in the trees than in other years. They left the responsibility for the effectiveness of the programme with staff. When we proposed certain control measures, farmers expected it to work completely. Should the measures not work, then staff was responsible and could be labelled "bad priests". The division of tasks between the community and staff had striking similarities with the same division between the community and local priests. In religion, the responsibility for the working of rituals was in the hands of the priests, and ordinary people never understood the actual working mechanisms those rituals represented. Similarly, only few farmers took the effort to really understand the working mechanism of baiting and the majority left the responsibility of both failure and success with programme staff.

Development and disintegration of a fly control organising structure.

Even if in 1994 a poor community organisation resulted in incomplete orchard treatment, fruit drop was probably reduced as a result of baiting activities (Table 3). However, as the community put little effort it did not recognise this partial success and the programme was regarded a failure. The district administrator got the news and when he asked me for an explanation, I found myself complaining about the working attitude of the community. The district administrator gave two comments. First he instructed us to install a citrus committee that was responsible for the proper implementation of the activities. This gave us administrative back up for working on farmers' organisation for citrus fly control. Second, he let us know that, should control fail again, he would withdraw his support for in-village research to take place in his district, as farmers had to invest too much time without them benefiting from the programme.

The organisational development of citrus fly baiting over the years is described in Box 13. Establishing a stable citrus fly control organising committee took considerable effort and was not very successful. Nation wide, farmers' organisation was a contentious issue and the official policy changed by the year, so that expertise could hardly develop in the country. Yet, for economical purposes organisations were reluctantly allowed so that technical people could experiment with village level organisations. Thus, the Dungmin community managed to pull together two baiting committees; one for the upper and one for the lower village, that worked for about two years under the experimental set-up of the programme. In absence of professional backup however, the organisation ran into difficulties when money was to be collected for the purchase of chemicals for communal application.

Box 13. Development of in-village organisation of community-level IPM activities.

For the testing of citrus fly control options, all 80 households in the Dungmin community had to carry out repetitive bait treatments. We were aware of the earlier failing internal organisation in the village. The community once blocked a water channel after two seasons of hassle over water distribution, to return to traditional upland crop cultivation. On the other hand, a religious organisation was blooming and the community managed to organise communal praying ceremonies with quite some spending twice a month. This was done under the co-ordinated efforts by the local lama and his crew, who were permanent residents and thus could sort out emerging difficulties. Unfortunately, it was impossible for the IPM programme to join in with this religious organisation, as pest control entailed killing of insects. For the 1993 experiment, the local extension staff prepared citrus fly bait mixtures to distribute it among farmers for application (see Box 5); in that year technology appeared premature and did not result in better yields.

In 1994 the experiment continued, but now the community was to think about organising baiting by itself. Representatives of the community selected three people who volunteered to carry out the season's baiting activities. These took much more time than anticipated and this set-up appeared not to function as needed. In stead of the recommended twelve treatments, the volunteers carried out baiting only three times. Although in that year fly occurrence was at the lower limit of natural fluctuation, the harvest was still not exceptionally high (Table 3), and farmers did not acknowledge that the yield had improved as a result of fly baiting activities.

As the organisation of activities organised by the village did not result in proper carrying out of the experiment, staff called a meeting in which the most innovative farmers were invited to discuss whether the community wanted to continue with the experiment or not. Mr Ugyen Wangda had a few years of education and had become the new village headman; he and his assistants took the responsibility for the internal organisation for the programme. The village was split into an upper and lower part, in each part a citrus committee (Figure 6) was responsible for keeping chemicals and distributing them among citrus growers in their sub-village. In summer 1995, the committees managed to carry out between 8 and 11 bait splash treatments all over the place. Yet, the extension staff was still involved in the *programme, particularly if conflicts emerged. This year the work resulted in reduced citrus fly infestation and the best harvest ever. It was high time to hand over the entire programme to the community. In 1996, the community still availed of some amount of chemicals, and was expected to collect money for a revolving fund. In the upper village, farmers carried out bait splashes; in the lower village however, the leader had family problems and nobody else took the responsibility to carry out control activities. Nevertheless, again there was a very good harvest, possibly because of a combination of limited bait splashing and a poor recovering of the fly population from the previous year's control. A few attentive farmers noticed that still 20% of all fruit dropped, but their observation went unnoticed in the euphoria of the still lucrative mandarin trade.*

In 1997, animosity between the upper and lower village resulted in the community still whimpering about the organisation of baiting at the fly emergence period, and hardly any control activities were carried out. In contacts with individual farmers, research staff provided them a few bait-loaded cotton wicks that they could experiment with. In autumn, fly infestation levels in different sub-villages varied from 35% to 75%, more or less the level under uncontrolled conditions.

Figure 6. The extension staff hands over responsibilities for citrus fly baiting activities and the control of mistletoe to a representative of the citrus committee. The committee managed to achieve record harvests in 1995 and 1996.

Even if the programme restricted to organisation of the management of citrus pests alone, the aim to have the community independently organise activities appeared to be far-fetched. The Dungmin programme showed that even economic success does not guarantee a technical programme to sustain. The community could impossibly initiate communal activities by itself, and needed outside support to have such activities take off. But even when such activities had been introduced, the community lacked a group of people to sustain the innovation and able to deal with opposition. A few (female) farmers lacking the social status to organise baiting activities were socially isolated in their efforts to keep the programme going. On the other hand, the next section shows that experimentation was on-going, and who knows, by the time I am writing down this story the community may have found ways to simplify baiting procedures and organise citrus fly IPM to return to the production level achieved in 1995-1996. Further, for research purposes the Dungmin programme revealed a wide variety of social bottlenecks governing communal activities. He next section shows both technological and social organisation ways out of the problematic situation, as perceived by a few involved members of the Dungmin community.

The future of citrus IPM in Dungmin village.

In the Am Shing programme, the community itself determined for a great deal what the future of the programme in their village looked like. To some extent, individual farmers in Dungmin continued to work with ideas generated by the programme, although the ambitions of the community were of lower-profile. Mid 1996 the earlier extension staff had been transferred and from then onwards there was little involvement of staff, although research staff still regularly visited the village to measure fly infestation levels and to inform farmers on new technical developments. In August 1997 I visited Dungmin village for the last time. Such visits allowed me to loosely follow developments through interviews with people I had got acquainted to over the last few years. I wish to end the report of the Dungmin programme with a report of the last few interviews I held, in which three people give their account on the latest developments and future of citrus IPM in the village. The interviews are presented in Box 14.

Box 14. The progress of the Dungmin citrus management programme as seen by three community members, two seasons after it was fully handed over to the community.

Wangda, the local lama's son and mandarin trade contractor in the lower village.

"When mandarins start dropping, we get really disappointed. The tree is full of fruit, we expect a good harvest, and then suddenly we see over half of the harvest dropping and become useless. You know, I am a lama and can not organise a programme in which to kill any living creature. Yet, I think there should be a programme to control these flies, but I am really not in a position to organise it. Last year, in the lower village people did not bait citrus fly, and my own orchard was also left untreated. In the upper village Mrs Tshering Choedon organised baiting. Then this year, she had to collect money for chemicals, because her's were finished, but people started complaining, because they knew that in the lower village nobody had to pay for chemicals. They thought that Mrs Thsering Choedon might take the money for "local business". I think it would be better if the agriculture extension staff helps us carrying out this programme. When money handling is involved, people do not trust their village mates, they trust the extension staff better. Within the village it just leads to quarreling and in the end nothing happens."

Tshering Choedon, woman farmer who organised baiting activities in the upper village.

"Last year we had chemicals left from the experiments of previous years. The powder [bait] became hard, yet I cut it into five pieces and solved it in water and distributed it in the upper village. We baited citrus fly four times [which should suffice if timed well, FvS]. Before citrus fly was controlled, from ten poun in the tree, five to seven dropped, and last year out of ten poun only two dropped, so fruit drop reduced, no doubt [1 poun = 80 fruits]. Still, two poun fruit drop per tree is a great loss, and I feel we should control the fly better, although most other people said fruiting was good and they feel quite happy. When our chemicals were finished I had to collect Nu 2 per bearing tree from the people. I have no education, so I counted the number of trees and put two maize grains per tree and then I knew how much money each house had to contribute. Six houses did not want to pay money. I requested the extension staff to assist me collecting the money, but he refused, as he said that he could not involve in the programme anymore. Then those six houses said: "next time we will pay, but by that time the government may again give chemicals for free". If that will not happen they will pay I think. Anyway, eighteen households did agree to pay and I collected around Nu 300 and bought one packet of powder and one bottle of malathion, yet some money is left. In the lower village although, people did not bait, so their chemicals were not finished and they did not have to collect money like we had to.

The insects will fly from the lower village to us and then there is no control. Moreover, some of my village mates complained as they think I took the money myself. "Did you really buy these chemicals or did you take some money yourself?" they said, and they wanted to see the bill. I went to the village headman to complain about the fact that the lower village did not splash. I said: "you are not doing your work properly but now even we have to suffer because we have to contribute for chemicals and there is both no control of the fly." The village headman said this is the mistake of the lower village's citrus committee and he took no further action.

"This year research staff provided us with a few cotton wicks with bait. We produced a few more and placed them in all trees, and after a few heavy showers we again dipped the wicks in a bait solution. I distributed wicks in the upper part of the village, and at some point children saw some flies on the wicks, and they called me to look at it. Then we trust it would work like splashes, and next year we will put these wicks everywhere just like splashes last year."

Ugyen Wangda, the village headman living in the lower village.

"Last year we reduced the number of bait splashes in order to reduce costs of fly control. Now this year, you provided us some bait-soaked cotton wicks to bait the flies, loosely covered with plastic to prevent the bait from washing out. These wicks are much easier to apply than the splashes we used so far. There was heavy rain, and I felt we could not splash the chemicals in the tree. It would be a great loss for the people if it rained after splashing. So I decided not to splash at all and place these wicks with plastic. At one point I saw two flies on these wicks and then I believed it would work. After a few heavy showers we collected all the wicks from the village and dipped them in freshly made solution made from chemicals left in stock. I gave five of these wicks with plastic to the block headman in Lanari, three hours walk from here, to see whether he will be interested in using them next year. We made quite a few bait-loaded wicks ourselves. We bought iron thread from Subankatta and used all kinds of reject cloths from the village itself so that the construction of baited wicks would be rather cheap. We should put more wicks per tree, about five per tree would make a much better impact than the present rate of one per two trees. In that way we can control the fly without all the laborious splashing. Moreover, with splashing, in particular when the machine is used, people really splash overdoses. With these wicks it is not going to happen. Another issue is that people still think that splashes might induce branch dying; this rumour still goes around in the village. With these wicks nobody is afraid of such effects by the treatment.

"Should these wicks not work, then organising bait splashes and payment for chemicals should be done differently than we did so far. We should not collect money from everyone. People think that the money will then be lost in local pockets. We should ask two or three households to contribute enough money for one treatment. The money they collect will be finished in one go by buying chemicals from the extension staff, and the chemical will then be finished through that one treatment. In that way we do not need to keep money. Turn wise households should contribute, and the citrus committee should then co-ordinate the whole exercise. Already I collected money from two households in this way. [The local way of organising communal praying ceremonies works this way: each 10th, 15th and 30th day of the Bhutanese month six households contribute for the ceremony, so that each household contributes twice a year].

"I have noticed that in several places mistletoe is coming back. But, you know, I have told the people so often it should be cut out, now it should be their own responsibility. We had discussions both on fruit fly and mistletoe in the village development meeting. We tell the people that we will impose fines on the defaulters. But in fact, we do not have the right to do that. To impose fines, we need permission from the Dzong, and that is a lengthy process and too difficult for us. So we just threaten with fines,

hoping that the people will fear and control the pest. Mistletoe has come back to some extent, but is still below 1% of the earlier infestation. Previously the entire village was full of mistletoe, now it is not there at a damaging level, and people will prune it out after the harvest.

The interviews reveal that individual people started experimenting with devices as provided by the research station. Just like in Am Shing, theoretical options are immediately put to practice, even before their effectiveness is proven. Just a technically plausible story and observations of single flies being trapped makes farmers adopt a technology if there is just a slim chance for it to solve problems in the village. Am Shing farmers grabbed the mimic fruit trap to reduce the number of treatments they had to apply. Next year Dungmin farmers abandoned lucrative but cumbersome bait splashings for easier-applicable bait-loaded cotton wicks to avoid problems in organising communal activities, even if the wick's effectiveness was not yet established.

The difference between the two villages is that in Am Shing, the knowledge of experimenting farmers was immediately put to use for the full community, whereas in Dungmin individual experimenters were unlikely to be able to invoke village-wide programmes. The interviews display disappointment or even frustration about the lack of potential in the community to have itself organised. The lama's son wished that the community were strong enough to pull itself out of the deadlock of internal quarrels to efficiently organise baiting for better yields. The active women farmer feels isolated in her efforts to have the community carry out fly control activities. The village headman expressed ideas of how to organise fly baiting without the need for internal money transactions that he had never expressed before. During programme implementation, this "tacit knowledge" had never been recognised, and had the possibility to be a viable organisation model for repeated communal activities. Nonaka and Takeuchi (1995) argue that exploring such "tacit knowledge" is an explicit objective of the knowledge management within Japanese company culture. Interestingly, even if staff had the ideology of "putting farmers first", it did not recognise this knowledge and thus left it unexplored.

From the researcher's point of view, the programme revealed complex mechanisms governing the organisation of simple tasks such as fly baiting. In Am Shing, the way the community acted may have speeded up research, although possibly research would have come up with similar technology, even without its involvement in the Am Shing programme. The problems in Dungmin on the other hand pushed technical research towards new grounds: the inability of the community to carry out communal treatments led to the development of bait-loaded cotton wicks. Dungmin showed many possible constraints in making citrus fly IPM effective at village level, as a result of all the difficulties during the experimental programme. The programme clearly showed where the traditional training-and-visit extension routine fails to introduce communal baiting activities, and shows that extension not only has an informative, but also a community guiding or facilitation task if one wants the community to apply technology such as citrus IPM.

Retrospective remarks.

For the Dungmin community, a programme to develop and apply citrus IPM was possibly too far-fetched. The community had difficulties to appreciate the experimental character of the programme and take responsibilities in it. The obligatory village-wide application of fly baiting was a difficult barrier to take, and both laggard and religiously inspired people had their reasons not to participate in the programme. Moreover, the community was too big to keep all its members involved and it had to organisationally split in two, which resulted in more complications. In theoretical terms, this resulted in the village failing to develop a "social cognition" to carry out fly baiting activities. The fact that the programme activities depended on individuals and the fact that their values were not shared by a sizeable portion of the people made that the organisation of baiting activities was not robust and flexible. When the village leader of the lower village could not carry out baiting because of family problems, nobody took the initiative to have baiting carried out. Staff expected that a shattering success such as the 1995 record harvest would induce a firm interest in citrus IPM, thus invoking an organising process by the community itself (i.e., the start of "social cognition" building). This notion also failed in absence of a group of people able capitalise on the success and strong enough to resist opposition by doubting households. A simpler method to apply bait, i.e., the use of bait-loaded cotton wicks by individual households (but still to be applied village-wide) would possibly meet less resistance and make bait application and sharing of responsibilities simpler and thus feasible. Although this technology is not yet fully tested, it bears the potential to have even communities like Dungmin apply citrus IPM. In short, in the present state of the Dungmin community and the type of support that the Ministry of Agriculture is able to provide, citrus fly IPM (just like any other programmes for which the community as a whole is responsible) seems not feasible in villages such as Dungmin. The lack of capability of the community to act as a unity made that the technically proper implementation of the programme was difficult, and this must have been the main reason why staff tagged the village "conservative" in comparison to Am Shing village (Section 3.3).

On the other hand, it must be stressed that the Dungmin programme was experimental in its set-up. Farmers succeeded to control a key pest in their village, which was an important success, well acknowledged by both regional and national level policy makers. Unfortunately, few people realised that this technical success was based on an understanding of social dynamics within the community and support of a citrus management structure. Both extension and research staff gained a wide experience on the social dynamics governing common resource management (as a reduced citrus fly population can be regarded a common resource). Such knowledge can then be used when introducing citrus fly control in neighbouring villages. I feel that, should we have availed of more explicit expertise on working with co-operative programmes, we would probably have succeeded in introducing a more sustainable fly baiting structure in Dungmin. Many problems, such as the difficulties in handling money by the groups, could have been addressed earlier and thus their problematic consequences could have been avoided. Unfortunately, the learning process social dynamics governing such programme were poorly recognised by policy makers, let alone that the learning process of how to develop technology feasible in villages was appreciated. Even if staff presented the multi-sided character of the village research programmes in a variety of fora, only isolated results were seen as the actual success. The next chapter will show what happens if policy makers (including donors) only appreciate one aspect of such integrated programmes, and regard either social or technical aspects of such programmes as marginal, or separate aspects.

One final remark is needed. Although problems in Dungmin are not very exceptional in eastern Bhutan, it must be noted that, as a spin-off of the Dungmin programme, there are quite a few villages in which citrus fly IPM has successfully been introduced. Five smaller villages near the main village participated in experiments and succeeded in independently organising citrus fly baiting. These cases, and quite a few more, are described in Chapter 4. But first I will return to the starting point of the complete programme: technological innovation.

3.5. Station-led research creates opportunities for in-village experimentation.

This chapter started with an outline of the technical origin of IPM, and the need to seek links to social aspects of technology application. In the previous sections, the in-village research has been highlighted as if it was mainly driven by the interaction of different stakeholders. This section briefly describes the theatre in which ideas for technological innovation were usually first explored, i.e., in station-managed research in experimental orchards.

Changing learning situation for research staff.
In the early sections of Chapter 2 it is argued that in the existing Training and Visit routine, the role of research was to produce innovations, which the extension service then communicated to farmers. In line with this set-up, the research section initiated research on citrus fly control in summer 1991 in various orchards in eastern Bhutan. After two years this resulted in ideas on the cause of fruit drop and theoretical control options (Hollands 1994). Some of the ideas were communicated to farmers during the then on-going extension programme (cf. Chapter 2) but they did not make practical control strategies. However, in terms of findings the on-going research had been rewarding. Every year new fundamental findings were done (such as the fly's univoltinity, its exclusive oviposition on citrus, it attraction to a particular bait) that made good presentations at research workshops and during extension activities, which in itself used to justify the researcher's job.

In the pilot-village set-up of research, this situation changed. Although research was still defined in technical outcomes (rather than social process), the researcher now had to negotiate with the farmer's community for their co-operation, thus providing some farmers a communication link with the research programme. For the citrus work on-station research continued (although in all other programmes station-led research was completely abandoned). This station-led research did not always have a straight application in villages, although the team was now fully aware of the technological needs of village programmes and could thus develop theoretical notions into tools for the village programmes. To put it more bluntly, the research team's exposure to farmers and administrators forced it to not only think in scientific processes, but also link these to practical circumstances. Thus, the research group placed itself into a field of influence in which technology is eventually appreciated for its applicability, while it kept a bit of academic freedom, in which it could fiddle around with notions from literature and field observations. Without such a freedom of experimenting, one might end up experimenting with poorly substantiated control strategies rather than carefully considering technical control options before doing so.

The relation between in-village and on-station developments.
The fact that one researcher co-ordinated both the on-station and in-village programme made that there was no informational gap between the two. Moreover, in the exploratory research such as the initial research on the citrus fly, opportunities for progress depends on observations done by chance. Because experimentation now took place in three places (on-station and in two villages) and by different actors, more "chancy" observations were done and definitely, technical progress went much faster than during the time when research was done on-station alone. The fact that the fly had only one generation a year made that research was to be carefully planned, as the next experiment could only be done one year later. Therefore, it was always good to carry out experiments in two or three places at a time, so that possible failure in one place was backed

up by valid observations in another place.

The different stakeholder groups doing research resulted in emergent properties that further justify a combined on-station and in-village programme. For example, in the search for reliable traps, it was found that flies were attracted to containers with holes loaded with high concentrations of protein (dry lure trap), and to green ball shapes (fruit-mimic trap). Within one or two weeks those traps were taken to the research villages, and in Section 3.3 it is narrated how farmers used newly developed traps to monitor the local fly population. Farmers immediately used these traps to monitor the presence of flies and reduce the number of bait applications. The researcher felt that this use would possibly make that year's control efforts ineffective; yet, farmers were apparently eager to use monitoring tools as a source of information for decisions. The researcher decided to figure out if and how the devices could be used for monitoring the fly population. Students attached to the research station carried out season-long trapping observations and they found that flies were best attracted to protein during the emergence period rather than just before oviposition (Section 6.1). This was a novelty in fruit fly literature in which multivoltine flies are better studied than single-generation fruit flies. The fly's early attraction to baits allows for pre-monsoon control of the fly to avoid the heavy shower season of June-August, when bait is easily washed away and flies are active only during the sparse sunny spells. Similarly, the season-long placement of fruit-mimic traps in various citrus tree species resulted in the identification of a potential trap crop (Section 5), another notion that was a result of the eagerness of farmers to use such traps as monitoring tools.

Yet, information stemming from relatively fundamental research may lead to new applications in villages. In Bhutan, technical researchers are often blamed for their unaccountability towards the impact of their work on society. Many a fundamental researcher thinks that the results of fundamental research have their value for society without considering the way in which the results are to be applied. I do not agree here and feel that "fundamental"-type of research can have practical value, if properly linked to field-level programmes. I wish to illustrate this notion with the following example. Late 1994, we had developed a lot of knowledge on the chinese citrus fly that we thought worth publishing. Basic biology (the fly's univoltinity, basic ideas on its behaviour and migration) had been revealed and a cheap control method had proven to work. When reviewing scientific articles in the same field, we found out that our knowledge lacked quantitative substantiation and that our data as such were not publishable. Thus, we started to collect some quantitative data, basically to construct the fly's life table (i.e., the reproduction and mortality factors in various stages in the life cycle). For this, among many more parameters, we needed to know the number of maggots per dropped fruit. Students cut open thousands of dropped fruit and counted maggots, until someone found that each fruit had a hard spot in the skin, which appeared to be the spot through which female flies had inserted their ovipositor. Once we had identified these spots, we could check fruits for infestation before other symptoms became apparent. This notion led to a whole series of innovations, such as the pre-drop establishment of infestation levels that enabled us to evaluate effectiveness of in-village control activities (Box 7). Flies appeared to prefer fruits in the upper tree and dense canopy trees (Chapter 5), a notion that resulted in the recommendation to place fly bait in the upper canopy of densely foliated trees. Thus, close links of on-station and in-village research led to technological innovations that are difficult to achieve if research takes place isolated from its final application, while at the same time it should be recognised that on-station research had an essential role in the dynamics governing technology development.

Yet, there is another reason why on-station research should not be neglected. Sections 3.3 and 3.4 show that in-village research is governed not only by technical, but also by social dynamics. When in 1994 extensive control efforts in the two villages did not result in a convincing reduction of fruit drop, we did not know what to attribute the "failure" to. Farmers could have poorly carried out the control measures, or the technical method as such did not work. Luckily, we had the backing of a successful station-led experiment, which showed a convincing reduction of fruit drop after bait treatment (Section 6.1). In other cases it was difficult to collect 0-treatment data from villages as we were obliged to explain our sample taking to the orchard owner. Quite a few farmers did whatever they could (including approaching the district administrator for their orchard to be taken up in the experiments) to be included in the full treatment schedule. In on-station research such incidences occurred less. Thus, on-station research was able to provide us confidence that we were on the right track, and that further investment in village-implemented experiments was justified. In this way, on-station research provided the programme a "save heaven" from in-village dynamics and a relatively quiet place to develop tools and notions for village-implemented experiments. The metaphor of a "safe heaven" was valid in another aspect. Whenever villages were inaccessible (due to roadblocks, high official's visits, unrest, etc.), station-led work could continue in the experimental orchards nearby the station and did not come to an immediate stand still.

Station-led orchards made nice publicity.

The regional plant protection service was administratively somewhat independent of other research institutions, and needed to pose itself towards (national and international) policy makers. The main activities took place in research villages. Dungmin village was about two days travel from the office and difficult to visit by interested visitors, and most official guests were not in a position to visit the village research programme. Moreover, if they did, they usually had an isolated experience that did not make much impact in the policy making process. Thus, experimental orchards near the station proved a good place to inform visitors on the programme. Groups of farmers, visiting government officials and consultants could be shown the technology under development. The damage in the untreated orchard could, in the season, nicely be compared with the cleanliness of the treated orchard, while the impact of the village programme could then be shown through video film productions. In this way, the station could inform many people and ensure political support that was badly needed to keep the programme going.

Retrospective remarks.

This Section substantiates that on-station research can still be an essential component of a village-based research programme. For such research to bear significance, findings and needs in one place should determine the agenda in the other place and vice versa. Similar experiences have been reported by van Weperen et al. (1998) in the transition to Integrated Farming in the Netherlands, in which farmers needed the back-up of on-station experiments to gamble for a reduction in the fertiliser inputs on their land. An on-station component may be less necessary in research on transparent pests in which farmers can in one go oversee the consequences of control actions. On-station research may be impossible if research components can not be transferred to the station premises (such as wild boar studies, or studies on village-managed soil fertility). Thus, the initiation of a research station managed component in such programmes is highly dependent on the characteristics of the problem under research.

When working out the mass of technical data collected over the years, I found that almost all data sets collected from the village programmes were either incomplete, inconsistent with each other or lacked control treatments, etc., even if we had done great efforts to collect presentable data. This, while much more time had been dedicated to having the village programmes work and monitoring their results than to on-station research. Villages were large experimental units, the research team could handle but a few, and citrus fly infestations appeared to vary widely within and among villages so that it appeared difficult to establish the relation between situation, treatment and infestation levels. That is why nearly all presentable data were collected at the station's premises. Thus, while the village-led research may have led to a valuable process and has greatly determined on-station research, the technological proceeding is mainly based on students' observations that were carried out on-station. As proper documentation is the corner stone of long-term progress, I think that on-station research is an essential component of all village-based research.

Still one should realise that there are limitations to research in remote agricultural centres. For example, the fly behaviour in trees ("lek"-behaviour) suggests that males employ a pheromone attracting female flies, and the research section was not in a position to identify such a substance, even if it would be highly relevant to the programme. Such type of research should be carried out in universities or fundamental research centra rather than a station such as the regional plant protection service. Yet, a basic laboratory filled with mosquito net fly cages, beer bottles as emergence-monitoring traps and painted ping-pong balls as fruit-mimic traps can help a lot to provide village level programmes with useful tools, as is substantiated in this Section.

It must be noted that the parallel implementing of in-village research and station-led research is far from self-evident. In the PTD-tradition, many a socially moved researcher has left the station premises to never return anymore. Technological development is then made a subordinate aspect of larger movements such as farmers' organisation and empowerment (Veldhuizen et al. 1997), at the cost of some aspects of technical innovation. On the other side, in the linear model tradition, accounts of station-led research that have little or no meaning in village circumstances are as numerous as there are mandarin trees in eastern Bhutan. Self-referential technical research is widely accepted as a way to effectuate progress, without researchers being accountable for the way their technology is to be used by farmers. For fundamental research the absence of a direct application is defendable, for more applied research (such as all agricultural research in Bhutan) the absence of a village-check means doing investments that never pay back.

4. Learning phase III. Scaling-up successful IPM technology.

We shall not cease from exploration
And at the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

T.S. Eliot, Four Quartets.

4.1. Scaling-up of socio-technological knowledge: theory and experimental set-up.

So far, IPM in research villages has been considered as the development of a pattern for practicable application of IPM. This chapter briefly discusses theory and initial practical efforts to apply IPM outside the initial experimental villages. What stakeholders are responsible for making developed socio-technological knowledge available to farmers? And how do these stakeholders communicate and co-operate?

Village experimenting yields "socio-technological" knowledge as part of a future extension strategy.

In hindsight, the programmes that were described in Chapter 3 resulted in the development of technology that is only applicable in a certain social configuration. For the sake of the argument I label such a construct as "socio-technological" knowledge. The case studies provide examples of such socio-technological knowledge. The chinese citrus fly can be controlled through monitoring the emergence of the fly, upon which bait must be splashed in time and repeatedly, during dry spells in-between the monsoon showers; this will only work out if the community is well organised. Thus, for technology to work, the community must have the capacity to handle communal resources and to carry out village-wide bait application. Without outside assistance most citrus growing communities will not be able to do so. A technological alternative is the procurement of bait-loaded cotton wicks, to be placed just before fly emergence in each tree in a village, i.e., by individual households. Such a fly control alternative is more expensive but entails less organisational efforts as individual farmers rather than the community handle baiting materials. Moreover, in Dungmin, farmers attributed all kinds of unusual phenomena to liquid bait application and trusted cotton wicks better because they hardly resembled the magic gestures commonly applied in the village.

Outside Bhutan, Chinese literature reports that the fly was controlled by once picking all fruits in an area, thus breaking the life cycle and ensuring the near eradication of the fly population at the cost of one year's harvest (Yang, et al. 1994). Such actions are only possible in totalitarian regimes with state-owned orchards. A non-IPM alternative would be the application of insecticidal cover sprays that can be done at individual scale. This method is used in Sikkim with a free-market economy and little emphasis on communal level pest management (Subba 1984). In all four cases farmers mould the technology further after it has been introduced to their community. The example shows how both social and technical features are essential aspects of a fly control strategy, and how they interact. A social approach emphasises communally owned baiting materials for group action; a technological approach emphasises individually owned baiting activities (still to be implemented over an entire village); a free market would emphasise the use of inputs such as insecticides for cover spraying (and neglect group aspects of the technology);

the case of destroying a full harvest in China to get rid of the fly is a long-term strategy only possible in a totalitarian environment. A "best mix" would allow for a solution optimal to the community by whom it is to be applied. Thus, the field of knowledge on citrus fly control is an example of "socio-technologial knowledge" in which both the social set-up and the technological possibilities determine an optimal strategy for fly control, or crop management in general.

This is the type of socio-technological knowledge that is the result of having developed pest control strategies in villages. The knowledge differs from "classical" technical knowledge in that it can not be "transferred" from one place to the other without reconsidering it. Local social conditions form an essential component of this type of knowledge, and expertise on social aspects of technology application is needed to successfully apply the technology in a new place. Thus, the diffusion-of-innovations theory (Rogers 1995) that was formulated for easily transferable technology does not apply, as it emphasises technology as a "thing" that is hardly changed by its users (Röling and Groot, in prep.). In the next sections I will highlight different aspects of the development and application of the here proposed socio-technological knowledge.

Concerted innovation in an Agriculture Knowledge Systems perspective.

So far, learning theory and diffusion of innovations theory have been discussed with reference to farmers and IPM. The theories have their bearing on extension methodology: learning theory advocates extension staff to take up a more facilitating of learning role rather than the earlier role of information bringer. Moreover, in view of the minimum scale at which IPM is to be applied, somebody has to initiate concerted action. This stresses that a change of social configuration is needed for the introduction of sheer technological innovations and in most communities extension staff is the only actor in a position to induce such changes. Thus, if we want farmers to apply IPM (as per national policy) rather than chemical pest control or no control at all, village level extension is to take up additional roles such as facilitator of learning and of concerted action. An essential aspect of such an innovation in extension approach is the way extension activities are organised in time. The community has to learn how to utilise technological concepts offered for which a learning route is to be set up with feedback loops and extension staff as change agent.

Such an introduction of experiential learning methods can be regarded as an innovation in the extension services. Now we wonder, how is such an innovation introduced into the extension service? If the innovation is successful at pilot scale, does it follow the diffusion of innovations pattern (Rogers 1995) just like a single successful technology? A brief look at the service, even if it is regarded a social group with group cognition characteristics, shows that the introduction of new ideas will not follow the same cycle of adoption by innovators and opinion makers. In an extension service such mechanism do not take place as freely as in farmers' populations. Such institutions are much more rigidly organised than farmers are. In the population of extension agents, the roles of change agent and opinion maker are institutionalised in the form of team leaders (district officers), (external) consultants (in Bhutan usually researchers) and policy makers. Such actors exercise their influence to the district policy-making process through planning based on policies of the Ministry of Agriculture. Thus one can see that a possible shift towards more participatory extension, however promising it may seem in field situations, needs support from policy makers and their administrative power. Thus, a following question is, how does this group again adopt innovations? To answer this question, I first want to introduce a theoretical notion that is useful at this juncture. By now it is obvious that for the introduction of IPM in villages, multiple stakeholders are needed. Röling 1992, uses the Agriculture Knowledge Systems perspective to regard the role of different stakeholders in the implementation of a shared task. For the ease of the argument, we stick to the example of the development and application of citrus IPM, in particular the control of the chinese citrus fly. Chapter 2 argued that the innovations necessary for application of IPM need certain changes in the way farmers are trained, and Chapter 3 shows that the implementation of IPM has its bearings on the roles of the respective social groups. That chapter showed that for the introduction of group cognition, the classical transfer-of-technology routine does not work. A change in extension practice is needed, and thus, purposeful communication is necessary between different stakeholders in the AKS to effectuate such changes, i.e., between the extension service, researchers and policy makers (and eventually farmers).

In this end, it is interesting to have a brief look at theory about communication between social groups, keeping in mind that such groups tend to develop a social cognition. Social network theory as explained by Granovetter (1974) distinguishes "strong" and "weak" ties between people. Strong ties, such as between members of a stakeholder group, always occur "clumped" and thus information popular in a particular strong-tie cluster keeps being repeated among people in such a cluster. Thus, social cognition develops with its own references and vocabulary, and with an eventual self-referential character. In this discussion I will regard each stakeholder in the AKS as a social group with its own group cognition. As opposed to strong ties, weak ties often form "bridges" between clusters of strong ties and thus, weak ties have a larger potential to make information flow among social groups. There are several fora in which stakeholder groups interact. Training sessions, research priority setting workshops, policy making workshops, etc. are activities in which they interfere and co-ordinate their joint efforts. Thus we can regard the various discussion platforms as occasions in which weak ties between individuals of various social groups do their work. This type of (vertical) communication between partners from different social groups (that can be seen as multiple weak ties) stands in contrast with (horizontal) communication within social groups (in which more strong ties occur). In this field of shaping of realities and opinions, two competing mechanisms take place. Innovations (such as the awareness of the need to include social mechanisms in the extension strategy) enter social groups through weak bridges by contact between individual members of stakeholder groups in the AKS. This flow competes with self-reference and group cognition within the social group each stakeholder group represents.

This is the communication field within and between stakeholder groups in which we want to introduce an innovation, in our case the notion that for citrus IPM both social configuration and technology need to be spread simultaneously. In Chapter 3 it is shown that not only individual farmers may differ in innovativeness, but also stakeholder groups. Would it not be possible to rank stakeholder groups according to their innovativeness? The transfer-of-technology organisational configuration inherently assumes so: research is more innovative than farmers and information should flow "down the slope" to the more laggard groups. Diffusion of innovations theory says that followers seek opinion leaders of higher socio-economic status (Rogers 1995) and the transfer-of-technology paradigm gently conforms to this notion. Let us once briefly look at the different stakeholder groups in the AKS in Bhutan. The hierarchy of relevant groups is, in descending order of social status, policy makers, research, the extension service and farmers. Thus, theory predicts that innovations diffuse from policy makers through research and extension to farmers. This is definitely the way most stakeholders see the task of their respective professional group. This flow however stands in contrast with learning theory and participatory methods that advocate that theory and practice, or policy and implementation, must be shaped through a dialectic process. Thus, feedback from field level experiences to policy making is, on theoretical grounds, not ensured or even unlikely to take place. Policy makers often advocate participatory methods for farmers, but rarely apply similar movements to the relation between their policies and the practices these effectuate (e.g., Wagemans 1987). This leads us to a final question: in the flow of information and suggestions for innovations as described above, who in the AKS is actually responsible that innovations participatory research resulted in are indeed taken up in mainstream thinking? Or, to confine the question to the question asked in this thesis, who ensures that IPM as pest control strategy is actually promoted? The question gains value as IPM in citrus seriously contributes to another important policy objective, i.e., the improvement of the socio-economic status of farmers (Planning Commission 1991) by improving citrus yields (cf. Chapter 3 and 6.1). Theory thus predicts that in a system in which multiple social groups are interdependent, such accountability is difficult to achieve if the "dispersion of innovations" is not put in a framework that allows for spreading of valuable findings at field level, against the hierarchical flow, towards higher levels in hierarchy.

Problem identification.

We can define a set of interdependent elements for successful application of IPM.

For IPM application, one should be able to identify a pest, quantify the damage, monitor its activity and carry out control measures at the appropriate time and scale. This group of elements work at crop level and can be tagged *technological* elements of IPM application.

In order to carry out control at the appropriate time and scale, farmers should have the capability to carry out control measures, at the right time and scale. This group of elements works at farmers community level and can be tagged *organisational* elements of IPM application.

Further, one needs an input supply system and a capability to spread proven technology. The latter makes that knowledge on IPM of a particular pest is necessary including its scale of occurrence, the capability to communicate this knowledge, and have the scale-defined organisation supporting capability. These are *institutional* elements of IPM application.

Finally, if known technology or organisational or institutional elements do not work, new IPM elements should be developed, that can be called *innovative* elements of IPM application.

Now that the citrus fly could be controlled in a clean and cheap way, policy makers (mostly national) were eager to capitalise on the technological potential thus created. The technology was to be introduced to other citrus growing villages through the regular extension system and policy makers ordered the citrus IPM technology to be spread over citrus growing areas. Although the actual implementers regarded the efforts to scale up IPM technology as a regular programme, here I want to consider the attempt as an experiment. This loosens the demand for physical success: the main objective of an experiment is to yield ideas for a later standardised programme, even if it is already carried out in society as a whole. Programmes right in society can be regarded experiments if they are learned from (e.g., Krohn and Weyer 1994 and Lee 1993). For this programme, policy makers adhered to the instruments they had, i.e., an extension service waiting for technological innovations from outside to disseminate them over the relevant farmers' population. Thus, as scaling-up of such socio-technological knowledge had never been carried out before, policy makers carried out an "experiment" with the implicit research question to be formulated as:

- *How can the extension service spread socio-technological knowledge such as developed in village experimental programmes?*

Based on the experiences of the village experimental programmes one can see that a few components are needed for a successful scaling-up exercise. For villages to implement citrus fly control there must be a feasible fly control strategy and the implementing community must avail of the social cognition to be able to apply this technology. But for an associated scaling-up programme more is needed. There must be an agency or group of agencies implementing the scaling-up programme and they must have the capability to disseminate the socio-technological complex. This capability is again a dynamic construct, that it is compounded of the knowledge to introduce the socio-technological complex to villages, an appropriate institutional configuration, input supply, people and capital and an appropriate policy. When considering such needs for a scaling-up programme, one might question:

- *Who is responsible to make sure that the various components needed for scaling-up activities are indeed available to the implementing agency?*

Experimental set-up for scaling-up programmes.

Stakeholders in scaling up of IPM technology.
The promotion of successful technology is not to be done by one actor alone. For such a programme, one can see that at least the extension service and the farmers are important actors. However, other stakeholders must be involved as well. The previous chapter already highlighted the role of the research service in developing IPM, and the role of the district administration in supporting such an experimental programme, while the previous section showed that policy support is essential as well. Here I want to briefly discuss the stakeholders in the diffusion of the idea of IPM over Bhutan. For this moment I use a very coarse categorisation of actors in the AKS, i.e., policy makers, the research service, the extension service and the different communities of farmers.

Policy makers consisted of Thimphu-based officials of the Ministry of Agriculture. The Royal *Government of Bhutan*, in the shape of *the Ministry of Agriculture*, has an official policy to apply IPM rather than conventional (i.e., chemical) pest control methods (Planning commission 1991). Yet, when it comes to action such as during pest outbreaks, the Ministry often resorts to chemical control even if technically not justified. At regular intervals the public complained about fruit drop resulting in heavy losses, and the Ministry was under pressure to reduce such losses by any means, and there is a fair risk that, in absence of alternative approaches, citrus fruit drop would be addressed by large-scale spraying campaigns. Such pressure particularly mounted during the fruit drop season (August-November) in heavy fruit drop years (see for example Chencho Norbu and Phuntsho Lodey 1995). The Ministry is interested in a simple technology to control fruit drop that the extension service can spread, while it is not so much interested in deliberations about research and extension methodologies. The Ministry regarded participatory methods as a means to meet the objective of fruit drop control rather than as a desirable working method in itself. The *European Commission* was the main donor of the national IPM development project and was mostly interested in the development of IPM packages for citrus, to effectuate the establishment of a sustainable plant protection practice. *The Netherlands Development Organisation (SNV)*, that delivered technical assistance to the plant protection service, did see the introduction of participatory methods as a goal as such. The organisation was always more interested in social aspects of the programme, such as the introduction of a process approach, gender issues, consolidation of the developed working routines in local and government institutions, etc.

The Pemagatshel district administration has been highly co-operative during programme implementation. It was mainly interested in improved citrus production (Dasho Penden Wangchuk, Samdrup Jongkhar, pers. comm.) rather than on methodological issues. However, when discussing the prerequisites for fly control, the administrator was always ready to allow time investments in public organisation and training to have the citrus growing communities organised for the control of the chinese citrus fly. To some extent the district administration represented the view of the *farmers*, who were also mainly interested in better yields. The intermediate objectives such as the increased organisational and experimental capabilities needed for citrus fly control were taken as necessary investments for control of fruit drop rather than assets that could be used in other programmes as well. The *extension service* was happy with the programme as long as the district administrator favoured it. The service definitely liked the close co-operation with researchers, although the service had preferred a more formal set-up of the co-operation rather than the starting of a research programme more or less out of their control. The service often showed interest in the results of the programme that were taken up in the regular extension activities.

Although the objectives of most stakeholders were not conflicting at first sight, they worked out to be conflicting in practice. National stakeholders often wanted to see fast results in terms of better yields, and the EC added a wish for the introduction of IPM all over the country. SNV changed interest focus several times during programme implementation, and wanted the programme to work on gender, process approach and institutional development in the course of time. Throughout the programme the author was employed by SNV, and detached at the (EC-funded) plant protection service in Khangma covering six districts in eastern Bhutan. As such he was for the main part functioning within the organisational structure of the Royal Government of Bhutan.

Implementation of the scaling-up experiment.

The scaling-up activities as documented here were the consequence of decisions by policy makers and were official programmes of the Ministry of Agriculture, the District Administration and associated donors. Policy makers genuinely wanted to capitalise on the promising results of village experiments. Yet, in this discussion I consider this effort as an experiment to emphasise that it yielded a lot of insight and knowledge for the use of future dissemination of socio-technological knowledge.

It has been argued earlier that the implementation of the village research programme always had partly an extension aspect as well. During the period of experimental village programmes, farmers and extension staff often requested the research team not to work in the original villages alone, but to have more than just the programme communities profit from the experimental work. Throughout the programme, Pemagatshel district was most eager to utilise the expertise the plant protection service offered, and therefore scaling-up activities were limited to Pemagatshel alone. Thus, during the experimental programme, about five villages within three hours' walk from Dungmin were involved in testing different baiting methods. That was the first attempt to upscale the technology developed in experimental villages. The second attempt for scaling-up technology was carried out in 1995, when the Dungmin experiments had proven successful. The national plant protection service opted for an expansion of the original "village research"-set-up and wanted to carry out a "pilot district" programme. For this, the citrus programme was selected to expand its activities from the original pilot area to an entire district. Early 1996 the Pemagatshel District administrator assented to this idea and ordered the entire district to be treated against citrus fly. A third effort to scale up citrus fly control technology was the implementation of national campaigns. In 1994-1997 the Deputy Minister of Agriculture ordered for a National Fruit Fly campaign, to have fruit drop controlled all over the citrus growing areas in the nation. The National Plant Protection Centre was the implementing agency of this programme and acted more or less independent of efforts in eastern Bhutan.

4.2. *Citrus IPM outreach activities out of experimental villages.*

Scaling-up citrus fly IPM in the research village's environment.

In 1994, the programme staff measured fruit drop percentages in a few villages close to Dungmin for comparison with the treated village. This resulted in informal contacts with neighbouring citrus grower's communities, i.e., Bainang Zor, Martshala, Jorphung and Kalishong, up to two hours walk from Dungmin village. In early 1995 village meetings the extension staff demonstrated that bait attracted flies, so that people became interested in carrying out citrus fly control. As the fly control method needed some further testing, the researcher agreed that in exchange for experimental materials in the first year, farmers would test proposed citrus fly baiting methods.

Activities in those "outreach" villages went more smoothly than the earlier activities in the original experimental village. In a few places, just the example of Dungmin controlling mistletoe made the community prune out the parasitic plant. For citrus fly control however, farmers lacked expertise and baiting materials and they needed assistance from the extension staff in this end. In contrast to Dungmin, in the outreach villages communities organised baiting independently because they were small and in each village one individual farmer (usually a woman village leader) was in a position to co-ordinate the fly baiting activities. The extension staff visited the villages once or twice during the following season, and individual farmers visited the extension staff whenever they felt a need. During follow-up training extension staff presented the new tools and briefly discussed organisational matters. Such tools were then used for monitoring purposes just like in the original village. After the baiting season, research staff visited villages to evaluate baiting activities and to establish infestation levels.

This programme soon resulted in a reduction in losses, and by 1996 three out of four participating communities carried out citrus IPM independently, including collection of money, and procurement and application of citrus fly bait. In the one village in which baiting was not very successful, the male village leader was heavily involved in block-level administrative matters resulting in poor organisation of the activities. The fly population in the other three villages was monitored during the following years, and in all villages the fly was nearly eradicated after two consecutive years of fly baiting. In one village, Bainang Zor, citrus yields increased from a marginal few baskets sufficient for the yearly ration of salt, to a volume that made professional trading through contractors and mules necessary. The local woman village leader, Mrs. Sonam Choedon, declared: *"After two years of mandarin trading, we cleared our debts and now we can buy a school uniform for my brother and clothes for my children".* Her co-ordinating citrus fly control had yielded her respect of her village mates, even when her family was of low caste. The programme had instilled a sense of optimism in the community, and some farmers requested staff for a follow-up programme such as the planting of other orchard crops. For staff, the successes in these outreach-villages alone justified all efforts for the entire citrus IPM programme in the district.

Evaluation: dissemination of a socio-technological set-up is easily done.

The outreach village activities show that scaling-up of technology as developed in experimental villages is not a time-consuming task, as the initial experimental programme had suggested. The communities easily developed a social cognition needed for proper implementation of fly baiting. However, the outreach-programme was carried out by a thoroughly experienced extension staff, which apparently put him in a position to successfully carry out scaling-up activities in other villages. He knew how to approach the communities and how to effectively facilitate the organisation of village-wide baiting activities. Moreover, in view of the positive results of the Dungmin programme, farmers were ready to participate in the programme without initial problems such as encountered in the experimental programme. The combination of factors made that the introduction outside the original experimental village could be done apart from the main programme. This suggests that scaling-up of technology developed in experimental villages is a relatively easy task that can be carried out by extension staff as part of their regular tasks.

4.3. The Pemagatshel district extension service carrying out a scaling-up programme.

The citrus IPM outreach activities suggested that technology was ripe for dissemination to larger areas. Early 1996 Pemagatshel district was selected as "pilot district" for a wider application of technology developed in village experimental programmes. This Section presents and evaluates how this programme was implemented.

Preparation and implementation of the district wide programme.

Moving towards a citrus IPM scaling-up programme.
The previous section shows that for a skilled extension staff scaling-up of technology developed in experimental villages is an easy job. This observation led to the plan to have the technology developed in Dungmin spread over the entire district. Early 1996 the national plant protection service endorsed the expansion of the "village research" programme with a "pilot district" component. The district administrator agreed to this programme and he instructed the entire district to be covered in a general meeting of the livestock, forestry and agriculture sections, although no details were worked out. Thus, the division of tasks between the district and plant protection service was not clear, although many a government official meant that the regional plant protection service went too far in promoting the results of the village experimental programmes. There was an occasional sentiment stating that *"now technology has been developed, disseminating citrus fly IPM is the task of the extension service".* Thus it was silently agreed that the district extension service was to carry out the citrus fly IPM dissemination programme, remotely assisted by the regional plant protection service. This led to a shift in initiating task regarding the programme: the main responsibility was transferred from the plant protection service to the district agriculture service.

Because Dungmin village in Pemagatshel district had been the arena of citrus IPM development, all extension staff were well informed on the citrus fly problem. Programme staff often visited the quarterly agriculture workshops in which the programme was discussed. Individual extension staff had been demonstrating the attraction of flies to bait in their respective blocks and some had carried out premature experiments with hygienic measures and baiting to control the fly. Thus, extension staff was familiar with the principles of fly control and also most farmer communities were aware of the fly causing fruit drop. This awareness however had never led to a programme involving the entire community of particular villages. Extension staff had so far been training villages but never involved in the organisational set-up needed for citrus IPM.

Despite all these preparations, the programme was never officially taken up in workplans because the plant protection service did not have the time and manpower to go through the machinery of having programmes taken up in district plans. Moreover, it was virtually impossible to have subjects such as citrus fly IPM taken up in the annual plans as the technical confinement of the subject was not in line with the mainstream policy such as the integration of the forestry, veterinary and agriculture services (see Box 23).

Initiating programmes in individual villages.
The developed control method consisted of a mix of technology and organisational configuration of farming communities. Technically, the method consisted of four bait splash treatments in April-May; the bait solution had to be prepared from a particular protein hydrolysate and malathion and sticker solved in water (Box 5). Communities needed to organise activities such as fund raising, and timely preparation and application of the bait mixture. In the experimental villages this was organised through the selection of a citrus committee and this model was taken over by district staff when trying to have communities carry out fly baiting. The following information is not a complete picture of the IPM technology scaling-up programme, but information as gathered during my occasional visits to the district during the said period.

A first difficulty in district-wide implementation of the programme was the temporarily poor availability of extension staff due to their involvement in ad-hoc programmes and administrative obligations (Box 15). This resulted in a reduction of participating villages from about twenty to five. District staff and the plant protection service jointly trained other villages to promote citrus fly baiting, mid April 1996, which included an explanation of organisational aspects of fly baiting. The training attendees selected village leaders for citrus fly control, who signed a contract that the inputs distributed by the district were used for communal citrus fly control purposes and would be paid after the selling of the citrus harvest.

Box 15. The Pemagatshel district extension service that carried out the citrus IPM scaling-up programme.
The Pemagatshel district agriculture team consisted of one District Agriculture Officer and about seven agriculture extension staff. Some older staff were diploma-holders, while newer staff had a more thorough technical education at a newly established Natural Resources Training Institute. Most staff were officially posted in their respective blocks, although two or three of them stayed in the administrative centre where they mostly carried out administrative tasks. The extension staff who had been involved in the experimental village programme could play an important role in the IPM scaling up activities. He was fully equipped to organise citrus fly control activities in citrus growing villages. However, he was transferred to a block with little citrus cultivation. When the DAO mentioned this under-utilisation of technical know-how to his superior, the latter reportedly commented: "... ***all staff can promote citrus fly control*** *...". Thus, higher government officials regarded citrus fly control as a "trick" that could be communicated easily, rather than a "skill" that had to be developed over years.*

When the citrus fly baiting programme was due (before the fly emergence period), some individual staff had to report for their yearly census and were out of station for a few weeks. In other blocks, a few extension staff expected to be transferred before the end of the financial year (June 30). Thus they were not willing to carry out a programme that had a time span over their expected period of posting in their blocks. This resulted in a reduction of village programmes from about twenty to five. A few of those were initiated by research staff expecting that they would take over the responsibilities for the respective village programmes at the return from the census.

A peculiar drawback of IPM in general was its need of relatively small amount of inputs. For bulky agriculture inputs such as fertilisers and herbicides, a semi-privatised supply system is functioning reasonably well, but traders were hardly interested in handling inputs needed in small quantities such as vegetable seeds and chemicals because profit margins were fixed. For example, if baiting was carried out in time and the weather was favourable one bottle of 100 ml malathion sufficed for five hectares of orchards. Thus, when the in-village bait application was due, it appeared difficult to arrange such small quantities of chemicals (Box 16), and the researcher had to arrange for materials from stocks meant for experimenting. A latest finding in experimental villages had shown that farmers rarely, if ever, mixed different components of the baiting solution in the correct ratios, and the plant protection service distributed pre-mixed preparations to avoid confusion.

Box 16. Procurement of citrus fly baiting material.
For citrus fly baiting activities, farmers needed chemicals such as protein bait (to lure the fly), malathion (to kill the fly) and sticker (to prolong the effectiveness period of bait). The IPM experiments had been successful in the sense that investments for materials were very low: if applied properly, less than 1% of the in-tree added value needed to be invested in baiting materials. Per hectare citrus only 20 ml malathion 50EC, 50 g protein bait and 100 ml sticker were needed in a year. For a big village with 2,000 bearing trees (20 hectare) this meant a need of four 100 ml bottles of malathion and one kilogram protein bait. Pest control related chemicals were not available through commercial traders, but were to be procured through the extension system. Farmers were expected to place orders and pay for chemicals nine months in advance. The extension staff submitted money and indents to the DAO, who then ordered chemicals from the national plant protection service, who collected the indents and issued a tender based on received orders. The system had been set up after earlier non-sellable stocks of chemicals had piled up at district headquarters and in block centres. The system worked reasonably well in areas where farmers lived close to the delivering office or needed bulk amounts of chemicals. However, in the remote areas where the citrus IPM programme was in effect, the agriculture extension service appeared not in a position to arrange small amounts of chemicals.

Although the programme was meant to be fully implemented by the district extension service, at nearly all phases the plant protection service had to back up activities to ensure that at least in a few places the programme had a chance for success. Therefore, the scaling-up situation was still artificial. After the programme had been finalised, the district organised an evaluation workshop on extension of IPM technology with extension staff early 1997. The regional extension programme officer, the district agriculture officer, most district extension staff and representatives of the regional plant protection service participated in this workshop.

Evaluation: the district extension service lacks the social cognition to disseminate socio-technological knowledge on IPM.

Perspectives used for evaluation.
Now, I would like to evaluate this case through social cognition theory and the experience that multiple stakeholders are involved in the construction of socio-technological knowledge. I want to stress that at the time of programme implementation, we did not avail of these theories. This evaluation of the scaling-up programme is not meant to establish the performance of the extension service or give marks to the involved researcher or policy makers, but to draw a lesson and formulate an informed hypothesis on how scaling-up programmes should be implemented in future.

This thesis is divided in a technical part and a more sociological part. The division is an artefact, necessary to comply with mainstream scientific traditions. In this section I want to abandon this division, and adhere to the construct of the socio-technological complex for citrus fly control. Three interrelated aspects of the scaling-up programme are: the effectiveness and validity of technology outside the original experimental villages, the social cognition that goes along with it, and the way in which the extension service supports village programmes from the same social cognition perspectives.

Technology is usually regarded as a technical "fix", a recipe to be applied and giving particular results. Social cognition however can only be introduced through a learning process, and similarly the ownership of the programme by the extension service is not something that can be transferred like a technological innovation. Therefore, these entities can only be considered from a learning perspective: actors need feed-back to see whether they are on the right track or not, and need to act after failure in order to learn how to overcome difficulties. I hope that this exposure provides the tools to clarify many a development in the scaling-up programme, as described in the following sections.

The topographical situation of the village and the social configuration of the community determine the applicability of citrus fly IPM.

In Chapter 3, we saw that some villages were more innovative than others. In hindsight, it was rather naïve to believe that the two villages represented enough spreading of variation in socio-economic and physical aspects to cover the entire area. Surely, when scaling up the technology, still unexplored problems will come up and research is still necessary to address and solve such problems. In a few villages we found that citrus fly baiting was ineffective under heavy rain conditions. In Burna, one extension staff personally carried out bait treatments. Nevertheless, infestation was around 75%, close to the highest record ever. The 1997 spring had been very wet, and probably heavy showers just after splashing had washed away the bait. Possibly also the surrounding by jungle of the orchard may be another cause for the failed control. Also in upper Thongsa, a well-treated village, a single orchard neighbouring forest was heavily infested while in the main village, a few hundred meters down, infestation was around 30%. Possibly, in such orchards flies that escaped baiting and that foraged in the forest undid the effect of fly control.

When communities fail to carry out splashing properly, treatments are not likely to be effective. This phenomenon was seen in many villages. For example, in Shumar, problems occurred with citrus village leaders quarrelling over the collection of money or utilising heavy doses of bait in their personal orchards. Just like we have seen in Dungmin, a failing social configuration to organise baiting activities results in poor application of bait. It goes without saying that in such circumstances technology has little if any positive effect.

Box 17 In Shumar organisational problems hampered continued citrus fly baiting.

The citrus belt in Shumar block consists of a few scattered villages in which farmers organised themselves into 11 (!) groups with a leader for the carrying out of citrus fly bait splashing. In some groups, organisational problems soon arose. Collecting money appeared too complicated a task for most leaders, and in one case, the group leader left the village before his job was over. In another case the group-leader over-used group-owned bait in her family orchard. When later fruits dropped abundantly due to the citrus green stink bug, other farmers attributed this to the misuse of inputs and they refused to pay for the chemicals. The extensionist was not in a position to visit the area regulary (he was engaged in administrative jobs at the district centre), while the researcher did not do any follow-up visits, and never supported the extension staff. The extension staff later had to collect money that group leaders had failed to, which he regarded as an unpleasant task. Still most farmers were *happy with the programme, and wanted to continue, in particular if baiting materials were provided for free. Some however regretted to have participated in the programme because of the problems that had emerged. And, because of the citrus green stink bug problem in lower altitudes, some farmers were puzzled and did not support further baiting activities, as they were not explained about the two different causes for fruit drop. In 1997, the same extension staff implemented a citrus fly baiting programme in a smaller village, close to the district centre which was reportedly successful (Report by Ugyen Tshering).*

A more serious failure of the fruit drop control technology appeared its inability to control the citrus green stink bug (Box 2) in low-altitude villages. 1996 was an exceptionally warm year and the area in which this bug caused substantial fruit drop expanded from a few very low-altitude orchards to substantial lower mid-altitude areas where the pest hit unusually hard (over 90% fruit drop). Fly baiting was designed to be selective and did not control this bug. The excessive fruit drop occurring while farmers had carried out control measures caused a lot of problems, as illustrated in the following section.

Failing technology and organisational problems result in waning support for the scaling-up programme.
Chapter 3 shows that programme success is the best way to ensure support for village research programmes. The previous section listed a few reasons why success was not guaranteed, and one could suspect that under such circumstances individual stakeholders would withdraw their support from such a programme. This happened in various villages. In Khar, farmers observed excessive fruit drop soon after they had applied bait (Box 18). Some farmers then attributed the season's excessive fruit drop to baiting and blamed the programme for their losses. Even if the plant protection service supported extension staff through extensive training and discussion sessions, he discontinued fly baiting activities based on interviews with most houses in the village. Thus a chance was missed to learn from earlier mistakes. Similarly, in Darchung village an isolated farmer baited citrus fly and his orchard was hit hard by the stink bug. This farmer was an important innovator in the area and he was fully aware of the two different types of fruit drop. He discontinued baiting because he could never discuss the various factors of fruit drop occurring in his orchard.

Box 18. Khar village - Opposition to the fly control programme after an outbreak of the citrus green stink bug.
Khar village consisted of 120 households situated on a slope, at one hour walk from the motorable road. In 1996 farmers carried out three to six bait splashes to control citrus fly. In the upper village, citrus fly losses were at an acceptable level, between 10 and 25%, against the usual 35 to 75%. Farmers of the upper village seemed aware that citrus fly baiting reduced damage. In the lower village however, heavy fruit drop occurred. Examination of dropped fruit revealed that it was caused by the citrus green stink bug which in the exceptionally hot summer of 1996 was a problem in low-altitude orchards all over the country. In Khar, first fruit drop coincided with application of bait to control citrus fly. One farmer saw a causal relationship between the control activities and heavy fruit drop and he held the citrus IPM programme responsible for his losses, and demanded compensation from the government in this end. He approached the mayor and local representative in the national assembly and he filed his complaint with the district administrator.

The situation was embarrassing for the district agriculture section that asked the regional plant *protection service for support. It was decided that the issue was addressed through technical training and an open discussion in the village. On November 8 and 9, 1996 the district organised a workshop on fruit drop with representatives from various villages in the area. First, the difference between fruit drop by citrus fly and fruit drop by the citrus green stink bug was demonstrated and farmers were asked to bring fruits from their own orchard to check the ratio of citrus fly – stink bug caused droppers. The supposed fruit drop effect of the bait splash was put in perspective of all villages: villages "voted" for one of the four situations (the combinations baited - non-baited; heavy fruit drop - little fruit drop). When looking at the fruit drop record of individual villages, it became clear that there was no relation between baiting and early fruit drop by the bug, but there was a relation between altitude and fruit drop by the bug. The excited farmer was still did not accept that bait splashing did not cause the fruit drop in his orchard. Then, the team proposed the farmer to carry out an experiment: in the 1997 season he could get baiting materials for free to put as much bait as he wanted in a few trees of his orchard, and compare the fruit drop in those trees with non-treated trees.*

The training made both farmers and staff aware of the different causes for fruit drop. In this way, hick-ups in the programme were useful to advertise its strength as well. Now, it was the district's turn to address the bad advertisement by the particular farmer. The plant protection service had hoped that after this explanation, the local extension staff had developed confidence to further carry out a citrus fly baiting programme. The extension staff however did not support continuation of the programme. He surveyed the village and asked all houses whether they wanted to further participate in the citrus fly control programme, and found that 37 households were in favour, and 50 households were against a further citrus fly control activities. Thus, the programme and its inherent learning process was discontinued. Also at district level staff from other blocks referred to the complications in Khar when explaining why they were not eager to further involve in citrus fly control efforts. (Report by F. van Schoubroeck and Samba Dorji.)

In Thongsa village the programme was more successful. The village was well organised and had a few times been trained and supervised by extension staff who used to work in Dungmin. In 1996 and 1997 the fruit drop was in the lower level of natural fluctuation and farmers attributed the favourable harvest to their well-implemented bait treatments. During the training in which the problems of the stink bug outbreak were discussed (Box 18), Thongsa people expressed their happiness with fly baiting and said that their orchards had become much healthier due to the citrus fly control programme. Later this message was heard more often, and the people of Thongsa apparently attributed the better vigour of orchards to the fly baiting. Although at the time the programme badly needed such support, the statements of Thongsa farmers were not always justified. Fly baiting has, to our knowledge, no effect on tree vigour. Orchard vigour probably increased because of a few exceptionally wet spring seasons in a row so that the water stress period was shorter than usual. The Thongsa programme showed a similar feature to the earlier Am Shing programme: a first sign of success makes people enjoy the programme and ensures support, even for reasons that are not justified from a technical point of view.

Box 19. Thongsa – Improved orchard vigour was attributed to citrus fly baiting.
In Thongsa village the citrus growing community was well organised and needed little assistance to carry out citrus fly bait splashing. The extension staff was young and promising and the DAO often kept him in the district administrative centre because of his good command of English. He often had to receive officials from outside offices and programmes. Therefore, at key dates in the pest development, extension staff did not visit the village, while farmers waited for instructions from the extension staff to

*start bait applications. When the plant protection researcher once visited the village by chance, he found that control was not yet carried out and informed village leaders that they should start the baiting programme. Then, in 1996 fruit drop was about 35%, which was not much less than the usual 35-75%. Yet, the harvest was good and people were happy with the programme. Some people (including the major) stated that "the medicine" had improved tree vigour and that bait treatment was the reason of a good harvest in 1996. This was not a justified judgement, as bait splashes are not likely to improve the vigour of trees. In 1997, the community carried out citrus fly control in a similar way. However, farmers still relied on instructions by staff and it is unlikely that they will continue citrus fly baiting without outside support. The Thongsa extension staff stated: **"I had never been able to carry out a citrus IPM programme without assistance by the plant protection researcher."**, thus expressing that the extension service was not yet in a position to carry out the programme independently (Report by F. van Schoubroeck and Karma Wangchuk).*

In some cases, expectations of the technology were too high. Farmers often did not fully understand the nature of technology, and expected that a ritual implementation would lead to yield improvement, very much like the services of local priests. Similarly, in some villages farmers expected the government to solve their problems, if not through the introduction of promising technology, then through the distribution of funds for their programme. For programme implementers it was sometimes difficult not to try to meet such demands in exchange for the community's support. Such a set-up invariably failed to instil a sense of ownership of the technology and citrus fly control was never achieved (Box 20).

Box 20. Ngangmalam village - Farmers expected miracle solutions and capital investments.
Already in 1994 a few active farmers of Ngangmalam village had made pits in which they collected big amounts of dropped fruit. Fruit drop was as high as 75% in that year, and farmers did not see any positive effect of treatments in individual orchards. In 1995 one plant protection researcher advised the community on possible organisation patterns, but after she left the village, farmers neglected the programme, despite strong support by some individual farmers. Farmers expected high profits without investments from their side. When such fast results were not achieved, farmers lost interest in the programme. Moreover, most farmers availed of another cash crop, i.e. seed potato, as introduced by a national potato programme in the early 1990's. For that programme farmers had received free inputs and a sizeable starting capital for marketing associations, and they expected similar incentives for their citrus IPM programme which they never received. All over, the Ngangmalam programme was neither successful in improving yields, nor in developing local know-how for a future programme (Report by Mr. Lobzang).

The extension service did not have the know-how and morale to introduce socio-technological knowledge.

At the start the plant protection service meant that the citrus IPM scaling-up programme was well-supported by administrators and policy makers. It was hoped that the extension service supported the programme. Some extension staff did not initiate any programme by themselves. In Chemung, the extension staff did not start a programme because he waited for the plant protection service to initiate it, and he felt that more research people were needed so that he would get assistance in initiating programmes in his village.

Other staff genuinely tried to introduce the technology, but could not cope with emerging difficulties as discussed in the previous section. The DAO and some individual staff tried their best to introduce the technology in villages, but were surprised at every hick-up that followed the introduction. Apparently, socio-technological knowledge was too difficult to spread for the extension service resulting in the paralysis of further programme implementation. Ironically, the previous experimental village staff was present in the district, but was placed in the only block in which no substantial citrus was cultivated. The extension service preferred to get assistance from the plant protection service rather than utilising expertise from a junior staff within their own group. I conclude that in the extension service lacked a "social cognition" to have such a programme work. The joint evaluation session was an effort to introduce such a social cognition, but unfortunately this never led to a follow-up programme in which drawn lessons could be put to practice.

Evaluative views by district officials.

After the involvement of the regional plant protection service was over, it held interviews with the district administrator and the district agriculture officer (Box 21). Both of them stressed that the programme had never been officially planned, so that it did not always get the priorities it needed. As a result, the programme implementation had not been thoroughly discussed with relevant stakeholders and was organised in an ad-hoc way. This was one reason why the administrator originally did not acknowledge the particular know-how needed for dissemination socio-technological knowledge. Interestingly, the DAO, who was senior in his profession and a well-experienced man, never expected the technology to work in eastern Bhutanese conditions. He meant that the technology should be introduced in other areas in the country where farmers could definitely benefit from research investments. He considered a good market the best way to have farmers adopt technology.

Box 21. Evaluation of the citrus IPM programme by district officials.

District official 1. – *"The citrus IPM programme was very useful, despite the problems that came up. In Dungmin, no wonder it was difficult to get people carrying out citrus fly control. The people did not want to have a water channel for free, while in another village, Am Shing, people paid Nu 40,000 for an orange irrigation scheme! Actually, I thought Dungmin could have been a good place for orange irrigation, but now that they turned down our offers they will not get anything. If I would have to decide again, I would have asked you to carry out the village experimentation programme close to the administrative centre and the road so that everybody knew what you were doing. Now, you worked all the way in Dungmin and it was difficult for most of us to follow the progress of the programme. The citrus programme has never been in the district planning. I think the district never took the programme seriously enough. That was our mistake. Of course we first wanted to see positive results. But later, it could have been an official district programme. I understand that just giving information to a village will not work to change the local habits. Your work in Dungmin showed that another way to deal with people is needed. For that, the programme should be well-planned."*

District official 2. - *" Any technology that gets introduced fast, will fail fast. Adoption of any new technology by farmers takes time because they will avoid risk. (...) The same counts for Mr Frank's citrus fly control programme. A few years ago we did not know what to tell to farmers about fruit drop. Now, if farmers say fruit drop is a problem, we can propose a solution. But, there are so many constraints. I think that the fruit drop package is not for Pemagatshel district alone, it has to be used in other districts. You have to consider the farmer's absorbing capacity. Farmers in western and southern Bhutan have the capacity to evaluate themselves, but such a capacity is not there here in the east. In southern Bhutan, the first year half of the farmers will follow your information, the next year all farmers will adopt. If you tell anything to eastern farmers, they will not easily accept what you say. That is their mistake. In fact we should punish them if they do not listen to us, that is the best way to make them* *work. Or we should help farmers only when they themselves ask for a solution to this problem. Once the horse is thirsty, it will drink. If farmers want to apply citrus fly IPM, then they should come as a group to the administrative centre. The package is there and we then have to provide the know-how. For technology such as citrus fly control, we can not expect 100% adoption. Here in Pemagatshel, people at least started doing something, a few bait splashes, collecting some of the dropped fruit, which is quite a positive result in itself."*

"We did not put citrus IPM in the district's work plan, even if we are fully aware of its potentials. We were never instructed to do so. But, if work is not in the work plan, it may become an ad-hoc activity. Moreover, if ad-hoc work clashes with the work plan, the work plan will get priority. Be citrus IPM in the work plan or not, the main thing is marketing. In Thimphu, nobody promoted apple and yet apple is being grown anywhere. Development will never take place if there is no proper market, like in Samdrup Jongkhar [the market outlet for a sizeable part of Pemagatshel district], where the auction is dominated by a few and the price is always less than half of the price one km down, over the border. No wonder the farmers never try to improve the mandarin production."

The first two years of scaling-up activities yielded many ideas for future programmes.
The previous sections show that the system to introduce citrus fly IPM was still very fragile. Knowledge and materials needed to be in the hands of various stakeholders simultaneously for the effective application of citrus fly IPM. The problems can be summarised as follows. The agriculture extension service was defined more by the government system than by the seasonal dynamics of pest management (or any other technology). The deadline for starting citrus fly IPM activities was in April when most staff was out for census, while baiting materials had to be ordered and paid nine months earlier. Staff was transferred according to status rather than according to their specialised training and developed skills. Consequently most staff was not competent to address village organisation and consequent problems led to quarrels within communities and failing baiting activities. At implementation individual farmers questioned the effectiveness of the proposed technology and their doubts were poorly followed up, which led to the failure of complete village programmes. Recently educated extension staff had learned how to assess key problems through rapid appraisal techniques, but had never learned how to solve problems in their social context. Moreover, individual staff would not get any benefit from the said programme, while risks involved were considerable. Reports of failed village programmes could lead to serious reprimands, particularly if handling of finances was involved. The pesticide distribution system by the national plant protection service was organised in a way that building up of waste chemical stocks was avoided, rather than to enable farmers to buy the chemicals they needed. In short, it can be concluded that the technology and organisational patterns developed in villages did not suit the government environment. Despite the fact that the village research team had developed cheap and easy methods, the extension service was not in a position to make them available to farmer's communities. Table 4 gives a summary of problems encountered during the scaling up of citrus fly control programme.

Table 4. Learning points for the dissemination of citrus fly control to villages.

domain	*problem*	*result*	*development of solution (and stakeholders involved[1])*
technology	fruit drop caused by stink bug rather than by citrus fly	excessive fruit drop despite control, heavy opposition to programme	in-village research on stink bug control (research and farmers)
	heavy rain in baiting period	failing control of fruit drop, farmers and staff doubt effectiveness technology	making rain-proof control methods available; eradicate fly in dry years (research, extension, farmers)
	proximity additional sources of flies	failing control of fruit drop, doubt on effectiveness method	identifying fly sources and including them in the control programme (research, extension, farmers)
farmers' community organisation ("social cognition")	failing collection of money for inputs	quarrels in the community, delay of the baiting programme	training and facilitating by outsiders (extension, farmers)
	activities carried out wrongly, too late or incomplete	inputs spoiled, baiting ineffective, waning support for the programme	training and facilitating by outsiders (research, extension, farmers)
extension service organisation ("social cognition")	staff unavailable during peak season	insufficient support to implementing communities	proper planning of activities (research, extension)
	procurement materials cumbersome	delay of control activities, failing control	co-ordination with input supplying organisation (national pp-service, extension)
	staff poorly aware of technological and organisational details	poor instruction to villages, failing control activities, waning support	in-village training of staff (research, extension)
	stopping programme after difficulties rather than learning from problems	promising technology not put to practice	co-ordinating activities by relevant stakeholders (policy makers, extension, research)
policy making (see Section 4.4)	considering socio-technological knowledge as a "thing" that can easily be copied	failing introduction of socio-technological knowledge	review of extension policy (policy makers, extension, research)
	no feed-back between grassroots-experiences and mainstream policies	impossibility to incorporate field-level lessons into policy development	creation of fora in which different stakeholders interact (farmers, extension, research, policy makers)

[1] It is assumed that the extension service needs support from research to incorporate technical details in scaling-up programmes.

4.4. Scaling-up socio-technological knowledge in the national context.

So far, the scaling-up process has been described from the viewpoint of implementers. The district scaling-up programme showed that the impact of such programmes is limited if they are not supported by appropriate policies. This section discusses the national scaling-up programme, and efforts to inform national level policy makers on problems to scale up successful programme results. Moreover, it is high time to leave the narrow objective of scaling up citrus fly IPM, and look at the implications this study has for the construction of socio-technological knowledge in general and the consequences for scaling-up programmes.

The National Fruit Fly campaigns.

Earlier sections showed that training-and-visit dissemination of IPM-technology did not work in changing farmers' practices. Thus, field level workers had noticed that the current extension methodology left technological opportunities unused. This notion was to be brought forward to decision-makers in the Ministry, which by the nature of the information flow (up the hierarchy) is a difficult process. Yet, in Bhutan, the Ministry of Agriculture often picked up issues brought forward by developments in the field. For example, local pest outbreaks often led to large-scale pest control campaigns. But also, when authorities or donors heard about successful field-level initiatives, they wanted to make use of the potentials technological developments offered. Authorities soon heard the news that fly control activities could improve yields and they wanted to capitalise on this notion, preferably independently of the know-how developed in the field, as the following section will show.

The Nation-wide citrus harvest varied considerably over the years. This variation had important economic consequences, after all, mandarin is by far the most important cash crop in the country. When in 1993 the national citrus harvest was exceptionally low, fruit drop was soon tagged a major cause of the low volume. Already in 1993 a video film on the citrus IPM programme had drawn the attention of national policy makers. Initial ideas on citrus fly control formulated for this programme were taken as technical inputs for the "national fruit fly campaign" the Ministry launched in 1995-1997 (Box 22). The national plant protection service implemented the programme in about four citrus growing districts. Unlike in similar campaigns in other crops, the recommendation did not include chemical cover spraying, but bait splashing as under development in the experimental village programme. The national citrus fly campaigns' activities consisted of short training sessions; plant protection staff (not very experienced in citrus fly control) visited districts and lectured a group of farmers and extension staff on citrus fly baiting methods.

In 1994-95 fly baiting technology was not yet matured. The distribution over the country of the citrus fly and green stink bug was not yet known, baiting was still linked to oviposition rather than to the fly emergence period. Nobody realised that at village level organisational and technical issues were interdependent aspects of IPM application. Pre and post-treatment fruit drop was never formally established and success of the technology was thus measured through farmers' impressions of the effects. The programme resulted in a number of individual farmers in each district applying citrus fly bait. Village research experiments had shown that farmers never applied bait properly after a single training; therefore, the effectiveness of the campaign in terms of control of fruit drop must be doubted. As in any initial programme, such campaigns yield ideas rather than improved harvest volumes.

Box 22. The national fruit fly campaigns and the problematic relation between control effects and success in political terms.

In 1993, the nation-wide mandarin harvest was exceptionally low, and the Ministry of Agriculture was directed to make sure that next year's harvest would be better. The Ministry identified fruit drop as one of the causes for the low yield. In mid and high altitude orchards where most research took place, 90% of droppers bore signs of citrus fly infestation, and the fly attracted considerable publicity in the national newspaper. Even at that time the national entomologist realised that citrus fly was probably only one of the causes for fruit drop; he pointed out that the citrus green stink bug was a major cause as well, but his argument was hardly heard.

The attribution of the irregular yields to the fly resulted in a series of "national fruit fly campaigns" in 1994 to 1997. Every year, officials from the National Plant Protection Centre visited some districts and trained extension staff and farmers during a few hour sessions. Individual farmers living nearby the administrative centre bought bait and insecticide for application in their orchards. In 1995 the Ministry planned to cover substantial parts of the country; officials talked about 10-30% of all orchards to be covered. This high coverage was never achieved, as the programme was to be implemented by districts that availed of neither the means nor know-how to carry out such a programme.

The programme was regarded successful in the first year. After applying bait, the harvest was good and farmers and authorities were satisfied. However, citrus growing communities were never coached in their efforts to control the pest on communal basis, and citrus fly was unlikely to be controlled by individual efforts. The good harvest could be explained by the fact that heavy losses occur irregularly over the years; high-damage years rarely occur two years in a row. Therefore, a technology applied following a disaster year seems to work well, even if it does not have any control effect. In this way, the fly baiting technology was tagged "successful" on sentimental rather than on technical grounds. But also the other way around, the technology was often tagged "useless" if applied in an environment it could not be expected to work. This happened for example in the orchard of a high-level official who applied citrus fly IPM where the citrus green stink bug was the cause for fruit drop (see Box 18). Such dynamics made that activities in the framework of the citrus fly campaigns were sometimes called a success, sometimes a failure, with little (if any) reference to the actual working mechanism of the technology. At times the appreciation of technology resembles the mechanisms for support of religious rituals for "a prosperous and healthy life", which "sometimes work, sometimes don't work, but render peace of mind anyway". Similar mechanisms occur in western countries in environmental protection programmes.

The national citrus fly campaigns utilised the best of technical and extension methods available at the time. They show the problematic relation between successes in terms of improved harvest and success in political terms (Box 22). They show that, in the views of the Ministry, technology was the sole core of citrus IPM. The campaigns yielded awareness of fruit drop as an avoidable cause for losses all over the country, but failed to address community organisation, and failed to challenge the underlying extension philosophy. Thus, a self-propelling citrus fly control practice was not established, although eventually the citrus fly programme as a whole triggered initiating discussions on the coherence between technology, farmer's organisation and extension methodology.

The policy to integrate livestock, forestry and agriculture services.

One can wonder why the citrus IPM programme (and other small-scale IPM programmes) had so little impact on the agriculture extension policy. Policy makers were aware of their potentials, even national campaigns were organised to capitalise on the successes, yet the main feature of the success, i.e., the integration of technology and sociology, was never picked up as a policy issue. Thus, the citrus fly campaigns were initiatives isolated from the main thinking on extension policy. For a better understanding of this phenomenon we have to have a closer look at the mainstream thinking among policy makers in Bhutan at the time. The official plant protection policy was the adoption of IPM (Planning Commission 1991). This, however, was a minor issue compared to a policy embracing the entire Ministry, viz. the policy of integration of the Renewable Natural Resources (RNR) sectors (Pradhan et al. 1994), both in research and extension. This shaped developments at national and district level (Box 23). Agriculture extension staff were to become generalists over the borders of the agriculture discipline. The policy of RNR-integration targeted exclusively the integration of technology in the three RNR-sectors; other types of integration, such as the integration of technical and social domains of knowledge, were not valued. The then running village research programmes targeted technically demarcated issues (in this case, citrus IPM) and addressed social and technical aspects in an integrated way. National and regional level policy makers soon measured the proposals to scale up successful technologies with the criteria set by the RNR-integration policy, in which a confined technical principle was taboo. From several policy makers we noted a remark in the spirit of: *"The IPM pilot village programmes are among the best services implemented by the Ministry, but they do not comply with the RNR-integration policy."* Policy makers, who visited research villages heard farmers talking enthusiastically about their boosted yields hardly advocated the approach at national level; if they did, their plea did not find fertile ground in the mainstream policy of the Ministry. Lessons for the general policy moves of the Ministry were, to my knowledge, rarely, if ever, drawn. For several years in a row there was no way in which the plant protection service could even initiate a discussion on the incorporation of village research experiences into the mainstream policy of the Ministry.

One positive feature of the policy was the concentration of all RNR-research in four research complexes, in which researchers would naturally interact. A formalised co-operation of the three sectors could have created further potentials for activities if it would have been restricted to subjects in which the sectors had a common task, such as in pasture development or in agro-forestry. A formalised way of informing all RNR-sector staff on activities in the other two sectors would have provided a chance to co-operate when and where necessary. However, the rigid way in which the three sectors were to involve into each others work domain did not count with several human factors, such as the need for a professional identity of individual staff and separate sectors and the need to identify results of work as one's own in order to learn from experiences. In short, the RNR-integration policy appeared to hamper the up-scaling of necessary integration of social, organisational and technological issues in rural development.

Box 23. RNR-integration policy at district level.

Since 1992, the Ministry had adopted a policy called RNR-integration, as proposed by ISNAR and the Swiss Development Corporation (ISNAR 1992, RGoB 1992). This policy included integration between the Renewable Natural Resources sectors (RNR-sectors), i.e., forestry, animal husbandry and agriculture. The basic idea was that at the farm level, activities covering the three sectors were deeply intertwined. Through the RNR-integration policy, the Ministry wanted to reflect this relation in the government services for farmers. The policy was a hard-systems construct, i.e., it was defined in technological (farming systems) terms and left little or no room for participatory approaches. At Ministry-level, the three departments merged. Although the policy was originally meant for the research service only, also extension services in districts were combined. In refresher courses district staff was introduced to basics of the two other sectors, with the goal that all staff would be able to deliver services of each of the three *sectors. The regular discussion fora (such as quarterly workshops) of the three sectors were merged, so that all RNR-staff became aware of the on-going activities in all RNR-sectors.*

For the agriculture sector in districts this policy meant a decline of a valuable discussion forum. When certain issues needed to be discussed in detail (such as the citrus fly programme), always two-third of the audience was not interested in the particular topic. Nobody wanted to show weaknesses of their own programme to relative outsiders, so staff could not thoroughly discuss problems in programme implementation if they were felt. Moreover, the focus of the RNR-integration policy was government sectors rather than farmers. For example, the independent RNR-sectors used to produce separate plans; now this was regarded improper, and in some districts staff spent weeks to write integrated rather than separate plans. The RNR-policy represented farming systems thinking and any such a systems approach is too overwhelming to be functional as a start for practical programmes. At field level there was a lack of a clear problem to work on and the policy resulted in an obligation of individual staff to take over each other's tasks when necessary. Occasionally agriculture staff distributed medicines for cattle, and at pest outbreaks staff of all sectors were mobilised to apply chemicals all over the place. Yet, this made that sudden directives from the Ministry disrupted sector's own programme implementation. In the field, we never saw an effort to consistently develop technology or a change in farmer's practices that could be labeled "a typical result of RNR-integration". Occasionally combined efforts of sectors resulted in constructive programmes (such as a wild boar management programme, in which forestry, agriculture and nature conservation officials co-operated in village experimental programmes). Possibly, the merging of separate services made organising such programmes easier, although also institutions outside the RNR-sector participated.

The policy affected the professional development of a whole generation young research and extension staff because the policy advocated that any professional in the RNR-sector should be able to render any technical service to farmers, and thus it does not consider technical professionalism very important. The implementation of the policy met considerable resistance from researchers in the country, who felt that it hampered the adoption of participatory methods. The policy was evaluated positively, mainly because the Bhutanese authorities were extremely co-operative in having the policy introduced as an answer to the typical Bhutanese farming systems situation (Kinlay Dorjee et al. 1992, Goldsworthy 1995). Bhutan is quoted as one of the countries in which the opportunities the systems research approach offers to the research systems are fully explored (Goldsworthy and Penning de Vries 1994, p. 180).

When we discussed the problems of scaling up IPM successes with policy making national level extension staff, IPM scaling-up problems were seen as a lack of farmers' capabilities to organise themselves: *"We are aware of the problems in extension practice, like plant protection research staff brought forward. However, the situation at the national level is difficult. We have been trying to influence policies, but we are just a small section. We need experiences like the village IPM research programmes to make a case to administrators. We will soon look at all innovative extension programmes; possibly we will look at your village research programmes as well. Then, we will continue to work on pilot-base in the same line, and five years or so from now we can make it a policy. Farmers groups are a necessity, and we will try out organising more farmer's groups on more places in the next few years."* Such discussions revealed that the extension section did regard neither institutional configuration of the extension service, nor technological expertise of individual staff a problem. The farmers' organisation capabilities were regarded the constraint for further development.

Thus, it appeared difficult to arrange support for the integrated addressing of technological and social aspects of village-level problems. In a few national level workshops 1997 plant protection researchers were given a chance to present the technology delivery problems and solutions based on their work in villages. Possibly, these workshops were a factor in the decision to make an inventory of technologies laying on the shelf of the various technical programmes. In 1998, a proposed programme to initiate a national level extension programme on technology developed in village research programmes was cancelled. This is where this report ends. It seems that findings of the village research programmes continue to be incorporated in the general pool of knowledge in the national agriculture policy making. The citrus programme has put citrus on the agenda of MoA. The national plant protection service produced extension materials on citrus IPM, extension staff will carry on working in the way fixed by the institutional set-up that sometimes works, sometimes does not work, but in anyway, renders peace of mind.

Donor's policy: gender, process approach, institutional building.
Another party that had a role in the policy making process that governed the IPM programme was the Netherlands Development Organisation, SNV. The organisation provided long-term technical assistance to the IPM programme, so that individual researchers could develop a thorough view on developments in the field of plant protection. SNV's policies changed focus every few years. A constant factor was the notion that technical research was not a task of SNV in the on-going IPM programme. Literally at all phases of the programme, the organisation (in the person of various programme officers) encouraged researchers to discontinue technical research, and focus more on extension and institutionalisation processes. The focus on gender in the early 1990's made that SNV always stressed the need for bringing available technologies to women farmers (documented in Schoubroeck et al. 1999). Next keyword was the "process approach", and the organisation asked for a community-oriented programme. During later years, SNV stressed institution building as a main focus. SNV supported the RNR-integration policy at national level that entailed merging of all RNR-related institutions. At the same time the organisation directed the plant protection service to hand over the complete citrus IPM programme to national institutions with a general mandate. The plant protection service could see that such far-reaching integration of technical disciplines would put an end to confined IPM programmes that had been so successful. Further implementation of such policies would pave way for replacing the IPM policy for ad-hoc campaigns with a strong chemical bias, which the Ministry organised when a particular pest drew public attention. In short, SNV did recognise the value of farmer's organisation (in the early years) and the need to adapt the institutional setting for IPM development (in the later years), but regarded technology development as irrelevant to general policy. Although SNV provided inputs that helped in developing IPM application in villages, its strong and rapidly changing policy directives were usually irrelevant to a programme that aimed to make IPM available to large groups of farmers.

Evaluation and prospects.

Policy is constructed irrespective of problems and needs of the field it affects.
The theoretical introduction to this chapter predicted a few problems scaling-up of village-based successes would encounter. If the group of policy makers is considered a coherent group with its own social cognition, it would be difficult for field level actors to influence the reality construct of policy makers. This because information coming in through workshops, advertisement or informal

contacts competes with the social cognition processes in the group. Moreover, diffusion of innovations theory says that people only accept innovations from people higher in social status. It was postulated that the group of policy makers was highest in social status in the AKS and that it was therefore unlikely that field level experiences were taken up in policy making.

The previous sections however show that policy makers at times include experiences from the field in their directives. In Bhutan, they often launched programmes based on field level experiences, such as the national fruit fly campaign, therewith showing the willingness to act upon problems felt in the field. These initiatives however, although occasionally large in scale, never went further than isolated activities and never influenced the vision building in the policy-making environment. Thus one starts to wonder what source of inspiration policy makers use for the major policy building process. Interestingly, none of the major policy issues mentioned originate from felt needs outside the group of policy makers. Not a single farmer, extension or research staff had ever thought of RNR-integration as a policy before ISNAR carried the idea into Bhutan. The group of policy makers constructed "problems" (the poor co-operation between sectors) and "visions" (merging departments would improve this co-operation) thus finding a rationale for a radical RNR-integration programme (Kinlay Dorji et al. 1992). In the (less influential) donor environment addressing of gender and institution building were more popular at the time. This shows that policy makers formed their opinion outside the field they governed, i.e., the research and extension services, except for the workshops in which policies were promoted. Thus, the policy making process is more or less isolated from daily extension practice and misses the feedback mechanisms needed for adapting policies.

The above documented cases show the consequences of this inhibited communication from field level staff to policy makers. After a few years of implementation of the RNR-integration policy I am not aware of field-level problems solved in an original way that could not be addressed properly before the policy was in effect. On the other hand, policy making was rarely adjusted as a result of programmes carried out by Bhutanese services and successful in Bhutanese conditions. To my knowledge, positive pilot experiences such as the maize management programme (Grobben, Khangma, pers. comm.), the apple IPM pogramme (Chencho Dorji, Simtokha, pers. comm.), the wild boar management programme (Aaken, Wangdiphodrang, and DoeDoe, Khangma, pers. comm.) and probably many more led to nice articles in the national agriculture newsletter, but never led to major adjustments in research and extension policy. All those experiences consisted of a mix of social and technological issues addressed. Policy makers apparently felt foreign influence more interesting than research and extension staff who had achieved small-scale successes in the field itself. However, I want to stress that this bias of policy makers towards "grand policies" happens everywhere, and at every scale. For example, Auerbach (1999) found that introducing larger groups of farmers to a highly successful rain water harvesting system met considerable political opposition. Wagemans (1987) shows how an introduction of systematic planning in the Dutch extension service stranded at the impracticability of the approach at field level. Hamilton (1995) reports that policy makers in the Australian province of Queensland for a long time denied the need for feedback from field-level experiences. Van Weperen et al. (1998) showed that the dissemination of Integrated Farming in the Netherlands has never been effectuated at large scale because it needs a change in extension strategy, which has, so far, not been introduced.

Small-scale innovations do not find fertile ground in large scale policies.
This thesis describes a single innovation, i.e., the tackling of village level problems through the construction of socio-technological knowledge in small-scale village-based research programmes. I wanted to know why such experimental programmes never led to a policy that was conducive to a large-scale application of this knowledge. The theoretical framework, a combination of diffusion of innovations theory and social cognition theory, now explains this blocked flow of innovations to a great extent. The previous section showed that it is possible to influence policy making, however, in that end one should be higher in hierarchy than the group of policy makers who are to assimilate innovations. Field-level staff is always much lower in hierarchy than policy makers (irrespective of the nationality of the latter) and therefore they can use whatever communication channel they wish, their inputs hardly count in the "field of forces" of policy making. This implies that field-level innovations as such are unlikely to sort any significant effect. They should always be supported by parallel efforts at policy level, through a person or institution that gives weight to the argument through a higher place in hierarchy. An example of such an effort is the introduction of Farmers Field Schools for IPM in Indonesia, in which national level policy efforts and field level experimenting was combined to solve the problem of pesticide-induce pests in rice (van de Fliert 1993). In line with this theory, successful small-scale programmes that never made it to large-scale application of their findings are however countless. Possibly, the implementers of such programmes are rarely aware of the dynamics in the policy making process making that theoretical constructs from outside are more appealing to the group of policy makers than a small-scale success in the area of their command.

Possible solutions to the inhibited learning from field experiences at the policy making level.
Chapter 2 showed that in the early 1990's, on-station plant protection research was irrelevant to extension staff and farmers. In Chapter 3 it is shown how the self-referential social cognition of the research service could be enriched with village experiences, which led to the inclusion of social aspects of technology onto the research agenda. This chapter shows how the support of policy makers is needed to have these findings introduced at large scale, but that the place of farmers, extension and research in the hierarchy inhibit substantial influence of their efforts to the policy making process. So, what to do now?

Following the theory, one option is the inclusion of small-scale successes in international policy making, as to influence the national policy makers through a channel they accept. For example, the popularity of participatory methods in international policy making is an example of an idea that was brought from field-level successes to the international agenda. This is however a very coarse way of steering. Should for example the idea of a socio-technological research approach be picked up by an institution such as ISNAR, its influence would be global and faint, and the acceptance of the policy is dependent on local political factors rather than its actual working in the field. We have seen many policies developed in African or South-American contexts flying into Bhutan, and effects vary from total irrelevance in field conditions to an additional perspective to existing programmes. Only when such ideas (such as the Indonesian Farmers Field Schools) are completely adapted to local conditions, they start to be relevant to the local situation.

Just like plant protection researchers left the station and actively involved in implementing programmes in villages, individual policy makers could leave their offices in the capital and try to get something working in one selected district. I do not think that this is a feasible option. Involving researchers in village level programmes appeared a feasible job, involving policy makers in extension practice seems a more difficult task, even if in Bhutanese conditions this option is not too far away. Most policy makers have a village background and are ready to visit their places of origin, which, if well organised and for prolonged periods, would enable them to envisage the consequences of national policies at field level. Yet, can one imagine the effect of policy makers occasionally swapping their desk for a village programme in which the weight of their policy constructs may be seriously put to question?

Another option is that the Ministry takes up scaling-up of successful experimental programmes as an official policy. This is not too difficult, around each proven technological innovation enthusiastic staff is grouped that carries out district-wise special programmes. Such an approach was in fact followed by the Bhutan National Potato Programme that, although at limited scale, succeeded in introducing commercial potato cultivation in various pockets in the country. They guide extension staff in their efforts to develop appropriate socio-technological programmes in individual villages. Along with this, the incentive structure should be changed to have staff motivated to do such work. I regard this as the most realistic option. In Section 7.4 I give a practical outline with respect to this idea.

Part II. Supportive biological research.

5. Pest-host plant interaction in the chinese citrus fly[9].

5.1. Avoiding host resistance through behavioural decisions.

Abstract.
Bactrocera minax Enderlein is the most important tephritid citrus pest in southern China and parts of the Himalayas. This article deals with the pest-host plant interaction as studied in mid- and high-altitude mandarin orchards in Bhutan. It was found that the fly is univoltine with two rest periods, one as pupa in soil and one as egg or early instar maggot in fruit. Unlike most other tephritid citrus pests, the fly oviposits in the endocarp (pulp) rather than in the exocarp (peel) of citrus fruits. The long ovipositor enables the fly to prick through the toxic outer exocarp into the inner exocarp and endocarp, thus avoiding contact between eggs and toxins. This possibly explains the fly's wide host range within the citrus family. A dozen citrus species were examined and found susceptible to B. minax. Mandarin fruits resist against B. minax infestation by callus formation around eggs, tough carpel walls, and early abscission of infested fruits. A comparison of the life history of B. minax and other tephritid citrus pests is made.

Introduction.

Mandarin (*Citrus reticulata* Blanco) is an important source of cash income for farmers in southern and eastern Bhutanese villages at mid- and low-altitudes. Fruit drop is a major constraint to production. An important cause for fruit drop at mid- and high altitudes is the tephritid fly *Bactrocera minax* Enderlein (the chinese citrus fly), which together with *B. tsuneonis* Miyake forms the *Tetradacus* subgenus. Another important cause for fruit drop is fruit sucking by the bug *Rhynchocoris poseidon* Kirkaldy (the citrus green stink bug) predominant in lower altitudes. The work presented in this paper was carried out in the framework of a citrus IPM development programme in eastern Bhutan. IPM measures for a tephritid fly and a bug are completely different, so it was essential to properly identify the cause for fruit drop in each orchard or village before starting control activities. This paper deals with identification of *B. minax* damage, it describes characteristics of ovipunctures, egg placement and resistance mechanisms against *B. minax* infestation.

Ovipunctures and egg mortality.

Ovipositing flies obviously make punctures to channel their eggs into the substrate which larvae need for development. The nature of ovipunctures in citrus fruits varies for the tephritid citrus pests, viz. *Ceratitis capitata* Wiedemann, *Pterandrus rosa* Karsch, *Anastrepha ssp.*, *B. dorsalis* Hendel and *B. tsuneonis* Miyake (Greany et al. 1983) and *B. minax*. For example, in *Ceratitis capitata* in Chinese oranges, the egg cavity walls hardened into a corky substance that stuck out of the developing fruit. Most eggs placed in the flavedo (=outer layer of the peel with oil glands) were poisoned, while those in the endocarp suffocated, so that most surviving eggs originated from the albedo (inner, white layer of the peel) (Back and Pemberton 1915, Rössler and Greany 1990). Also *Anastrepha spp.* and other species of the *Ceratitis*-group made ovipunctures and placed eggs in the flavedo, where high mortality occurred (Greany et al. 1983). *B. tsuneonis* is the only fly that is reported to place its eggs in the pulp so that it can only attack fruits with a thin skin. Miyake (1919) reported that ovipunctures made by *B. tsuneonis* were oval or circular in outline, the margin afterwards becoming whitish. The aperture was often repaired by a brownish gummy substance secreted by the orange.

In this paper, it is investigated which oviposition strategy *B. minax* employs. Does it follow the strategy of *Ceratitis capitata,* which placed many eggs in the peel of which few survived? Or does

[9] The three sections in this chapter have been submitted to the Journal of Applied Entomology.

B. minax escape the resistance of citrus against fruit fly attack by position of its eggs below the oily exocarp, like its close relative B. tsuneonis, while overcoming suffocation in one way or another?

Larval development and mortality.

B. minax larvae develop inside the fruits where eggs have been laid, except for pupation that occurs outside the fruit. Contradictory reports exist on the time before hatching of B. minax eggs. Wang and Lue (1995) reported that the maggots fed immediately after oviposition in the exocarp. Yang et al. (1994) reported that hatching occurred 15-25 days after oviposition, while Zhang (1989) reported that hatching took place in early September (i.e. up to 90 days after oviposition). In *B. tsuneonis,* Miyake (1919) found that eggs hatched within 8-9 days after oviposition.

Larval mortality has hardly been studied in *B. minax.* A few larval mortality mechanisms have been described for other tephritid pests in citrus. In *Anastrepha* and *Ceratitis*, early larval stages died, just like the eggs, by the essential oils in the exocarp-flavedo (Greany *et al.* 1983). Hess *et al.* (1996) showed that in a gallmaker Tephritid, the number of emerged flies did not increase with an increased number of ovipunctures or eggs. Mortality during the pregall stage dramatically increased with the number of eggs oviposited. In *B. tsuneonis,* one larva, or at most two, emerged from one fruit, while the fly deposited up to 11 eggs per fruit (Miyake 1919). Thus, egg- or larval mortality plays an important role in most tephritid citrus pests, though little is known on the role of larval mortality in *B. minax.*

Finally, the mechanism through which the fruit is damaged needs some attention. In *Ceratitis capitata*, larvae injured developing fruits with ensuing decay and ethylene production, causing abscission. Moreover, the oviposition action alone sufficed to damage fruits with economical consequences (Back and Pemberton 1915). In *B. tsuneonis,* larvae fed on the pulp and usually fed on one-third to two-third of the carpels. The carpel in which the maggot made its first appearance appeared narrower and thinner than the other carpels. Infested oranges showed a growing reddish yellow spot early October, and dropped (Miyake 1919).

Again, the question raised was whether *B. minax* followed the pattern of the superficial egg-layers (that caused damage through puncturing as well as feeding), or of B. tsuneonis (in which only the feeding by larvae caused economical losses).

In conclusion, this paper describes the interaction of *B. minax* and its host, i.e. the period between female depositing eggs in fruits and maggots leaving the fruit. In addition, the reaction of the fruit to foreign intrusion and consequent egg- and maggot mortality factors is discussed.

Materials and methods.

Most observations were done in two orchards in Tashigang district, viz. in Rongthong orchard (1580-m asl.) and nearby Lyenkhar orchard (1250-m asl.), representing high- and mid-altitude orchards respectively. Both orchards were situated among forest and wetland, at 1580-m asl. on the eastern slope of Drangme-Chu river valley. Both orchards consisted of about 60 plants of various citrus species, i.e. mandarin, lime, bitter orange and citron, while fruiting and non-citrus trees were present as well. In high-altitude orchards, the occurrence of non-tephritid piercers such as the citrus green stink bug is minimal.

Ovipunctures and egg mortality.

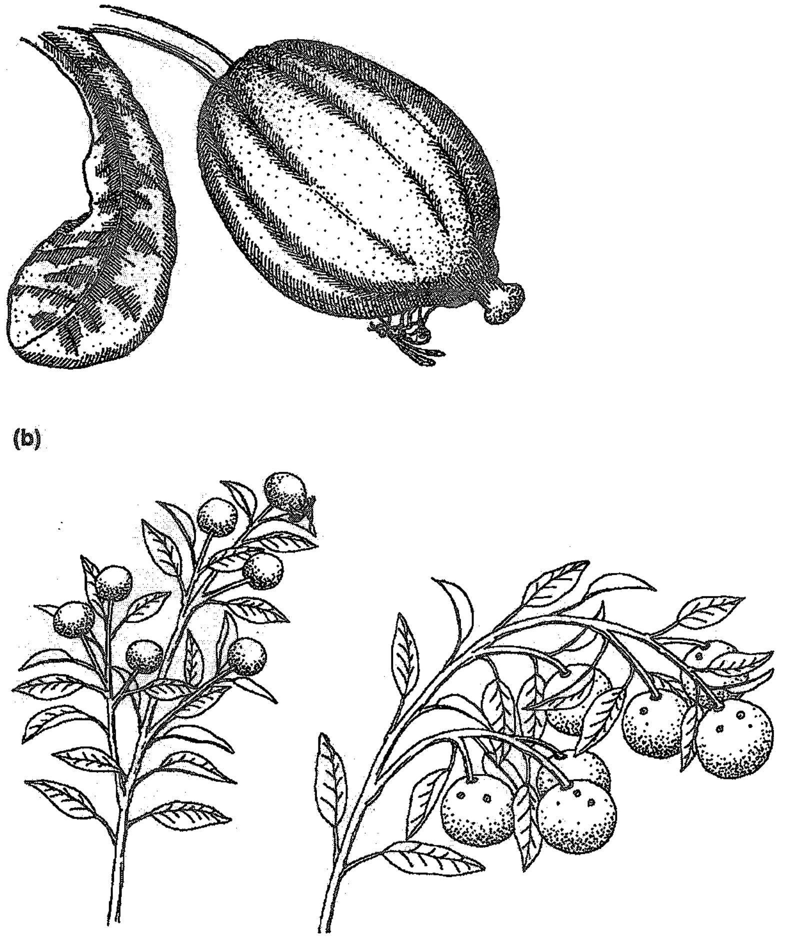
The nature of ovipunctures and resistance mechanisms were studied by dissecting a few thousand infested mandarin fruits, a few hundred lime fruits and about fifty citron fruits, picked from trees. Morphology of the ovipunctures was examined visually, in the field as well as in the laboratory while examining ovipunctures for the presence of eggs (Section 5.3). Once, during the fly's oviposition season, uninfested developing mandarin fruits were punctured with varying depth with a needle more or less the thickness of the fly ovipositor. The resulting symptoms were examined and compared with punctures made by *B. minax*. During the fruit development season, every week dropped fruits were collected and examined for signs of B. minax infestation. Lime, citron and bitter orange fruits were examined to follow *B. minax* infestation. During the fruit drop- and harvest-period, fruits were checked for *B. minax* punctures.

Larval development and mortality.
Similarly, in order to study larval development and mortality, a few thousand mandarin fruits were collected throughout the fruit developing season and during the pest-induced fruit drop, and examined for signs of B. minax larval development and feeding. During the checking of fruits for numbers of maggots, maggot mortality mechanisms were observed and classified.

Results.

Ovipunctures and egg mortality.
Damage of various origin found on developing mandarin fruits are listed in Table 5. Here, only damage related to *B. minax* infestation will be discussed. B. minax ovipunctures were found on all fruit of citrus species that were exposed to an active fly population. Ovipunctures were found from the early fruit development season onwards, i.e. when fruit was over 11 mm in diameter. Female flies oviposited on the underside of fruits. After oviposition flies neither dragged their ovipositor nor smeared fruit exudates over the fruit surface, so there was no behavioural evidence that female *B. minax* left chemical signals to mark the fruit, as reported in *Rhagoletis* (Prokopy 1972). The earliest citrus fruits to develop into sizes fit for oviposition were year-round developing citron fruits. In the early oviposition season, when no alternative host was available, we repeatedly observed during one day up to four subsequent oviposition actions on the underside of the fruit. Later in the season, mandarin fruits developed on the end of erect branches, and oviposition took place at the receptacle side of fruits. When mandarin fruits matured, they became heavier and bent over, so that after some time, ovipunctures were found on the side or upper half of the fruit (Figure 7). Fresh ovipunctures showed up as a wet hole in the epidermis, which after some time was filled with a rosin type of substance. Sometimes a corky spot developed on the outside, which superficially resembled injury by scab or small suckers. Ovipunctures could be distinguished from other infections by their exclusive occurrence on the underside of young fruit, and deeper penetration than the various similar looking infections.

(a)



(b)

Figure 7. B. minax usually oviposits on the underside of fruits: (a) oviposition on citron; (b) oviposition on mandarin, ovipunctures on the underside of the fruit appear up when branches bend over.

Different types of ovipunctures are shown in Figure 8 and are listed in Table 5. The clearest ovipunctures were formed through insertion of the ovipositor through the exocarp into the underlying carpel, or even further inside the fruit. In the exocarp, the puncture wound was repaired through a rosin-type of substance, which formed a brownish brittle "splinter" (2-3 mm long) forming the central spine of the puncture into the fruit. Around the tunnel, the albedo tissue showed a colourless, slightly transparent wall of 0.5-1 mm thick. Ovipunctures induced a spot where the skin stuck to the carpel wall. If familiar with the phenomenon, you could often find such spots when mandarins were peeled for consumption. On the entry point of the puncture into the carpel, there was a hard (callus) spot of 1-2 mm diameter. In the pulp, near or inside this spot, there were usually two to eight brownish, died structures of 1 mm length; maybe juice vesicles that were damaged when the fly oviposited, or encapsulated eggs. If eggs were spotted, they were usually placed in the same segment. Possibly the eggs were hatched, so that we observed first instar maggots, though this seemed not very likely. Sometimes, the fly had apparently pricked through the underlying segment into an adjacent or opposite segment, where the eggs were placed. Eggs were found in a compact clutch, near a developing seed, in-between juice vesicles, or near the central wall of the segment. Occasionally solitary eggs were placed on different spots in-between the juice vesicles. When fruits were pricked with needles, the resulting punctures looked similar to natural ovipunctures.

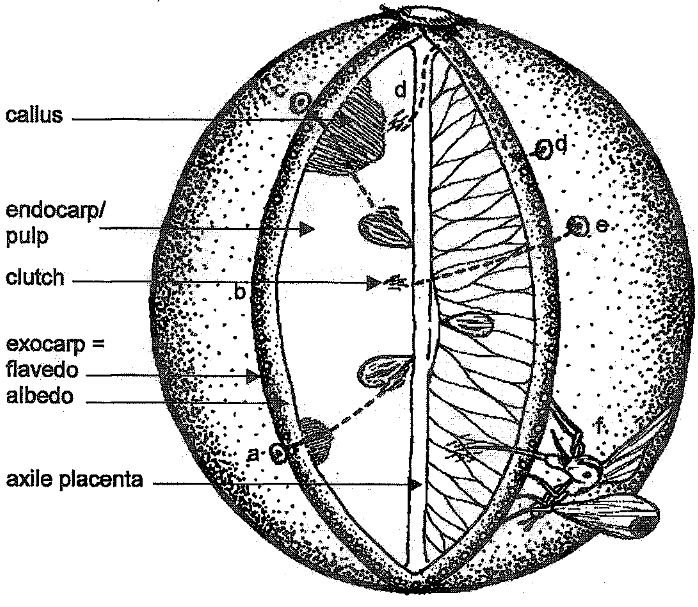


Figure 8. Ovipunctures in mandarin fruits. (a) ovipuncture penetrating the endocarp; (b) ovipuncture into the exocarp only; (c) ovipuncture of the early season, callus is extending over the endocarp; (d) sometimes tunnel through the albedo and axile placenta into the carpels; (e) early made punctures often penetrate through the first carpel into the next one; (f) fly ovipositing on the underside of the fruit

type of spot	deep	deep small	superficial	general injury
genesis	regular *B. minax* oviposition	test puncture by *B. minax*? sucking sign of Citrus green stink bug?	test puncture by *B. minax*?	damage by agents such as scab, small suckers, etc.
characteristics	a tiny black spot or wart on the flavedo; in the albedo a 1-3 mm circular spot with hardened rosin that sticks to the underlying segment	a tiny black spot or wart on the flavedo; in peel 0.5-1 mm circular spot that sticks to the underlying segment	a tiny black spot or wart on the flavedo; in the albedo a 1-3 mm circular spot that does not touch the underlying segment	any other abnormality like warty flavedo, formation of callus tissue, brown tender tissue, etc.
reaction fruit	rosin secretion, callus formation within pulp	rosin secretion, callus formation within pulp	rosin secretion	see up
vital fruit fly infestation	usually yes	usually no	usually no; if yes, there is a tunnel through the albedo into the pulp	no

Table 5. Different types of B. minax ovipunctures and other injuries in mandarin fruit

Some punctures penetrated only through the flavedo into the albedo ("superficial punctures"), others into the endocarp ("deep punctures"). These two types accounted for most of the punctures found in infested fruit. Superficial and deep punctures showed the same reaction in the exocarp: in the albedo, the hardened rosin and the discolouring of the flavedo showed clearly when cut through with a sharp knife. In many cases, in particular in older fruits, oviposition spots were difficult to detect unless the flavedo was sliced off and punctures showed as dark spots in the albedo. In lime fruits, oil glands showed more outspoken than in mandarin, and ovipunctures were more difficult to detect, in particular in the later season when fruits had become bigger and oil glands had developed more prominently.

A different type of ovipuncture was superficial with a long, curly tunnel leading 30-40 mm through the albedo towards the receptacle into the axile placenta of the fruit. The structure was seen in about 1% of the examined fruits. In the large citron fruits, all ovipunctures were longer than the fly's ovipositor and lead straight into the underlying carpels. Such structures did not occur simultaneously with the presence of detectable maggots. The form and length of the tunnel made it unlikely that it was made through the ovipositor, though possibly tunnels were made early in the season and fruit growth patterns had distorted the original form.

Another type of puncture bored into segments but did not show the typical reaction in the flavedo-albedo ("small deep punctures"). Possibly, both "superficial" and "small deep" structures were made by *B. minax* when probing fruit before actual oviposition. In such punctures eggs were never found. Such punctures were often found in mid- and low-altitude orchards, and were possibly generated by non-tephritid sucking or piercing agents.

Larval development and mortality.

Development of *B. minax* infestation in mandarin is illustrated in Figure 10. After oviposition, apart from the fruit's reaction to the physical insertion of the ovipositor, nothing seemed to happen to the fruit. Just after oviposition, eggs were relatively easy to detect, as fruits were still smaller than 20 mm; in September eggs could not be detected anymore. The eggs or early maggots were apparently in a state of rest until late September, when tiny maggots started to feed on the pulp and some on the developing seeds, resulting in collapse of the carpel of their residence. In double infested fruits, feeding started often in two separate carpels, not necessarily at the same time. When maggots became bigger, they jointly bored through the segment wall into a neighbouring carpel. When one or two segments were completely eaten, the green fruits started to show orange spots on the outside. At this point in maggot development, damage became clear to farmers, and in one or two weeks the entire fruit discoloured and dropped. Some dropped fruits did not only show ovipunctures, but also maggots and maggot escape holes. A small fraction of infested fruits never dropped up to harvest. Such fruits were often sold, providing maggots a free lift through the usual trade flows.

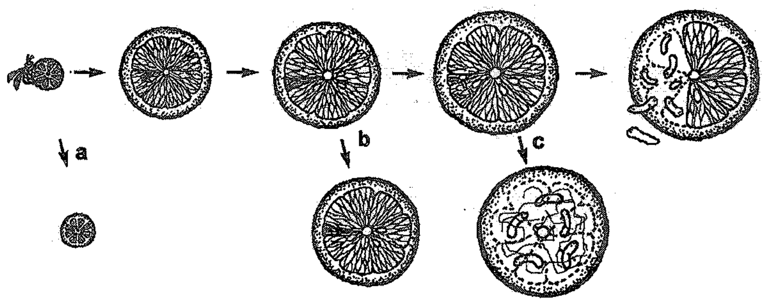


Figure 10. B. minax infestation in developing mandarin fruit: (a) flies oviposit in fruits over 11-mm diameter, in some punctures no eggs are laid; (b) infested carpels collapse, sometimes maggots get enclosed; (c) maggots develop and colonise carpels one by one and escape, sometimes maggots get enclosed by a dried, hardened exocarp.

A few resistance mechanisms could be observed during maggot development, such as callus formation and collapse of segments. Callus formation was induced by deep ovipunctures and eggs in the infested carpel. It happened in mandarins at all altitudes. In the callus tissue, we found small brownish particles about the size of *B. minax* eggs. These particles were possibly encapsulated eggs, or parts of damaged fruit tissue. Some live eggs and small live maggots were found encapsulated in callus tissue. Callus growth and maggot development were competing processes. In some fruits, one could see maggots that had escaped from the callus tissue, while in others maggots were clearly caught.

Collapsed segments became compact and hard. Sometimes small numbers of maggots were caught into such a compact segment, apparently not able to bore through the segment wall to a nearby juicy place. Fruits that were sold for consumption often showed a single compact segment, showing characteristics of a *B. minax* infestation that apparently had not survived the hardening of the segment.

Other mortality mechanisms included excessive infestation (so that none of the maggots survived, usually because of early abscission), exhausted resources, and occurrence of high temperatures in sun-exposed fruits (resulting in mortality of maggots). After fruit drop, fruits tended to dry out so that the skin became impenetrable. If during cold spells in high-altitude orchards maggots had no chance to escape the fruit in time, drying out of the peel resulted in maggot mortality. In Ronghthong orchard, late November 1997, 82% of dropped mandarins showed no escape hole and maggots had not survived due to this mechanism.

Discussion.

Ovipunctures and egg mortality.

The ovipuncture placement on the fruit was mainly determined by the position of the fruit at the time of oviposition. Flies tended to puncture the fruit in an upside-down position, so fruits were mostly punctured at the lowest point. A change in position of the fruit, such as by bending over branches, resulted in a change in position of the puncture. Thus, the position of punctures was one way to distinguish damage by B. minax and damage by other agents.

The findings on the nature and form of ovipunctures were generally consistent with previous findings as reported in literature, e.g. Wang and Lue 1995. On the outside of the fruit, there was usually a tiny wart-like proturbance, which formed the beginning of a tunnel filled with a gummy secretion. This tunnel usually led through the exocarp into the endocarp, where eggs were posited. Natural and artificial punctures looked identical, so ovipunctures seemed to be formed by the physical insertion of the ovipositor into the fruit alone. As the structure was not very specific, other boring agents common in lower-altitude orchards possibly induce similar spots. As punctures varied in depth, and puncturing occurred in a variety of fruits and in earlier and later stages of fruit development, there were various expressions of ovipunctures (Figure 8).

In most Tephritid-citrus interactions resistance mechanisms take place in the exocarp, where most tephritid citrus pests oviposit. Resistance of the rind to penetration, the oil content of the flavedo and the peel colour determine the outcome of the host-pest interaction. For example, *Ceratitis capitata* and *Anastrepha suspensa* flies lay eggs in dense clutches in the exocarp-flavedo, in which the oil content appeared to be the decisive mortality-inducing factor. Eggs in the rind and pulp showed a high mortality (98 and 84% respectively) and most larvae emerging from citrus fruits were from batches laid in the rag (Greany 1989, Rössler and Greany 1990, Back and Pemberton 1915). *Anastrepha ludens* has a relatively long ovipositor, and lays eggs in the albedo, thus avoiding contact with the toxic essential oils. The albedo thickness determines to some extent the suitability for A. ludens' survival in citrus (Levya *et al.* 1991). *B. minax* sometimes oviposits in the albedo, like *A. ludens*, but usually deposits its eggs deeper into the fruit, in the endocarp. Therefore, resistance mechanisms such as described in other Tephritids ovipositing in the peel did not affect *B. minax*, eggs and maggots were out of reach of essential oils, while no citrus ssp. was found to be impenetrable for the fly ovipositor. Only *B. tsuneonis* has similar habits (Miyake 1919), and of neither fly literature exists on resistance mechanisms. Yet, post-ovipositing mortality takes place. After puncturing, callus tissue formed at the insertion point in the endocarp, which gradually expanded over the carpel. In this tissue, encapsulated eggs or early instar maggots were often found. The callus formation and possible encapsulation had the character of a competition between the maggots and the fruit, and probably multiple eggs helped in overcoming this mechanism for maggots. Not all such fruits were saved from dropping, in mandarin, a sizeable portion of infested fruits dropped, while no maggots developed (Section 5.3), possibly also because of abscission before maggots could develop.

Larval development and mortality.

Young maggots probably died in similar ways as eggs. The collapse and hardening of infested segments was a mechanism specific for the maggot stage of infestation. This was induced by the inability of maggots, particularly if small in number, to bore through carpel walls. Feeding of maggots became first apparent by the infested segment becoming tender, and sometimes the tissue and wall of the segment hardened and maggots were trapped. Such fruits did not drop and were fit for consumption, except for the one dried segment. In heavily infested orchards, about one third of fruits remaining in the tree contained such segments (Section 5.3).

Other maggot mortality mechanisms included: mortality of (all) maggots in heavily infested fruits; heating of fruit above lethal temperatures by the (post-monsoon) sun in lower altitude orchards; cow- and rat-feeding on infested fruits; and drying out and hardening of the skin of dropped fruits so that maggots could not escape. Occasionally, such factors induced high mortality of maggots after fruit drop.

A few resistance- or mortality mechanisms mentioned in the literature for other Tephritids were not observed. Suffocation of eggs or maggots in infested fruits (as found in Ceratitis Capitata by Back and Pemberton 1915) was never seen, though we would not know how to detect such mechanism. Possibly, egg-size brownish structures often seen in the callus formed under ovipunctures were suffocated eggs, even if they were not placed in clutches but spread over the tissue. There was no evidence for cannibalism of maggots. Even in overloaded fruits, maggots perished collectively rather than devouring each other. The impenetrability of a peel due to its thickness (as found in *B. tsuneonis* by Miyake 1919) was rarely a problem for *B. minax:* almost all citrus species were successfully attacked by the fly.

The oviposition habits of *B. minax* make it unlikely that resistant citrus strains exist. Also the enhancement of resistance by application of gibberellic acid to change peel characteristics in favour of resistance against tephritid pests (e.g. McDonald et al. 1997) is unlikely to sort control effects against *B. minax.*

The position of eggs, and therefore the fruit devouring process, differs between the *Tetradacus* and other tephritid pests. Most Tephritids start feeding from the peel, and eventually attack the underlying carpel. Both *Tetradacus* species started feeding from where eggs were placed, i.e. from the inside of one carpel. After hatching, the host carpel became soft, and tiny maggots that consumed the segment could be spotted. At this point the fruit peel discoloured, and showed a distinct orange spot. When the carpel was finished, maggots bored through the segment wall into the neighbouring segment, that would be collectively attacked. Eventually the attacked fruit dropped. Maggots kept on feeding until they were matured for pupation, when they left the fruit through one exit hole, usually on the ground-touching side of the fruit.

Fruits with few maggots sometimes did not drop and were often picked and sold. This provided the maggot a lift and thus contributed to further spreading of B. minax. This mechanism is the reason behind quarantine restrictions imposed on fruits from infested areas (Zhang 1989).

Life history characteristics of B. minax.

In literature, there are conflicting reports on the period between oviposition and hatching. Wang and Lue (1995) report that the maggots fed immediately after oviposition in the exocarp. Yang *et al.* (1994) reported that hatching occurred 15-25 days after oviposition, while Zhang (1989) reported that hatching took place in early September (i.e. up to 90 days after oviposition). In *B. tsuneonis,* Miyake (1919) found that eggs hatched within 8-9 days after oviposition. In line with literature, it was found that *B. minax* oviposits in June-September, while there is little evidence of maggot activity before late September, when fruits have grown big enough to sustain multiple maggot feeding. No other tephritid flies are known to have such a long in-fruit rest period (D. Papaj, pers. comm.). So, reports on the duration of the in-fruit rest period are consistent, but also this study could not make out whether *B. minax* rest in fruits as eggs, or as maggots. No eggs could be detected after July, but, possibly, eggs had become more difficult to detect because the fruit volume had increased and the structure of fruits had become coarser. Another possibility is that eggs had hatched and tiny, hyaline maggots were hidden inside vesicles or in the developing carpel. Developmental arrest in the egg stage is rare in Tephritids (R.J. Prokopy, D. Drew, pers. comm.) and the feature needs further study.

The long in-fruit rest period has serious consequences for monitoring fly activity and control of the fly. It was often erratically thought that *B. minax* oviposits just before damage becomes apparent, i.e. in September-October (e.g. Nath 1973, Subba 1984). Subsequently, B. minax control measures have long been carried out late September and October rather than before oviposition.

Host range. Most tephritid citrus pests are variably successful in exploring different citrus spp., attributable to the flavedo thickness and oil content and structure characteristics (Greany et al. 1983). Both Tetradacus species attack fruits in their early development stage, so that they are less dependent on specific fruit shapes and peel structure in the ripening phase of the fruit. Yet, in the two species the host ranges differ remarkably: *B. minax* attacks all citrus ssp., while *B. tsuneonis* attacks only thin-peeled hosts such as mandarin. Different life histories and fly morphology are related to the different host ranges. *B. tsuneonis* oviposits after late July (Miyake 1919), while *B. minax* oviposits from early June onwards. Thus, *B. minax* appears earlier in the fruit development period and attacks fruits when they are smaller than *B. tsuneonis* does. Moreover, B. minax has a longer ovipositor than *B. tsuneonis* (Zhang 1989), the 8-10 mm ovipositor is long enough to reach the endocarp in most Citrus ssp, in particular when fruits are still small. Both the oviposition period and ovipositor length may explain the much wider host range of *B. minax* compared to *B. tsuneonis*. Some authors have regarded B. minax and *B. tsuneonis* as a single species, though lately the two are mostly considered separate species in one sub-genus *Tetradacus* (White & Elson-Harris 1992). Life cycle characteristics give more evidence that the two are separate species.

Concluding remarks.

With the data collected, we can also speculate about the place of *B. minax* in the spectrum of tephritid behaviour. On one hand, *B. minax (and B. tsuneonis)* shows characteristics of other *Bactrocera* species because of multiple egg clutches and apparent of Oviposition Deterrent Pheromone (ODP) (Section 5.2). On the other hand, the fly resembles *Rhagoletis* species for its monovoltinicity and its stenophagous character. This fly species distinguishes itself by the employment of two long rest periods in its life cycle, while the depth of oviposition results in host resistance mechanisms not described so far.

The identification of ovipunctures as a measure for fly activity enabled the eastern Bhutan citrus IPM programme to successfully link ovipuncture densities in fruit populations and later damage by the fly (Section 5.3). Moreover, the results presented in this paper were used by citrus growing communities to identify the relative importance of *B. minax* and citrus green stink bug in their respective orchards (Chapter 4).

5.2. Biggest fruits first: the process of fruit colonisation in the chinese citrus fly.

Abstract.

Bactrocera minax oviposits in citrus fruits early in the fruit development season. After May, female flies puncture fruits of over 11-mm diameter. Early developing fruits attract more ovipuncturing than fruits that develop into critical sizes later. This mechanism explained uneven ovipuncture distribution over fruit populations within trees, between trees, as well as between different citrus species. Ovipunctures were slightly overdispersed. Oviposition-deterring mechanisms, known to exist in other tephritid species, were not observed. The oviposition season lasted until September.

Development of eggs into active maggots took one to four months. In October and November maggots started feeding and induced early ripening and premature fruit drop. In all four years of observation the median of fruit drop was in the third week of October, and was slightly earlier in a high-altitude than in a mid-altitude orchard. Possibly, shortening light periods or minimum temperature played a role in maggot activation mechanisms. This may explain the uniform timing of fruit drop over the years.

Introduction.

Fruit drop is a major constraint to mandarin (*Citrus reticulata* Blanco) production in the eastern Himalayas. An important cause for fruit drop is the tephritid fly Bactrocera minax Enderlein (the Chinese Citrus Fly), one of the two species of the Tetradacus subgenus. In June-September the fly oviposits in fruits, which later prematurely ripen and drop. This paper deals mainly with quantitative aspects of the fruit colonisation process. Research questions are: (a) how do flies select fruits for oviposition? (b) when do maggots enter the feeding stage, and (c) what mechanisms make them do so?

Colonisation of the fruit population.

Oviposition behaviour of *B. minax* is described by Wang and Lue (1995) and in Section 5.1. Male flies occupy fruiting citrus bushes and trees from early June to late September. Gravid females approaching developing fruit are usually approached for mating by a nearby male fly. Females visit developing fruit and oviposit on the lower side, in upside down position. After one to four short insertions, females keep their ovipositor inserted for up to 20 minutes, turn four to eight half-circles and apparently oviposit. Then the flies briefly stand still and fly away. The mechanisms through which *B. minax* selects fruits for oviposition has not been described, although some work has been done in other tephritid species. Straw (1989) showed that two tephritid fly species attacking *Arctium minus* compare the size of flowerheads and the size of structures inside the flowerhead with their own body size to establish fitness for oviposition. Bierbaum and Bush (1990) showed that in two sibling *Rhagoletis* species, both visual and chemical cues play a role in selection of apple- and blueberry-fruits for oviposition. Miyake (1919) found that *B. tsuneonis* oviposits in the pulp of developing citrus fruit, so that it could only attack fruits with a thin skin. *B. minax* attacks a wide variety of citrus fruits (White and Elson-Harris 1992). In Bhutan, *B. minax* attacks fruits of the approximately fifteen citrus species or varieties (own observation). Yet, it was observed that lime and citron fruits were more intensely attacked than mandarin fruits, and that fruits in adjacent mandarin trees were sometimes attacked at different intensities. Thus, flies preferred some citrus species above others and some individual trees above others. Premature fruit drop by *B. minax* can be predicted by checking the ovipuncture density in a population (Section 5.3). An understanding of the mechanism through which flies select fruits to oviposit is needed to design a damage monitoring procedure. This study is meant to unveil such selection mechanisms.

Timing of maggot activity.
A second point of study concerned the timing of maggot activity. In the Tetradacus subgenus, there is a long interval between oviposition and maggot activity. *B. tsuneonis* flies oviposited in August, while infested oranges showed a growing reddish yellow spot early October, and dropped (Miyake 1919). *B. minax* oviposited in June-September, while no apparent maggot activity takes place until late September. It is not clear whether the rest period takes place as egg, or as early instar maggot (Section 5.1). This one to four months rest period before feeding on the fruits posed a question specific for the Tetradacus species: what mechanisms are involved in breaking the rest period? Is it a physiological change in the fruit that invokes feeding activity, or is it environmental variables such as seasonal influences? The presence of eggs as such did not invoke fruit drop, fruit drop happened only after initiation of maggot feeding. The fruit dropping process is probably similar to that in other tephritid citrus pests. When maggots feed on fruits, the latter produce ethylene that sets the early ripening process in motion. Thus, the fruit drop pattern of infested fruit is a function of the date maggots started sufficient feeding to induce early ripening. Characteristics of the fruit drop pattern may help in understanding the process of larvae starting to feed on a fruit population.

Materials and methods.
Observations on *B. minax* oviposition and infestation development were carried out in eastern Bhutan in citrus orchards at altitudes between 900 and 1,600 m asl., between 1992 and 1997. On-station type of observations such as colonisation of fruits were done in the Rongthong orchard (1,580 m asl.) in Tashigang district. The orchard was situated among forest and wetland, on the eastern slope of Drangme-Chu river valley. In high-altitude orchards, the occurrence of non-tephritid piercers such as the citrus green stink bug (*Rhynchocoris poseidon* Kirkaldy, Heteroptera: Pentatomidae) is minimal. The orchard consisted of about 60 plants of various citrus species, i.e. mandarin, lime, bitter orange and citron, while fruiting non-citrus trees were present as well. Mandarin trees were either planted densely (canopies touching), in small groups (three trees together, canopies touching) or single (typical well-developed oval-shaped canopy). Single lime trees had bushy and open canopies. Fruit drop was also recorded in the Lyenkhar orchard, situated at 1,250 m asl. on the same slope as Rongthong orchard.

In-village observations were carried out in ten villages of Pemagatshel district, viz. villages in Dungmin, Chongshing and Khar municipalities, where an on-going citrus IPM programme was carried out.

Colonisation of the fruit population.
The colonisation process was observed in Rongthong orchard in summer 1997. During the oviposition season, fruit colonisation was observed in a single lime and in a mandarin tree simultaneously. At the end of the season and after fruit drop, three tree groups were examined for the distribution of ovipunctures within the canopies. Ovipuncture densities of individual trees (mandarin tree types) and of different orchards within villages were examined. Next, the

distribution of ovipunctures over a number of large samples was examined.

Samples were taken as follows. Fruits were sampled randomly from the population to be examined. Samples consisted of 50 fruits for every observation. For observation on the fruit colonisation process, samples were taken between June 23 and August 4, every week, from the upper and lower canopy separately (for mandarin) or from all over the tree (lime). At the end of the oviposition season (early September), as well as after the fruit dropping period (late November), mandarin samples were taken from various parts of the canopy (i.e. the upper, outer-side, lower and inner canopy) separately. This procedure was carried out in the single fully-grown tree under study, but also in a group of three isolated trees with touching canopies and in six densely planted trees.

Fruits were checked through a standard procedure. The diameter of each fruit was measured with vernier callipers. With a sharp knife, the fruit was superficially peeled through the exocarp-albedo (white layer of the peel), where ovipunctures showed as dark spots. Superficial and deep ovipunctures were all taken into account.

Variables recorded for individual fruits included: date of collection, tree species (mandarin, lime), tree type (dense-open canopy), fruit position (upper, lower, outer, inner canopy), fruit size and number of ovipunctures. The effects of different variables and factors on "the number of ovipunctures per fruit" were analysed through ANOVA. "Sampling date" and "fruit position" were entered as main factors, while "fruit size" was entered as a variable. Only main effects were entered into the model. Both the contributions of individual variables to the Sum of Squares and the two-sided significance of differences were calculated.

It was checked whether oviposition took place evenly over villages. During a three-year citrus IPM programme samples were taken in ten participating villages. Mandarin fruit populations from different patches of trees within orchards or villages were examined for puncture density. Puncture density of fruit populations from the same village were paired and tested for significant differences.

The Poisson distribution describes the expected distribution of ovipunctures over fruit if flies oviposit randomly on developing fruits. But if flies mark fruits with an oviposition discouraging quality, one would expect that in highly infested samples the ovipuncture distribution is overdispersed, i.e. the coefficient of dispersion (CD) < 1. Similarly in case of clustering effects, the CD would be > 1. Examining different samples allows for testing whether ovipunctures on fruits are distributed following a normal Poisson distribution or not. For this, the following procedure was followed. Sample data from villages that had participated in a three-year citrus IPM programme were available. Samples with $n >= 100$ from villages situated in high altitudes (>1300 m asl.) or on north-facing slopes were selected. Data of fruits of over 11 mm were considered. The coefficient of dispersion (CD) was plotted as a function of the puncture density for each sample. But, as ovipuncture density was higher on bigger fruits, individual samples consisted as it were of merged samples of different size classes. It was expected that in most samples clustering of ovipunctures would take place because of the fly's preference for bigger fruits, unless punctured fruits became less attractive in one way or another. When samples were split up in size classes they became too small to identify dispersion characteristics. To still get an initial idea on the ovipuncture dispersion within size classes, the following procedure was followed. Samples with on average between 1.5 and 1.9 ovipuncture per fruit were selected and merged, and fruits were classified according to size. The CD of the ovipuncture distribution was calculated for each size class.

Timing of maggot activity.
In Rongthong and Lyenkhar orchards, six well bearing mandarin trees and one lime tree were selected. From the last week of September until mid December, from below each tree, fruits were collected and counted once or twice a week. Observations were carried out over four subsequent years, i.e. 1994-1997. The median of fruit drop (i.e. the date on which 50% of the total number of dropped fruits had dropped) was established through interpolation between the two nearest observation dates, for mandarin and lime separately.

Results.

Colonisation of the fruit population.
Sampling date, fruit size, position of fruit in the tree and the ovipuncture density of the respective fruit populations were all interrelated. It appeared difficult to select fruits "randomly" with respect to size, so that the fruit size in subsequent samples sometimes did not properly reflect the fruit size in the in-tree population. Oviposition in developing mandarin fruits started late June (Figure 12a and b), which was 2-3 weeks later than usual as temperatures in the 1997 spring were exceptionally low. Flies oviposited only in fruits of over 11-mm diameter, so that during the early oviposition season only the larger fruits were attacked, while later the entire population was prone to ovipositing females. Fruits in the upper canopy were more intensely punctured than fruits in the lower canopy. Most effects occurred simultaneously. Fruits increased in size during the oviposition season and fruits were punctured more densely later. Late in the oviposition season, fruits were bigger in the upper canopy than in the lower canopy and fruits were punctured more intensely in the upper canopy. Analysis of the data showed that high ovipuncture densities were associated with the size of individual fruits (Table 7); the effect of fruit size to the mean square is much higher than the effect of both other factors together. The effect of "sampling date" was still highly significant, but the effect of "position in tree" was not. Possibly, the effect of "fruit position" and "sampling date" (Table 7) acted mainly through the bigger size of fruits in the upper canopy and during the later oviposition season respectively.

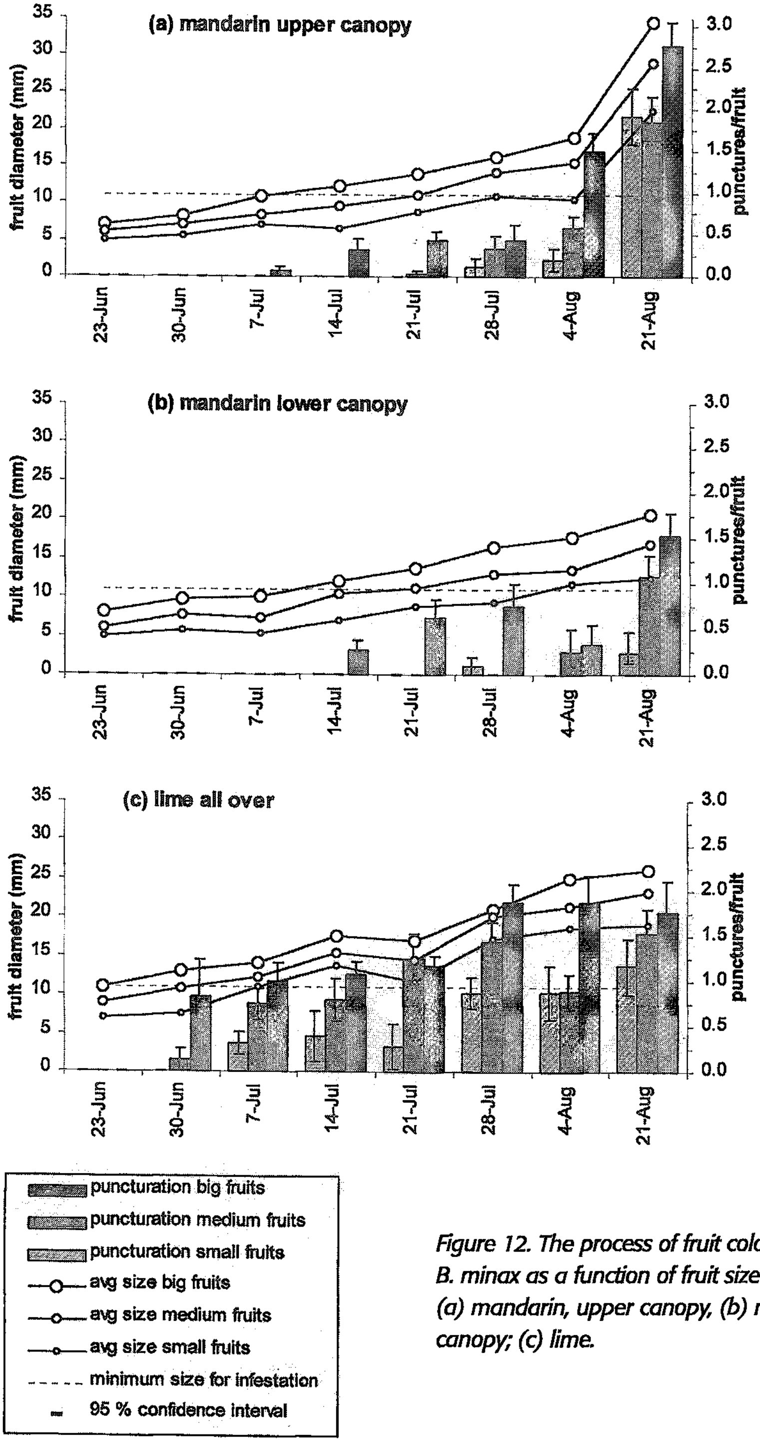


Figure 12. The process of fruit colonisation by B. minax as a function of fruit size and time in (a) mandarin, upper canopy, (b) mandarin, lower canopy; (c) lime.

Puncture density within canopies.

Puncture density within canopies of all three examined tree groups differed most between the upper and lower canopy (Table 7), while the puncture densities in the inner and outer canopies had intermediate values. In the single exposed tree, the outer canopy had infestation levels similar to the upper canopy; in densely planted trees, the outer canopy had punctures similar to the inner and lower canopy. Fruits were relatively bigger in sun-exposed parts of the canopy. The preference of flies for fruits in sun-exposed parts of the canopy is possibly caused by the bigger size of those fruits.

Source	Sum of Squares	df	Mean Square	F	significance (p)
Model	214.8 (R2 =0.615)	8	26.8	107.1	0.00
Intercept	25.9	1	25.9	103.4	0.00
upper-lower canopy	0.2	1	0.23	0.9	0.34
fruit size	61.7	1	61.7	246.1	0.00
date of sampling	6.9	6	1.2	4.6	0.00
Error	134.7	537	0.25		
Total	425	546			
Corrected Total	349.5	545			

Table 7. Factors determining the ovipuncture density in fruits of a single, dense-canopy mandarin tree in Rongthong orchard, analysed through Simple-Factorial ANOVA. For further explanation, see text.

The medium and highly infested samples examined for distribution of ovipunctures showed a slight overdispersion effect (Figure 13a); the coefficient of dispersion was significantly lower than zero. The different fruit size classes of heavily infested samples did not show a trend towards overdispersion in the bigger size classes (Figure 13b).

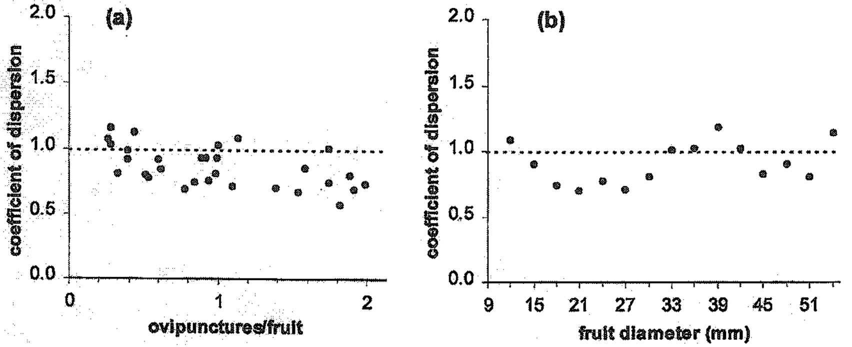


Figure 13a and b. The distribution of ovipunctures over (a) a set of 32 mandarin samples (with n>=100), and (b) fruit size classes of heavily infested samples (>1 ovipuncture/fruit), from ten different villages collected over three years. A coefficient of dispersion <1 indicates an overdispersed distribution.

Open canopy mandarin trees showed lower infestation levels than dense canopy trees (0.24 ± 0.52 and 1.10 ± 0.91 punctures per fruit, $p<0.001$), even if fruit size was taken into the model as well (Table 8). Apparently, flies preferred dense canopy trees for oviposition.

	single dense canopy tree		*densely planted dense canopy trees*		*group of three dense canopy trees*	
canopy part	*punctures per fruit*	*% fruit punctured*	*punctures per fruit*	*% fruit punctured*	*punctures per fruit*	*% fruit punctured*
upper	2.2 ± 1.2^{a}	80 %	1.6 ± 1.2^{a}	82 %	1.4 ± 1.0^{a}	78 %
outer	1.6 ± 1.2^{b}	65 %	$.5 \pm .61^{b}$	38 %	1.3 ± 1.0^{a}	63 %
inner	$.95 \pm .99^{c}$	48 %	$.3 \pm .55^{b}$	27 %	$1.2 \pm .9^{a}$	45 %
lower	$.93 \pm .94^{c}$	53 %	$.4 \pm .62^{b}$	28 %	$.65 \pm 1.0^{b}$	28 %

Figures with a different superscript were significantly different with the LSD-test at p=0.05.

Table 8. Puncture density on fruits sampled from different parts of three mandarin tree groups' canopies.

Comparison of ovipuncture density of sample pairs taken from within one village or orchard shows that ovipuncture density often differs significantly between samples (Figure 14). Double samples were taken as standard procedure if an uneven distribution of puncture density was found within villages, so that non-matching pairs are somewhat over-represented in the figure. The size of fruits was not always appropriately measured and the cause of the uneven distribution of ovipunctures within villages remains unknown.

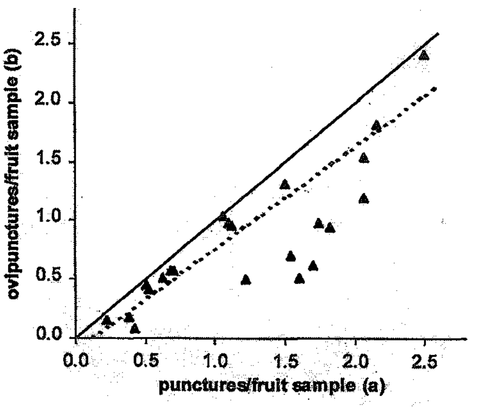


Figure 14. Comparison of puncture density of 23 pairs of samples taken from one village or orchard. The closed line indicates the sample (a) = sample (b)-line, the dotted line indicates the 95% confidence interval for H0 that the samples are from the same population.

In the single lime tree under study, it appeared difficult to collect random fruit samples, and observed sizes and infestation levels were somewhat irregular. Yet, the data showed some clear trends. In the early oviposition season, lime fruits were bigger than mandarin fruits, and oviposition in lime started two weeks earlier than in mandarin (Figure 12). During the period that lime fruits were bigger than mandarin fruits, they were more intensely punctured. Infestation levels of samples taken after the first month of oviposition were more or less stable.

Timing of maggot activity.

The fruit drop pattern was remarkably uniform in all four years. Late September few fruits dropped, drop boomed in the second week of October and went on until late November. The median of mandarin fruit drop varied from 14 October in 1996 to 21 October in 1995 and 1997. The median of lime fruit drop fell in all years on October 16 or 17 (Figure 15).
In Lyenkhar orchard (that was situated 330 m lower than Rongthong orchard), mandarin fruit dropped later than in Rongthong. The average median of fruit drop over 1994-97 was 26 October, versus 18 October in Rongthong (difference just not significant with the 2-sided paired samples t-test, $p = 0.089$). For lime, the average median of fruit drop was significantly later in the low altitude orchard ($p = 0.015$) and was October 23 in Lyenkhar and October 16 in Rongthong.

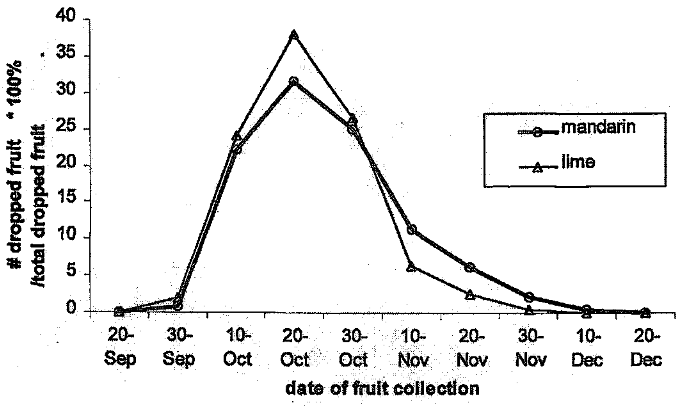


Figure 15. Fruit drop pattern of mandarin and lime in Rongthong orchard; average of 1994-1997 fruit dropping seasons.

Discussion.

Colonisation of the fruit population.

Colonisation of fruits by *B. minax* can best be described by following the serial "decision"-making by the fly, i.e. [whether to enter a tree], whether to land on fruit, whether to oviposit-bore, whether to deposit an egg, whether to oviposit another egg, whether to lay additional clutches on the same fruit, when to leave the fruit, when to leave the tree (Papaj et al. 1989a).

B. minax female flies dispersed at least 1 km over bushy areas where citrus trees are sparse (Section 6.1). In that area, mimic fruit traps were placed in solitary trees with and without fruits; only in the naturally fruiting trees flies were caught. Thus, probably flies enter trees if there is a considerable population of fruits fit for oviposition. This study shows that in adjacent trees during the early oviposition season, *B. minax* prefers particular citrus species in relation to other species for the bigger size of their fruits. This is in line with high visual attraction to mimic fruit traps when they are bigger than developing fruits (Section 6.1).

I am not aware of any study on the fruit colonisation process by *B. minax*. A comparison of *B. minax* with other tephritid citrus attackers is not justified, because it attacks citrus fruits much earlier in the season than other tephritid pests do. The data presented in this paper suggest that fruit size is responsible for most of the differences in fruit puncture densities, both within and between fruit populations serving as host for the same fly population. Ovipuncture density increased most when fruits became larger than approximately 15 mm, when they were clearly fit for oviposition. Most other differences in the puncture density of fruit populations seemed to be derived from this one factor. For example, mandarin fruits grew throughout the oviposition season and got more intensely punctured towards the end of the season. Fruits of sun-exposed parts (i.e. upper and outside parts) of the tree canopies were bigger than fruits in shaded parts of the canopy, and were more intensely punctured. In the early oviposition season, lime fruits were bigger, and they were punctured earlier (and more intensely) than mandarin fruits, while year-round fruiting citron was attacked weeks earlier than lime. Within villages, different puncture densities were observed between fruit populations from particular trees or orchards. Observations on fruit sizes were not done accurately, but differences in fruit size between trees and orchards certainly occur as mandarin trees in Bhutan are ungrafted and display some genetic variation. This mechanism is possibly most important when fruits are about to reach sizes fit for oviposition. In that period, all gravid females seek for fruits to deposit their eggs and the first fit fruits they find are those in early-developing trees or in slightly warmer patches. Surveys within villages should reveal whether the size-puncture density relationship accounts for this phenomenon, or whether other factors (such as proximity to forest or exposure to sun) play a role.

The higher puncture density of fruits in dense canopy trees compared to fruits in open trees could not be explained by differences in fruit sizes. Possibly, flies preferred dense canopy trees because of the better opportunities for shelter, as was observed in other tephritid species such as *Anastrepha obliqua* (Aluja and Birke 1993).

Monophagous, univoltine Tephritids such as most *Rhagoletis* species often mark fruits after oviposition, discouraging later arriving females to also oviposit in the same fruit (first reported by Prokopy 1972). However, few *Bactrocera spp.* mark fruits after oviposition. In *B. minax*, no typical marking behaviour (i.e. dragging of the ovipositor after oviposition) was observed. Marking fruits with the usual host marking pheromones would have little effect anyway, as such substances are mostly active in terms of weeks under dry conditions (e.g., Averill and Prokopy 1987, Prokopy *et al.* 1977, Prokopy 1972), while the oviposition season of B. minax is as long as three months during peak monsoon.

In other tephritid species such as *B. tryoni and B. jarvisi*, repeated oviposition was discouraged by repelling effects of maggots in developing fruits (Fitt 1984). Again, this mechanism is unlikely to be employed in *B. minax*, as the oviposition- and maggot-phases of the fly do not overlap. Thus, it is not surprising that in *B. minax* both repetitive and single puncturing the same fruit occurred frequently. This resulted in the hypothesis that ovipuncturing occurred irrespective of previous exposure if fruits were all of the same size. However, when fruit of different sizes is present, and taking into account that larger fruit is preferred for oviposition, one would expect a clustering of oviposition in larger fruit. Within size classes, ovipuncture distribution would then be Poisson distributed. Analysis of large fruit samples from villages however, showed that in most samples distribution of punctures was overdispersed rather than clustered (Figure 13a). Thus, already punctured fruits had a lower chance to get another ovipuncture than untouched fruits, though this effect was much weaker than in pheromone-marked fruits as reported in literature (e.g. Prokopy 1972, Prokopy *et al.* 1977, Fitt 1984). If flies systematically avoid already punctured fruits, one would expect that a possible overdispersion effect would possibly be more outspoken in the bigger fruits as they are more heavily punctured. This appeared not to be the case (Figure 13b), there was no clear trend in ovipuncture dispersion as a function of fruit size. Thus, if avoidance of already punctured fruits takes place, it is a slight effect that is less pronounced in bigger fruits.

Literature also reports on slightly overdispersed ovipunctures and eggs. Possible explanations are the following ones. Fitt (1984) suggested that bacteria introduced by *Bactrocera spp.* into the fruit during oviposition may release chemical cues. In *B. minax* however, ovipunctures were, as far as we observed, sterile, apart from the inserted eggs. Yet, the damage by the ovipositor may result in release of wound-associated chemicals. However, we often observed ovipuncturing activity of subsequent flies within a few cm^2 within hours. Therefore, wound exudates are not likely to be an oviposition deterrent either. In some Tephritids the odour of fruit wounds stimulate rather than deter oviposition (e.g., Papaj *et al.* 1989a). In *Cetatitis capitata* Wiedemann in caged host trees, flies rejected infested fruits, even in absence of oviposition-deterring pheromones (Papaj *et al.* 1989a). It was suggested that in-fruit marking, or chemical or physical changes in the fruit will bring about such changes. In *B. minax*, after infestation in some part of the fruit, callus tissue is formed, possibly resulting in the fly not depositing eggs after detecting such structures. The suggested mechanism would explain the lower chance of infestation of additional ovipunctures, as found earlier (Section 5.3), though the smaller chance of already punctured fruits to become ovipunctured is not explained in this way.

Another hypothesis to explain the ovipuncture distribution pattern is based on the fruit size development combined with learning capabilities of the fly. Many Tephritids have been found to be highly sensitive to fruit size, and can "remember" the size of fruit they successfully oviposited in (Prokopy *et al.* 1990, Papaj *et al.* 1989 (b)). In *B. minax* in Bhutan, the first host that is available in substantial numbers is fruit just fit for oviposition (fruit up to 20 mm), and flies may develop a preference for such fruits. In a developing fruit population, such fruits are continuously available and have relatively little chance to be already punctured. In this way, each fruit goes through the most attractive size stage for oviposition by *B. minax*. Figure 12 shows this pattern; the biggest increase in puncture density in fruits was when they were between 12 and 20 mm diameter. By this hypothesis, the attractiveness of a few bigger citrus fruits (such as citron) in the early oviposition season is not contradicting the later preference of flies for smaller fruits. If this hypothesis would hold, *B. minax* populations have a preference for fruit sizes according to the local dominant citrus species.

Finally, the possibility that the overdispersion effect reported here is an artefact should not be ruled out. Possibly, after one ovipuncture was detected on a particular fruit, further examination was not done sufficiently carefully by fruit examiners.

The apparent irrelevance of repelling effects after a first oviposition is important for the possible employment of catch crops in IPM strategies. Strong repellent effects after oviposition may deter subsequent visiting females. The weak or absent repellent effects however, show that trap cropping is a realistic option in an IPM strategy for *B. minax* (J. van Lenteren, pers. comm.).

Timing of maggot activity.

Unlike most other tephritid citrus pests, the time of hatching in the Tetradacus subgenus seems not to be determined by the time of oviposition. Fruit drop by *B. minax* (and *B. tsuneonis*) occurs in all infested areas and in all citrus species in October and November (Nath 1973, Yang et al. 1994, Miyake 1919) while eggs are deposited a few months earlier. Fruit drop in Bhutan showed a similar timing. In the years 1994-1997 the median of fruit drop hardly differed for more than a week in mandarin and lime, both in mid- and high altitude orchards. Within this small variation, in high altitude orchards, fruit drop occurred a few days earlier, both in mandarin and in lime. This, while the phenology of citrus took place about one month later than in mid-altitude orchards. Moreover, in multiple infested fruits, maggots from different clutches often showed different development stages, while within the same batch, larvae development was uniform. Thus, a causal relationship between physiological changes in the fruit and maggot development is unlikely. The time of hatching is more likely to be determined by the egg clutch than by the individual fruit, tree or orchard.

In other tephritid citrus pests, maggot-injured fruits produce ethylene that sets the early ripening process in motion, a mechanism that probably occurs in the B. minax maggot-fruit interaction as well. In late September-October, within trees, individual fruits continuously enter the early ripening process, and eventually drop. The average development stage of maggots in dropped fruits increased over the dropping season, though once, during a cold spell late October, the size of maggots in dropped fruits was smaller than during the preceding weeks (Section 5.3). Apparently, in an infested fruit population, the break of the rest period occurs over a prolonged period, which was also observed if two batches of maggots in one fruit had different development stages. Once maggots were big enough to be spotted, early droppers contained on average more maggots per fruit than late droppers did. Yet, both in the early and late fruit dropping season, individual highly infested fruits were found. The breaking of the rest period is apparently not exclusively dependent on the number of eggs in individual fruits.

The uniform timing of fruit drop over the years suggests that the process is initiated through a constant factor such as day length or the end of the monsoon (usually in the last days of September). Still, this does not explain why fruit drop occurs earlier in high- than in mid-altitude orchards. Maybe a certain minimum temperature is needed to break the egg rest period. It is concluded that the egg rest period breaking mechanism is not fully understood, even if its timing is accurately known.

Concluding remarks.

The research presented in this article was carried out to support a citrus IPM programme in a few villages in Pemagatshel, eastern Bhutan. The fruit colonisation process needed to be understood to sample fruits for reliable infestation level data. After a fly activity monitoring procedure was developed, it was successfully used by farmers to evaluate the effectiveness of their fly control activities.

5.3. Quantification of oviposition, mortality and damage.

Abstract.

Bactrocera minax is a tephritid pest of citrus. It oviposits early in the fruit development season, maggots develop one month before fruit ripens and induce fruit drop. The article presents quantitative data of oviposition and mortality of the fly in fruit. In mandarin, ovipunctures with clutches contained 6.7 ± 3.1 eggs. Multiple punctured fruits contained relatively fewer eggs per puncture than single punctured fruit. Mortality mechanisms accounted for 43% of in-fruit mortality in a high-altitude orchard. Dropped fruit of averagely 43 g with maggots produced 5.5 ± 4.0 pupae. In lime, clutches contained similar egg numbers, fruits were more intensely punctured, and dropped fruits of averagely 38 g yielded 8.3 pupae. Ovipunctures in attacked fruit populations allowed for pre-drop quantification of oviposition activity. Not all punctured fruits dropped; comparison of in-tree pre-drop and post-drop puncture density suggested that 76% of ovipunctures contained viable clutches. In high-altitude orchards puncture density of fruit just before fruit drop appeared a reliable measure for damage, more so if post-drop density was established as well. In lower-altitude orchards, non-tephritid fruit puncturing agents blurred the evidence of oviposition activity. Procedures for quantifying B. minax damage are discussed in the paper.

Introduction.

The chinese citrus fly or Bactrocera minax Enderlein is a tephritid fly that causes heavy fruit drop in mid- and high altitude mandarin orchards in the eastern Himalayas. This article reports on the relative importance of various host fruit resistance mechanisms against B. minax, and on a fast method to quantify damage by the fly.

Oviposition and in-fruit mortality.

Most tephritid citrus pests lay many more eggs per puncture than will develop into maggots. For example, in *Ceratitis capitata* Wiedemann in Chinese oranges, repeated oviposition of 6-egg batches added to 7-26 eggs per puncture (Rössler and Greany 1990), up to 153 eggs per cavity were observed (Back and Pemberton 1915). The egg cavity walls harden into a corky substance and point out of the developing fruit, resulting in massive egg mortality, e.g., in spanish lemons, only 3.3% of eggs survived the in-fruit period (Laborda *et al.* 1990). Most tephritid citrus pest such as *Anastrepha ssp.* and the *Ceratitis*-group make ovipunctures and place eggs in the flavedo, the outer layer of the peel. There, high mortality occurs due to toxicity of local essential oils in the skin (Greany *et al.* 1983). Greany (1989) reviewed host resistance against tephritid infestations in citrus. Susceptibility varied according to the fly species (through the oviposition behaviour), the degree of peel senescence (through the oil content of the peel), and the type of fruit (through the structure of the peel). These factors together determined the outcome of a given pest-fruit interaction.

B. minax does not oviposit in the peel, but in the pulp of developing fruit (Wang and Lue 1995, Section 5.1). So, the usual resistance mechanisms of citrus spp. against tephritid attackers do not affect *B. minax.* The other Tetradacus species, *B. tsuneonis,* also oviposits in pulp and laid 3.6 ± 1.4 (SD) eggs per ovipuncture, while up to three ovipunctures per fruit were observed. Thus, *B. tsuneonis* laid considerably fewer eggs per ovipuncture and per fruit than the *Ceratitis* (and *Anastrepha*) species of tephritid citrus pests. Yet, also in *B. tsuneonis* a considerable mortality occurred in the fruit. One larva, or at most two, emerged from one fruit, while the fly deposited up to 11 eggs per fruit (Miyake 1919). Thus, in most tephritid citrus pests egg- or larval mortality account for vast mortality of eggs. *In B. minax,* little is known on the role of egg- and larval mortality.

Several mortality mechanisms for *B. minax* in mandarin fruits occur, such as callus formation in the pulp after infestation, collapse and hardening of infested segments, perish of all maggots in over-infested fruits, heating of fruit by the sun, cow- and rat-feeding on dropped infested fruits and mummification of dropped fruits before maggots could escape (Section 5.1). This article reports on the relative importance of the various mechanisms.

Ovipunctures and fruit drop.
B. minax makes ovipunctures to channel its eggs into fruits. These ovipunctures can be detected throughout the oviposition season (Section 5.2) and can be used to quantify *B. minax* activity. Yet, the relation between fruits featuring ovipunctures and eventual fruit drop has not yet been established. Flies probably do not oviposit on all fruits even if they made an ovipuncture; and resistance mechanisms may make the pest insects die. Thus, there is a need to study the relationship between the density of punctures on fruit in a population, the puncture density in dropped fruits, and the puncture density in fruits that did not drop.

Why do not all fruits drop?
We wondered why fruit fly never induced complete losses. Fruit setting usually varied up to 300% between years. One year's fruit fly abundance is dependent on fly emergence from last year's crop. Thus, one would expect that under poor fruit setting conditions the fly population would attack almost all fruits. To our experience, this never occurred by attack of *B. minax* alone. Complete losses only occurred in situations where the green citrus stink bug *Rhynchocoris poseidon* Kirkaldy and *B. minax* attacked citrus concurrently.

In literature, additional mechanisms that may play a role in regulating the fraction of fruits attacked are mentioned. Host marking or other oviposition regulatory mechanisms, or specific fly behaviour are mentioned. For example, Zwölfer and Völkel (1997) showed that the tephritid gallformer *Urophora cardui* exploited only a small portion of the available host plants while predation by natural enemies played no role of importance. They suggested that possibly the fly inherited specific behaviour patterns originating from the species' evolutionary history. The situation in *B. minax* appeared similar. Possible explanations must lay in the female fly's choice for fruits, or resistance mechanisms of the host.

Monitoring B. minax activity.
Eastern Bhutanese farmers say that fruit losses vary considerably from year to year. It was difficult to carry out a precise quantification of *B. minax* damage, as dropped fruits rolled down the slope or into bushes where they were difficult to find. Moreover, the fruit drop period lasted two full months, and both the quantity of fruits dropped on the ground, and of fruits remaining in the tree were difficult to estimate, in particular when in-tree fruits were still green. Even in experimental orchards, it appeared difficult to reliably quantify fruit drop, so we needed a reliable fruit drop estimation method.

Several authors proposed IPM strategies to keep *B. minax* under economic threshold levels (e.g. Wang and Lue 1995, Yang et al. 1994, Section 6.1). Quantification of reproduction and mortality factors would help in evaluating effectiveness of various IPM measures. In this paper, the various ways we used to estimate *B. minax* damage will be discussed, i.e. pre-drop establishment of ovipuncture density, and counting dropped fruits and fruit remaining in the tree.

Life history characteristics of B. minax.
The two Tetradacus species *B. minax* and *B. tsuneonis* are the only univoltine tephritid citrus

pests, and the only ones that exclusively multiply on citrus. Other (multivoltine) tephritid citrus pests are usually generalists that attack citrus for only part of their life cycles in a year, usually when citrus fruit ripens (Greany *et al.,* 1983). Therefore, the Tetradacus species appear to occupy a specific niche in the ecology of citrus that should be reflected in their life history.

Materials and methods.

Sites of study.

Observations on *B. minax* oviposition and infestation development were done between 1992 and 1997 in eastern Bhutan in citrus orchards at altitudes between 900 and 1,600 m asl. On-station type of observations such as colonisation of fruits were done in two orchards in Tashigang district, viz. in Rongthong orchard (1,580 m asl.) and nearby Lyenkhar orchard (1,250 m asl.), representing high- and mid-altitude orchards respectively. Both orchards consisted of about 60 plants of various citrus species, i.e. mandarin, lime, bitter orange and citron.

In-village type of observations were done in ten villages of Pemagatshel district, viz. villages in Dungmin, Chongshing and Khar municipalities, where an on-going citrus IPM programme was carried out.

Oviposition and in-fruit mortality.

During the adult fly season, a protein bait monitoring trap (see Section 6.1) was set up and checked weekly. Female *B. minax* flies were collected and kept in alcohol. The flies were dissected and examined for the presence of semi- and fully matured eggs.

The clutch size of *B. minax* ovipunctures was established as follows. Eggs in developing fruits could only be detected when mandarin fruits were still small, in the early oviposition season. On 14 and 22 July 1996, when fruits were between 13 and 17-mm diameter, fruits were collected from various trees in Rongthong orchard. In total 65 fruits with ovipunctures were examined. The outside of the ovipuncture (peel) and callus spot inside the underlying segment were cut off, so that individual vesicles were visible. These cells were gently poked out and the segment was checked for eggs. All punctures in one fruit were examined, and the number of live eggs was counted. Similarly, 22 ovipunctures from 11 lime fruits were checked for eggs, while some citron- and orange fruits were examined as well.

For establishing the number of pupae per fruit, during the fruit dropping seasons of 1994-1997, every week 40 dropped mandarin fruits were collected from Rongthong orchard. Twenty fruits were dissected and checked for maggots. Twenty fruits were individually kept in a glass on humid sawdust. Glasses were checked after a few weeks for pupae. Samples with exceptionally low pupae numbers (such as during a cold spell in the late 1997-dropping season when maggots development stood still) were discarded. The number of maggots per fruit was determined by calculating the average number of pupae per fruit per sample, and by calculating a season-average weighed for the dropping intensity of the time of sampling. In 1994, the same procedure was carried out in four orchards with different infestation levels. Samples of the main dropping period were compared for number of maggots.

In 1997, pupae from mandarin and lime fruits collected on a particular date were weighed in bulk. The temporal intensity of fruit drop was reflected in weighing individual samples for calculation of the distribution of number of maggots per dropped fruit all over the fruit dropping season.

The in-fruit mortality of posited eggs was calculated by comparing the input of eggs into-, and the output of pupae from fruit populations. Figures from Rongthong orchard were used. Pre- and post-drop puncture density data were available. Variables such as the number of eggs per infested fruit and pupae production per dropped fruit were taken from the various observations discussed earlier. The same was done for lime.

Ovipunctures and fruit drop.

If fruit drop is caused by *B. minax* oviposition, then dropped fruits should be punctured. Ovipunctures can be considered as "marks", and if dropped fruits are predominantly punctured, a comparison of in-tree pre- and post-drop puncture density will allow for calculation of fruit drop percentages. Moreover, in the *B. minax* fruit drop season early droppers contain on average more maggots per fruit than late droppers do. One would expect that more intensely punctured fruits contain more maggots and drop earlier. These hypotheses were tested through the following observations.

Ovipunctures in dropped fruit were established as follows. From late July to late September, every two weeks fifty dropped fruits were collected from Rongthong orchard and checked for ovipunctures. When fruit drop intensified in late September to late November, the procedure was carried out every week. For each sample the 95% confidence interval for puncture density and the percentage of fruit punctured was calculated.

Pre- and post-drop puncture density in-tree was established as follows. The observations were carried out in orchards, in which dropped fruit was heavily punctured (of fruit dropped in October over 90% contained ovipunctures). In various sites within Rongthong orchard, and in eight experimental villages, fifty fruits were collected from trees before and after the main fruit dropping period (in September and December respectively). Fruits were checked for ovipunctures by cutting through the albedo (white layer) of the skin (see Section 5.2). Fruit drop was calculated through comparing pre- and post-drop puncture intensity through the following formula:

Formula 1: $p(drop) = p(pre\text{-}drop) - p(post\text{-}drop)*(1-p(pre\text{-}drop)/(1-p(post\text{-}drop)))$

in which p(drop) is the calculated fraction of fruit that dropped, p(pre-drop) is the fraction of in-tree fruits punctured before the fruit drop period, and p(post-drop) is the fraction of in-tree fruits punctured after the fruit drop period. The fraction of punctured fruits was (slightly) adjusted in all samples for the absence of ovipunctures in some dropped fruits, by multiplying it with 1/0.96.

Another way to establish fruit drop percentages is the following one. Eggs were found in 61% of the checked ovipunctures. It was assumed that this fraction of ovipunctures was infested, and that all fruits with infested ovipunctures indeed drop. In that case, a fruit with one ovipuncture has a 61% ($=1-(1-0.61)^1$) chance to drop, a fruit with two ovipunctures has a chance of $1-(1-0.61)^2$ to drop, etc. If the distribution of ovipunctures in a certain fruit population is known, the fraction of fruit that is going to drop can be calculated. This can be done through multiplying each fraction of single- and multiple-punctured fruits with the respective chance fruits contain at least one ovipuncture with eggs, as spelled out in the following equation:

Formula 2: $p(drop) = 1 - p(0) - p(1)*(1-p(inf))^1 \ldots - p(n)*(1-p(inf))^n$

in which p(drop) is the fraction of in-tree fruits that will drop, p(n) is the fraction of fruits with n ovipunctures, and p(inf) is the fraction of viable ovipunctures. Fruits with four or more ovipunctures were considered as having three ovipunctures. Puncture density and fruit drop pairs were calculated through employing Formula 1. The points yielded were compared with the model as described in Formula 2, using the previously found viability of ovipunctures of 61%. Assumptions are that flies choose and oviposit in a fruit randomly, i.e. fruit choice and oviposition take place irrespective of previous exposure (for a discussion see Section 5.2). Then, with Formula 2, a "best fit"- fraction of viable ovipunctures was calculated based on available measurements, to cross-check the earlier found fraction of ovipunctures with viable eggs.

For the quantification of fruit drop, observations were carried out four years in a row, in 1994-1997. In six mandarin trees of various orchards, during the dropping season, dropped fruits were collected and counted twice a week; the record of a few lime trees was kept as well. After the fruit drop season, the numbers of fruits that had remained in the tree were estimated and fruit drop percentages were calculated. In 1996-1997, the pre- and post-drop puncture densities of in-tree fruits were recorded through cutting through the albedo and counting the number of ovipunctures per fruit, as described earlier.

Results.

Oviposition and in-fruit mortality.

The results of examining female flies for eggs are presented in Table 9. Fly catches were irregular. The number of eggs per female increased until mid June. During the oviposition season, the number of eggs per female was constant 70 ± 22 (SD) per female. Egg numbers did not decrease in the late season. The highest number of eggs recorded was 127, in a fly caught on August 5.

For the establishment of the clutch size, in total 97 ovipunctures were checked on 65 fruits. The number of fruits with 1, 2, 3 and 4 ovipunctures was 43, 17, 4 and 1 respectively. In the fruit, the developing vesicles were hard and in form and colour they resembled fruit fly eggs, so that eggs were difficult to find, and maybe a few clutches were missed. Eggs were found in 61% of the ovipunctures. Not even once a solitary egg was found, while the maximum number of eggs in one ovipuncture was 23 in a dense clutch of a single punctured fruit. Usually, eggs were placed close together, in a few cases eggs were placed 1-2 mm apart or in two separate clutches. In infested punctures, the number of eggs found was 6.7 ± 3.1 (Figure 16); this number was equal in punctures of multiple or single punctured fruits. In infested fruits with 1, 2, 3 and 4 ovipunctures, the number of eggs was 6.6 ± 3.5 (SD)^{a}, 9.5 ± 4.7^{b}, 11.3 ± 8.3^{ab} and 24^{c} respectively (multiple comparison LSD-test, $p=0.05$).

The number of empty ovipunctures was higher in fruits with 2 and 3 ovipunctures than in fruits with 1 ovipuncture ($p=0.013$ and 0.051 respectively with the multiple comparison LSD test). Consequently, the number of eggs per fruit was not significantly different for fruits with 1, 2 and 3 ovipunctures (with the multiple comparison LSD-test). When taking into account the empty ovipunctures as well, in total 4.2 ± 4.1 eggs per ovipuncture were found. In fruits with 1, 2, 3, 4 punctures, 5.4 ± 4.1; 6.2 ± 6.0; 8.5 ± 8.9 and 24 eggs/fruit were laid. All over, in the period of checking, per fruit with 1-4 ovipunctures, 6.1 ± 5.4 eggs were detected (see Table 10).

In lime, the number of eggs per infested ovipuncture was 5.3 ± 2.2 eggs. In one 650-g citron with 17 ovipunctures, 85 maggots were counted (5.0 maggots per ovipuncture) and in one 120-g orange with four ovipunctures, 27 maggots were counted (6.8 maggots per ovipuncture). Apparently, the number of eggs per ovipuncture is quite constant.

The pupae production per infested fruit varied over the season. In the early fruit-dropping season, maggots were hardly visible and the number of maggots emerging from one fruit was systematically lower for fruits that were checked through dissection than for fruits kept on sawdust. When maggots became bigger, the number of maggots per fruit was similar for either checking method. In the late fruit dropping season maggots had already left most fruits and, as only intact fruits were examined, the sample was possibly biased towards the fruit fraction with low infestation-levels.

By late September, weight and size of mandarin and lime fruits were about the same (on average 30 g per fruit, diameter 35 mm). Limes yielded significantly more pupae than mandarins (tested with the independent samples t-test, $p<0.001$). Over the entire season, the average number of pupae was (excluding and including fruits without maggots respectively) 5.5 ± 4.0 or 4.2 ± 4.2 per mandarin fruit (weighing 43±8 g); and 8.3 ± 5.2 or 8.1 ± 5.3 per lime fruit (weighing 38±6 g) (Figure 17). The maximum number of pupae from single fruits was 27 for lime and 19 for mandarin. Both in mandarin and in lime, the number of maggots per dropped fruit decreased over the fruit dropping season. The average number of pupae per infested fruit decreased from 8.6 to 2.0 for mandarin and from 11.1 to 5.0 pupae for lime respectively between late September and early December (Figure 20). Incidentally, even late droppers contained high numbers of pupae. In the early drop samples of mandarin, fewer pupae emerged, in some (not included) samples of lime the same pattern was observed. The fraction of dropped fruits that did not yield pupae was 23% for mandarin and 3% for lime. The quality of issued pupae was better for mandarin, the average weight of the pupae was 40.5 mg versus 34.0 mg for pupae of lime, based on 400 and 700 pupae weighed in bulk respectively. The fewer maggots per fruit, the higher the average weight of pupae (Figure 17). At similar numbers of pupae per fruit, lime yielded heavier pupae than mandarin.

The number of maggots per infested fruit in orchards with different infestation levels is presented in Table 10. The table shows that the number of maggots per fruit is equal in low- and in high-infested orchards.

Examination of the mortality between oviposition and pupation gave the following results. In the early oviposition season, the number of eggs per infested mandarin fruit was 6.1 ± 5.4 (in a fruit population with averagely about one puncture per fruit). At the end of the oviposition season, trees varied in ovipuncture density and varying fractions of punctured fruits dropped. 73% of dropped fruits yielded pupae at 5.5 ± 4.0 pupae per fruit. These figures were applied in eleven pre- and post-drop puncture density observations in Rongthong orchard. It appeared that 57 ± 10% of oviposited eggs made it up to the pupal stage. Thus, in high-altitude mandarin orchards, under normal circumstances 43% of oviposited eggs die before they can turn into pupae.

date	May 3	May 19	June 9	June 24	June 30	July 13	Aug 5	Sep 12
n	4	8	2	4	1	3	8	2
eggs/ female	$3±3^{a}$	$3±6^{a}$	$28±32^{ab}$	$82±5^{b}$	68^{b}	$66±17^{b}$	$68±30^{b}$	$61±8^{b}$

Numbers with a different superscript were significantly different for the multiple comparison LSD-test at $p=0.05$.

Table 9. The number of eggs (±SD) per female B. minax. Flies were caught through protein baiting over the adult flying season in Dungmin village.

orchard	*Rongthong*	*Kharsa*	*Lyenkhar*	*Pam*
fruit drop	57%	23%	17%	<11%
n	92	81	74	15
maggots per infested fruit	$5.5 ± 3.1^{a}$	$6.5 ± 3.0^{a}$	$5.7 ± 2.8^{a}$	$6.1 ± 3.3^{a}$

The number of maggots per fruit in each orchard did not differ for the one-way ANOVA at $p=0.05$.

Table 10. The number of maggots (±SD) per infested fruit in orchards with different infestation levels. Only fruits with clearly visible maggots were counted.

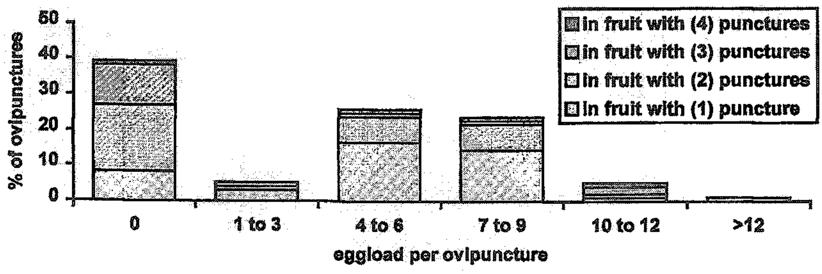


Figure 16. Distribution of the number of eggs per ovipuncture (n=97) in the early oviposition season of mandarin fruits with 1-4 ovipunctures.

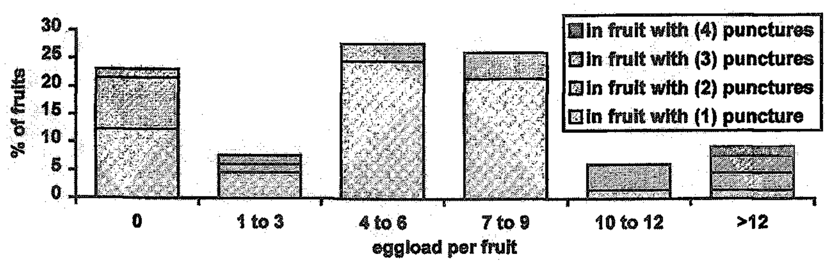


Figure 15. Distribution of the number of eggs per punctured fruit (n=65) in the early oviposition season of mandarin fruits with 1-4 ovipunctures.

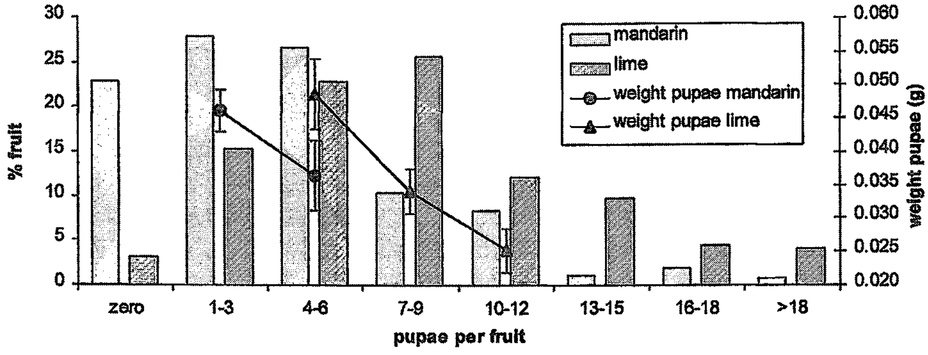


Figure 17. The frequency distribution of the numbers of B. minax pupae in dropped mandarin and lime fruits collected over the dropping season (samples weighed for dropping intensity)(bars), and the average weight of pupae from mandarin and lime separately (lines). Pupae were obtained by keeping dropped fruits on glass filled with sawdust.

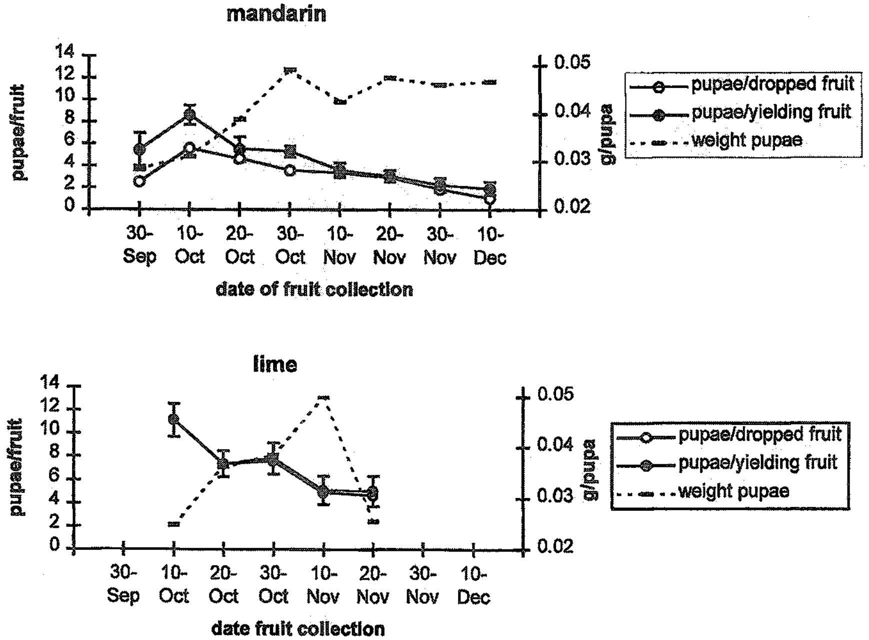


Figure 20a and b. The number of pupae per fruit and the average weight of B. minax pupae in dropped mandarin (a) and lime (b) fruits collected during the fruit dropping season. In the line with closed markers, fruits without maggots or pupae were excluded. The error bars indicate the 95% confidence interval of the average number of maggots per infested fruit

Ovipunctures and fruit drop.

The number of ovipunctures per dropped fruit hardly varied over the fruit dropping season. Ovipunctures Figure 18 shows that until mid September, a sizeable fraction of dropped fruits did not have ovipunctures. In fact, during this period, the ovipuncture density of dropped and in-tree fruit were not significantly different. Late September, when fruit drop intensified, puncture density of dropped fruit increased drastically. Between 92 and 100% of dropped fruits in samples contained ovipunctures; over the entire fruit dropping period, 96% of dropped fruits showed ovipunctures. Against expectation, puncture density was not clearly higher in early droppers than in late droppers; the slightly lower puncture density in late droppers may have been caused by the difficulty in detecting ovipunctures in over-ripe fruit.

Examination of pre- and post-drop puncture density in infested orchards gave the following results. Ovipunctures were found both in pre-drop- and in post-drop samples taken from trees. In a few low-altitude orchards post-drop puncture density was higher than pre-drop puncture density. Those samples were discarded, as apparently, punctures often did not originate from *B. minax* infestation. In mid-and high-altitude orchards, the infestation percentage of in-tree pre- and post-drop samples differed clearly. When applying Formula 1, the calculated fruit drop as a function of puncture density showed a clear trend (filled markers in Figure 19). Highly infested samples showed a higher fruit drop level than low-infested samples and the fraction of punctured fruits that indeed dropped increased with the puncture density.

Fruit drop figures thus obtained were compared with figures obtained through collecting and counting dropped fruits. There was a good correlation between puncture density and fruit drop in high-altitude orchards. In eleven double-measured trees, the average difference in calculated fruit drop fraction obtained by both methods of measuring was 7%, the correlation coefficient was 0.95, while both methods yielded practically the same values. In mid- and low altitude orchards, it appeared difficult to obtain reliable estimates of ovipuncture densities in citrus fruits.

Formula 2 was applied with the parameter "ovipuncture viability" valued 61% (Figure 19, lower line). This yielded an underestimation of fruit drop compared to values found when applying Formula 1 on pre- and post-drop sample pairs. The "best-fit" fraction of "ovipuncture viability" was 76%, confirming the notion that not all egg clutches were found in the checked ovipunctures, and that in-fruit mortality is not massive in *B. minax*.

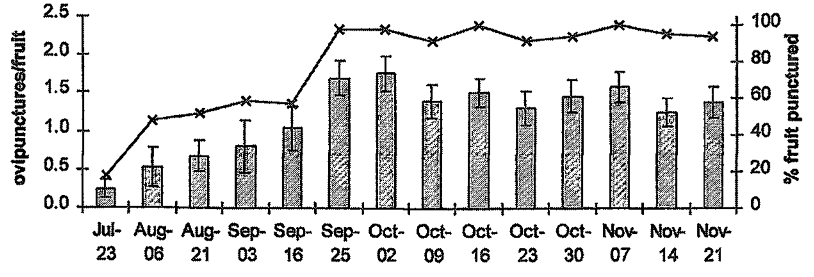


Figure 18. Ovipuncture density (bars) and percentage of fruit punctured (line) in dropped fruits collected during the oviposition and fruit dropping season. Until late September few fruits dropped, the bulk of fruits dropped in October and early November.

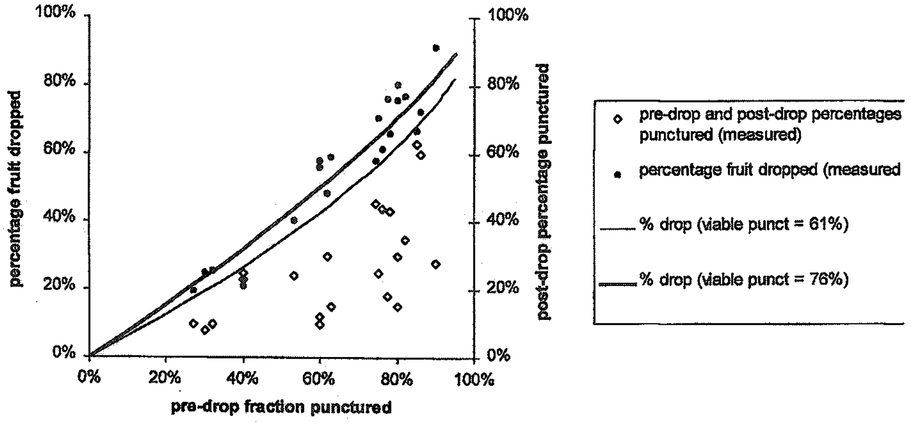


Figure 19. Pre-drop percentage of fruit punctured and the related post-drop percentage of fruit punctured (open dots) and fruit drop (closed dots). The measured (infestation of 61%) and calculated (infestation of 76%) trendline of the relation is inserted.

Discussion.

This study serves several goals goals. First, the oviposition and mortality of B. minax in mandarin fruits is quantified. By comparing the number of eggs that enter, and the number of maggots that leave fruit populations, in-fruit mortality and estimates on the vitality of ovipunctures can be quantified. The information is used to discuss the apparent limitation of the damage inflicted by the fly. Further, a fly activity monitoring method was developed to evaluate effectiveness of IPM methods.

Oviposition and in-fruit mortality.

Number of eggs per female. In literature, it is found that female *B. minax* produces over 100 eggs (Zhang 1989) (who based himself on dissection of single females), or 3 to 8 batches of 80-90 eggs (Wang and Lue 1995). Findings in Bhutan were consistent with these figures. In flies caught during the emergence period, the number of eggs per female was low. Egg numbers increased until mid June, when mandarin fruits became fit for oviposition. Possibly, egg production was stimulated by the presence of these fruits, as was observed in *Rhagoletis* (Papaj, pers. comm.). The number of eggs in caught females was around 70 during the entire oviposition season. Probably, flies kept on producing eggs, as until the end of the oviposition season the number of eggs per female was stable. Therefore, the egg production per female could not be estimated.

Clutch size. In our observations, all *B. minax* ovipunctures contained more than one egg, just as found in *B. tsuneonis* (Miyake 1919). Repetitive ovipositor insertion in the same puncture was never observed, flies always made new punctures even if punctures of their predecessors were made only hours before. In high- and low-level infested orchards, there was no difference in the number of maggots per infested fruit. These observations supported the hypothesis that clutches were placed in one oviposition action. Our observations on clutch sizes were inconsistent with reports that *B. minax* laid one or rarely two eggs per puncture (Wang and Lue 1995). Maybe the fly behaves different in China. The clutch size of single B. minax ovipunctures was 6.7 $\pm$ 3.1 eggs, and was the same in mandarin, lime, citron and orange. Here, *B. minax* seems to follow the same pattern as *Ceratitis capitata*, of which the clutch size was constant over a variety of fruits and fruit sizes (Papaj 1990). Eggs were found in 61% of the ovipunctures, though through comparing pre- and post-drop puncture density, 76% of the punctures seemed to be viable. The fraction of empty ovipunctures per fruit was significantly higher in multiple punctured fruits. The number of such punctures examined was small and more observations should be done to verify this finding.

Pupae production per infested fruit. Mandarin yielded averagely 4.2, and lime 8.1 pupae per dropped fruit, while towards September fruit size hardly differed (averagely 41 and 36 g respectively). Apparently, the high oviposition pressure in lime before mandarin fruit had developed eventually resulted in higher numbers of pupae per fruit. Striking was the near absence of maggot-less dropped fruits in lime, while in (lesser densely punctured) mandarin, a sizeable fraction of dropped fruits did not yield pupae (Figure 19), in particular in the early oviposition season (Figure 20a). Possibly, the higher number of eggs in lime (through higher puncture densities) resulted in a better overcoming of resistance mechanisms. On the other hand, most of the maggot-less dropped mandarins occurred in the early dropping season, suggesting that mandarin shed fruits too early for maggots to develop. Alternatively, lime was more conducive to maggot development than mandarin, which was confirmed by the observation that at comparable maggot density pupae from lime fruits were heavier than pupae from mandarin fruits.

In both early and late dropped fruit incidentally fruits with high maggot numbers were found, but on the average earlier droppers contained higher numbers of maggots than late droppers, both in mandarin and in lime. Probably, in heavier infested fruits, eggs did not hatch earlier, but maggots developed faster and made fruits drop earlier. Extremely high infestation levels in individual fruits resulted in early droppers with few, light pupae. Apparently, *B. minax* does not employ a "scratch-off"-mechanism. Such a mechanism was reported in *B. tsuneonis*, which produces only one maggot per fruit, even if clutches contain multiple eggs (Miyake 1919). *B. tsuneonis* attacks only small citrus fruits, and possibly, in this way it avoided massive mortality of maggots in overloaded fruits, which sometimes occurs in *B. minax*.

Egg- and pupal mortality in the fruit. When comparing the number of eggs entering a given fruit population and the number of maggots leaving it, mortality of eggs and larvae in mandarin fruit was, in a high-altitude orchard under normal circumstances, about 43%. The relative importance of different mortality mechanisms varies for different citrus ssp. and for different climate conditions, so this figure can not be extrapolated to other conditions. Nevertheless, in-fruit mortality is usually not very high in *B. minax*. In this respect, *B. minax* differs not only with the Tephritids ovipositing in the exocarp, but also with its sibling *B. tsuneonis* that produces only one maggot per fruit, even if multiple eggs are laid (Miyake 1919). Apparently, the strategy of *B. minax* to oviposit early in the season, and deep in the pulp, is very successful.

Life history of different citrus pests. Fletcher, 1989, reviewed the life strategies in Tephritids. The r- and K-strategies as described in general life strategy theory could be applied to Tephritids in general. In citrus, both sides of the r-K-strategist spectrum of tephritid flies seem to be represented. The multivoltine, polyphagous flies such as the *Ceratitis* and *Anastrepha* groups, and *B. dorsalis* Hendel are typical r-strategists. Such flies lay 10-25 eggs in the in the exocarp-flavedo, and egg mortality is high because of the essential oils present in the rind. The diapauses, if present at all, are not synchronised with the phenology of a single host. On the other hand, *B. minax and B. tsuneonis* are univoltine and stenophagous, they lay eggs in the endocarp, where in one puncture typically 4-9 eggs are laid; in *B. minax* most of the eggs develop into maggots and pupae. Both species employ two diapauses, one in winter to overcome fruitless period of citrus, and one after oviposition, so that fruits acquire sizes fit for multiple maggot development. Thus, the *Tetradacus* species behave more or less like the temperate *Rhagoletis* flies, and show many features of relative K-strategists. In line with this, the incidence of *B. minax* is much higher in cooler mid- and high-altitude orchards than in low-altitude orchards (J.R. Subba, Sikkim, pers. comm., own observation), while its emergence weeks before the first fruits ripen allow for a dispersion period.

Ovipunctures and fruit drop.

Ovipunctures in dropped fruit. In high-altitude orchards, fruit that dropped from July to mid September did not show higher ovipuncture densities than fruit in trees (Figure 18). Thus, summer fruit drop is not likely to be caused by *B. minax*, and puncturing fruits as such has apparently no abscission effect. A probable cause for early fruit drop is the bug *Rhynchocoris poseidon*, which was scarcely present in high altitude orchards (and is the major cause of fruit drop at low altitudes). From late September onwards, both fruit drop and the ovipuncture density on dropped fruits increased; 96% of dropped fruits showed ovipunctures or feeding signs by maggots. Apparently, fruit drop after late September was almost exclusively caused by *B. minax*. Moreover, the fraction of non-punctured dropped fruits did not decrease in periods when relatively few fruits dropped (the early and late oviposition season), and it is likely that in apparent clean fruits, punctures were missed. Early droppers usually yielded more maggots per fruit than late droppers did, and it was expected that early droppers were more heavily punctured. This appeared not to be the case; early and late droppers were equally punctured.

Pre- and post-drop puncturation in infested orchards. We needed a method to measure effectiveness of control measures, which could theoretically be done by comparing pre- and post-drop fractions of ovipunctured fruits. For verification of this notion, ovipunctures were recorded before and after fruit drop. It was found that practically all dropped fruits were punctured, but that not all punctured fruits dropped. A comparison of pre- and post-drop punctured fruit fractions the fruit population in the tree then allowed for calculation of fruit drop percentages. This fraction fitted well with estimates of dropped fruits and fruits left in the tree.

For this method however, still two observations on fruit puncture density need to be done, i.e. one before, and the other after fruit drop. Through further elaboration of the infestation process, the fraction of fruits that eventually dropped could be derived from the initial ovipuncture density (Figure 19). It was assumed that ovipunctures were Poisson distributed over fruit populations and that, for each ovipuncture, there was a binomial distributed chance for infestation. In the high-altitude orchards where the observations were done, an ovipuncture vitality percentage of 76% fitted best with the data points collected. This is higher than the 61% ovipunctures in which eggs were found, which underlines the notion that in some ovipunctures eggs were missed when checking infested fruits.

An exception formed a few cases where a low puncture density was found, and where fruit drop was less than expected. Maybe, in those orchards, the relative low occurrence of *B. minax* made puncturing activity of other agents relatively important.

In conclusion, it is best to take a pre-drop and post-drop sample to calculate fruit drop. Yet, for practical programmes, it may be better to take a well-balanced sample once in early or mid-September and calculate fruit drop based on standard vitality of ovipunctures.

Why do not all fruits drop?

During surveys in Bhutan, we wondered why *B. minax* never took 100% of fruits and restricted to a damaging percentage of 30-80%. One would expect a bigger fly-population in orchards after high-bearing years, that would do extra heavy damage if fruit setting in the following year was poor. In China, now and then up to 100% damage occurs (Yang et al. 1994).

Three years of surveys in some ten villages revealed that the number of ovipunctures per mandarin varied from 0.90 to 1.80 in uncontrolled conditions. This as such was remarkable, as fruit setting varied for over 300%, while apparently puncture density varied not more than 200%. Possibly, there was a feedback between fruit density and fly population. Moreover, the fly was hardly deterred by previous ovipuncture activity, and tended to attack only bigger fruits. Under an oviposition pressure of 1.8 puncture per fruit, with the usual Poisson-distribution still 17% of the fruits remains untouched. In the field we found more spreading of ovipunctures, yet, even in densely punctured samples, always a fraction of (usually smaller) fruits did not show ovipunctures.

In addition, it was shown that only 76% of ovipunctures was viable. In some ovipunctures, simply no eggs were deposited, while some eggs and maggots were killed by resistance mechanisms of the fruit. Therefore, a sizeable fraction of punctured fruits remained in the tree as well; in heavily infested orchards up to 50% of fruits were punctured even after fruit drop. Under an ovipuncture pressure of 1.8 puncture/fruit, only 74% would contain one or more viable ovipunctures (applying Formula 2), or slightly more if the fly spread its punctures more regular than Poisson.

Most probably, the combination of the poor recognition of previous puncturing by female flies, the non-viability of part of the ovipunctures and a migration-inducing mechanism at high population densities account for a fairly stable harvest in Bhutanese orchards.

Monitoring B. minax activity.
A few methods may be used to quantify fruit drop by *B. minax*, including asking the farmer, estimating dropped and in-tree fruit, and counting the fraction of discolouring fruits in the tree before fruit drop started. All methods had their merits, but hardly gave consistent results. Two methods may be used to evaluate effectiveness of control programmes in terms of reduction of losses, i.e. collection and counting of dropped fruits, and checking fruit for ovipunctures. Counting dropped fruits appeared reliable only under specific circumstances. Orchards should be relatively flat so that no fruits roll down the slope, they should be clean and void of cattle. In eastern Bhutan, very few places met these criteria, though Rongthong orchard was one of them. About 90% of marked dropped fruit was found back after a week, unlike in many other places, where sometimes even less than 10% was recovered. Checking fruits for ovipunctures is less time-consuming though not without loopholes. Firstly, the occurrence of non-tephritid puncturers might blur the picture, which is common in lower altitude orchards. Secondly, the fly prefers bigger fruits and dense canopy trees, and differences in ovipuncture density occurred in fruit populations within tree canopies and within villages (Section 5.2). This makes quantifying *B. minax* activity through examination of fruit samples a tricky task. A sample with a size-bias will also show an ovipuncture-bias, and how does one know if a particular sample is representative for a particular orchard or village? We have no clear-cut solution to this problem. In practice, sampling procedures must differ with the objective of sampling. To detect the presence of oviposition activity by *B. minax*, examination of a limited sample of the biggest citrus fruits in the orchard in the early oviposition season will do. This procedure may be applied when establishing fruit fly activity in fruits for export with quarantine restrictions. When the effect of control activities is to be examined, pre-treatment samples (if possible of two or more seasons) should be compared with post-treatment samples. Samples should be taken on the same date, from the same trees and through the same sampling procedures. Infestation levels of various locations can be compared by taking samples from both upper and lower canopies, from dense and loose canopy trees and from different patches in the orchard or village. Samples should be examined separately. The various samples from one village should then be compared with samples from another village. In the latter two methods, apart from ovipunctures per fruit, also fruit size is an essential parameter in comparing samples for *B. minax* activity.

Concluding remarks.
Estimation of fruit drop through examining the ovipuncture density has been successfully used in citrus IPM development in eastern Bhutan. The method proved useful in high-altitude and shady mid-altitude orchards. Furthermore, this article presents data that allow for building a quantitative model of the fly life cycle period that takes place in mandarin and lime fruit. Section 6.2 presents data on mortality of pupae in the soil and on migration habits of the fly. Wang and Lue (1995) mentioned the egg production of individual female flies. Thus, a preliminary data set is completed to build a quantitative model of the fly life cycle in mid- and high-altitude Himalayan orchards. Small adaptations may make such a model fit for the various situations in China. Such a model may be useful to evaluate possible IPM strategies. Also, Farmers Field Schools type of extension may use such a model to fast evaluate the combination of various control measures, including communal action, by farmers. Simplified quantitative models have been successfully used in extension programmes in Bhutan.

6. IPM of the chinese citrus fly[10].

6.1. Trapping and proteinaceous food-baiting[11].

Abstract.
Bactrocera minax is a univoltine tephritid pest of citrus that inflicts up to 80% damage in the in the eastern Himalayan region and in southern China. Most Tephritid flies can be controlled by proteinaceous baiting starting a few weeks before oviposition. It was tried whether this was a feasible option to control B. minax as well. Olfactory and visual traps were developed to identify different periods of attraction to bait and fruit shapes. Bottles with pupae were used to establish the local emergence period, during which (both male and female) flies were optimally attracted to proteinaceous bait-loaded dry lure traps. After the emergence period, no flies were caught in either trap. When fruits became fit for oviposition protein traps caught few (female) flies but mimic fruit traps attracted (mostly male) flies, particularly if placed in early developing Citrus spp.
Proteinaceous baiting during the emergence (i.e. starting ten weeks before early oviposition) and oviposition period controlled the fly in one isolated orchard; after two years of bait application the fly was near extinct. The paper concludes that proteinaceous baiting during emergence combined with use of catch crops in the early oviposition season bears the best potential for suppression of B. minax populations.

Introduction.
Mandarin *(Citrus reticulata Blanco)* is the most important cash crop in Bhutan. The export value is on the order of 10 million US$ per year. Trees grown at mid altitudes (1,000-1,500 m) form erect oval closed canopies and grow up to 10 m high. Fully-grown healthy trees may bear up to 400 kg or 4,000 fruits, equivalent to 40 tonnes per hectare. However, in poorly managed orchards, yields as low as 20 kg per tree (2 tonnes per hectare) are not uncommon; the average yield is about 6 tonnes per hectare (Fullerton 1988, confirmed by own observation). Fruit drop is a major cause for reduced yields though so far farmers hardly carry out control measures against fruit drop. In lower altitudes, the citrus green stink bug *(Rhynchocoris poseidon Kirkaldy,* Heteroptera: Pentatomidae) is the main cause for fruit drop. *Bactrocera minax* Enderlein (Diptera: Tephritidae) causes fruit drop in mid-altitude (1,000-1,500 m asl.) and shady orchards (own observation).

This paper reports how control of fruit drop caused by *B. minax* was achieved. The fly is univoltine and stenophagous on almost all citrus species, it oviposits in fruits that then prematurely ripen and drop. It was described by Enderlein (1920) and Chen (1940). *B. minax* or the *chinese citrus fly* (also called *citrus maggot* in China and *citrus fruit fly or citrus fly* in India and Bhutan) is reported from China (Chen and Wang 1943), Sikkim, and West-Bengal in India (Nath 1973[12]) and Bhutan (Bigger et al. 1988). My recent investigation suggests that *B. minax* is also present in higher situated orchards in the mid-hills of Nepal, even if from Nepal only *B. dorsalis* has been reported. The pest does not occur in the hills of Meghalaya in Northeast India (Dr. K.M. Sohklet, Shillong, Meghalaya pers. comm.) where the climate conditions seem favourable to the pest; even if mandarin transports from Bhutan to Bangladesh pass through this state. *B. minax* oviposits exclusively in fruits of *citrus spp.* (White and Elson-Harris 1992). The fly has been studied in China (e.g., Wu 1958; Sun 1961; Cao 1987); research is reviewed by Yang et al. (1994) and Wang and Lue (1995). The pest has been spreading in China since the 1940's. It now it occurs in most citrus producing regions and is still important in mountainous areas; it was found on wild as

[10] The two articles in this chapter have been accepted by the *International Journal of Pest Management.*
[11] By Frank H.J. van Schoubroeck and Marja Kool-de Rie.
[12] Nath mentions *Callantra minax* to occur in October-November in the hilly areas of Sikkim and Darjeeling. In that period *B. minax* maggots make fruit drop in abundance, but adults cannot be found. The fly Nath described is not *B.minax*

well as cultivated citrus, and in temperate and subtropical areas. In cultivated areas in China the pest inflicts damage at (measured in weight dropped fruit per total production) 5-7.5% (Wang and Zhang 1993) and 50-80% (Chen 1940 in Yang et al. 1994).

B. minax is closely related to another citrus pest, *Bactrocera tsuneonis* Miyake. B. tsuneonis is univoltine, it attacks citrus, and occurs in subtropical areas (Miyake 1919). In Bhutan, the principle hosts of B. minax are mandarin and lime (Citrus aurantifolia Swingle). Other *B. minax* hosts include citron (*Citrus medica* L.) with year round fruit setting, and sweet and bitter orange. *B. minax* was not detected in non-citrus fruits such as avocado, guava, mango, peach, pear and pomegranate, even if grown close to infested citrus trees.

To our knowledge, no reports on particular trapping methods for *B. minax* exist. Tephritid flies in general are attracted by the odour of ammonia from bacterial decomposition of protein hydrolysates (McPhail 1939, Steiner 1952, Bateman and Morton 1981), a characteristic that has widely been used in trapping and in control programmes (Roessler 1989). *B. minax's* particular attraction to protein hydrolysate was mentioned in Wang and Lue (1995). No pheromones or para-pheromones are known to attract *B. minax* (IIE 1991), and cue-lure and methyl eugenol were tested without success (Hollands 1994). Tephritid flies are often attracted by fruit mimicking shapes with particular colours, while in some cases colour/shape combinations, particularly tree mimicking shapes, are attractive (Economopoulos 1989).

Wang and Lue 1995, report on a developing Chinese tradition of baiting *B. minax*, though it is not clear whether the results are applied in practice or not. Traditionally Chinese research has concentrated on sugar based lures with additions such as orange juice and vinegar offered on straw bars. Baiting recommendations in Sikkim include spraying of poisoned gur (molasses?) on the fruits in September-October, and hygienic measures, i.e. collection of infested fruits which are then treated with insecticide (Subba 1984 and Subba et al., undated). The Chinese also reported on experiments with the sterile male technique for control of the pest (Wang and Zhang 1993). Irradiated males were released in orchards with relatively low fly densities (0.55%, 7.5% damage in kg fruit per total production) resulting in vast reduction of damage (to 0.003 and 0.0005%, in one and two years respectively). Through the sterile male technique, the pest may be eradicated to comply with quality demands for fruit export to uninfested areas. The sterile male technique was impractical for Bhutan, as transport of living flies to villages days walk from the road would be problematic, while there is no radiation source available in Bhutan or nearby India. Another option for control was the rigid implementation of dropped maggot-loaded fruit disposal, which appeared not to bear potentials for controlling the pest (Section 6.2).

The economic importance of citrus stressed the need to control fruit drop. Complaints regarding fruit drop were communicated to administrators every few years. It was likely that the Ministry of Agriculture would come under pressure to initiate chemical control campaigns, even if pesticide applications would hardly contribute to better yields. Such had earlier happened in apple and rice in western Bhutan. When the citrus IPM research programme was launched in the early 1990's, *B. minax* had been identified as one of the causes for fruit drop, though little information on the pest was available. The geographical distribution of the fly was not known, neither was its importance in comparison to other causes of fruit drop. Timing of the fly's life cycle, its voltinicity and basics of its behaviour had not yet been published in accessible literature. Initial control experiments had not sorted adequate control effect (Hollands 1994), and for successful IPM, knowledge on the fly's behaviour and identification of the emergence and oviposition period were needed. The best option for control seemed proteinaceous baiting combined with destruction of dropped maggot-loaded fruit. Thus, reliable traps needed to be developed to identify periods of attraction to baits and practical bait application methods needed to be developed. A research programme was set up with the goal to develop practical IPM for *B. minax*. On-station and in-village experiments were carried out simultaneously. The village programmes yielded information that was to be reconfirmed by replicated station-implemented experiments, while technology developed on-station was put in practice in the village research programmes (Chapter 3). This article reports on the traps developed to make the various stages of the life cycle visible to farmers and extension staff. Further, it discusses developed baiting methods and a possible trap crop to be employed in an IPM strategy for *B. minax*. Control of the fly in orchards in a larger citrus growing area is discussed in Chapter 3 and 4.

Materials and methods.

Experimental orchards.
The study was conducted along the Tashigang-Kanglung highway, on the east slope of the Dangme-chu river valley in eastern Bhutan. The area was characterised by a mixture of wetland area, fallow dry land, and subtropical forest on steeper elevations. The local climate is sub-tropical with a dry and cool winter (October-February), hot spring (March-mid May), and humid summer with heavy showers (late May-September). The local climate varies considerably, even within villages, because of differences in altitude and exposure. Characteristics of the study sites are presented in Table 12.
Most experiments were carried out in Lyenkhar and the Rongthong orchards, which were situated 1,200 m apart (as the crow flies). Both orchards consisted of about thirty 25-35 years old mandarin trees, five lime trees and a few other *Citrus spp.* Without pest management, 55 to 75% fruit dropped in Lyenkhar (Hollands 1994), and 54-78% in Rongthong (Table 14), measured in number of fruits dropped per total fruit production. The Rongthong orchard was situated close to a village with an extra fifty scattered, bearing and infested mandarin trees, while the surroundings of Lyenkhar were void of *Citrus spp.* The Lyenkhar orchard was treated with protein hydrolysate baiting in 1994-'95. In the Rongthong orchard, traps were tested and emergence, trapping periods and fly behaviour were studied. In both orchards fruit drop and bearing were recorded in 1994-'97.

A few km further down the road to Tashigang town were the Kharsa, Pam and Phomshing orchards, each consisting of about 30 bearing mandarin trees and void of other citrus spp. The orchards were originally included in the research programme, but after two years it appeared that the local fly activity was irregular and in Pam and Phomshing was below economically important levels. Later, this appeared to be a general characteristic of low-altitude orchards.

Village	**Rongthong orchard**	**Lyenkhar orchard**	**Kharsa orchard**
altitude (m)	1580	1250	1200
characteristics	shady mansion orchard	shady mansion orchard	sun-exposed orchard
main trees (age in years)	30 bearing mandarin (25-35 y)	30 bearing mandarin (25-35 y)	30 bearing mandarin (20 y)
other bearing Citrus spp.	lime (5), citron (5), bitter orange (5)	lime (8), orange (3)	not found
natural B. minax *infestation*	57-78 % (1994-1997)[1,2]	55-75 % (1991-1993)[1,2]	up to 70 %[1,2]
environment	village with about 50 scattered mandarin trees, mixed orchard	mixed orchard (mango, guave etc.), wetland, forest	bushes without citrus spp.

[1] measured in number of dropped fruits per total production, obtained through counting dropped and in-tree fruits
[2] measured in number of dropped fruits per total production, obtained through checking fruits for ovipunctures

Table 12 Characteristics of the experimental orchards along the Kanglung-Tashigang highway.

Development of baits and traps.

Bait identification.
The protein hydrolysate (PH) adopted as a standard attractant was a substance labelled "protein hydrolysate", obtained from the Indian market (marketed by Lab instruments and Chemical Works Ltd., Siliguri). It was a hydrolysate processed from casein. This material, hereafter called PH, was chosen because preliminary tests had shown its attractiveness to *B. minax* and it was easily available. It was readily solvable in water, hygroscopic, and therefore difficult to keep; the pH of 10% solutions was about 5. This substance was tested against a range of other materials such as sandovit™ wetting agent (with ammonia smell); Mauri's Pinnacle Lure, Di-Ammonium Phosphate (DAP, an ammonia releasing salt); three locally available protein hydrolysates; fermenting food grains from local beer production and molasses; aromatic substances such as vanilla, orange juice, sugar and vinegar (suggested by Yang et al. 1994); and the para-pheromones cue-lure and methyl eugenol.
Tests were carried out in the Rongthong orchard during 22 days of the fly emergence period of 1997. Four dry-lure traps (Figure 20c and d) per attractant with 0.1% malathion as killing agent were prepared. A maximum of three traps per tree were placed in the upper canopy of mandarin trees. Traps were checked daily and shuffled twice a week. Due to the cold and wet spring, no conclusive results could be obtained. Traps with Mauri's Pinnacle Lure, PH, Di-Ammonium Phosphate and 0.1% malathion alone attracted a total of 45a, 18ab, 9b and 3b flies respectively in fifteen observation days (multiple-range test, figures followed by the same letters were not significantly different at $p=0.05$; $p=0.052$ for the difference between PH and control). Traps with other substances caught fewer flies than the control traps. The results suggested that Mauri's Pinnacle Lure, PH and DAP attracted *B. minax* at decreasing levels. As PH was readily available from the market, this substance was used for control programmes. It appeared difficult to find the optimal concentration for fly control (Table 11), so the used concentration was derived from Hendrichs et al. (1992). For control programmes, a watery solution of 0.5% PH, 0.1% malathion and 0.1% detergent (Sandovit™ agriculture wetting agent) was splashed at the rate of 50 ml with a cup or water gun high into every full-grown tree.

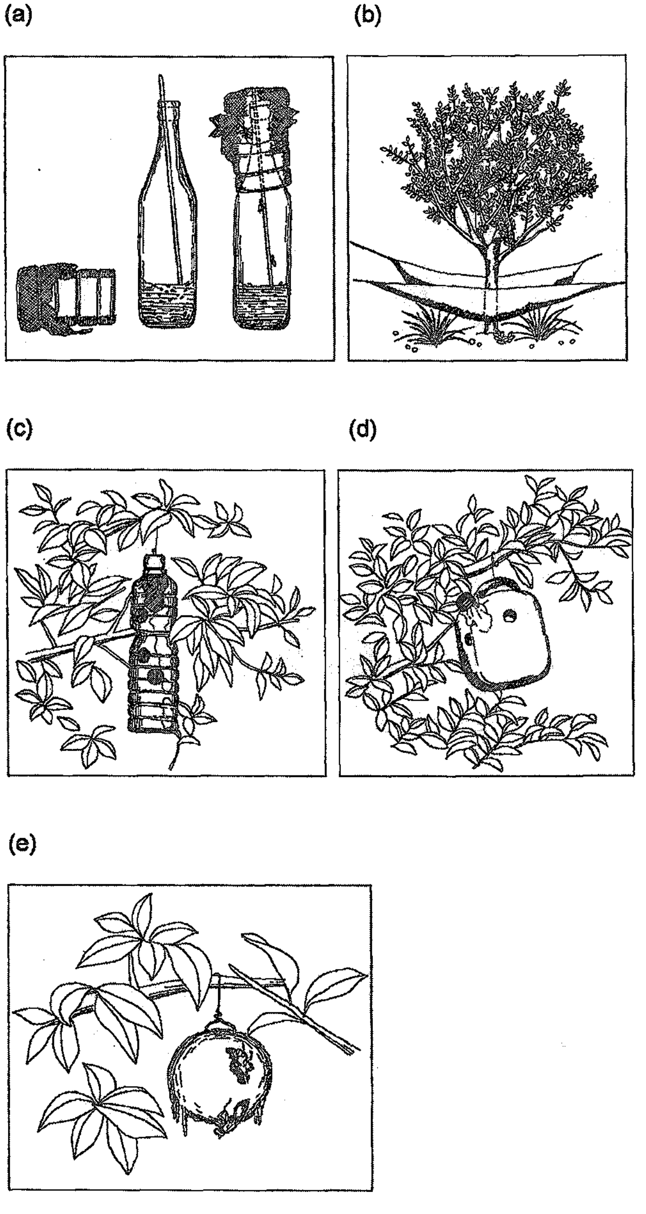


Figure 20. Different fly catching devices. (a) emergence-monitoring bottle (b) bait-monitoring trap (c) dry-lure trap, the plastic bottle version (d) dry-lure trap, the jerry-can version (e) fruit-mimic trap.

(a)

PH concentration applied	male flies	female flies	total
0.0 %	1	14	15[a]
0.1 %	13	24	37[a]
0.5 %	12	13	25[a]
2.0 %	3	19	22[a]
total	29[a]	70[b]	99

Numbers of a contrast followed by the same letter were not significantly different. Treatments were tested with the one-way ANOVA at p=0.05. Male and female fly catch numbers were tested with the paired sample t-test at p=0.05.

(b)

date	24-6	26-6	28-6	30-6	1-7	3-7	4-7	5-7	7-7	9-7
bait application	X	X	X	X	-	-	X	-	-	-
rain after last application (mm)	0	0	0	0	7	17	0	14	14	21
catch per trap	3.8 ±4.0[a]	2.1 ±2.4[ab]	1.6 ±2.3[abc]	0.9 ±0.9[abc]	1.0 ±1.1[abc]	0.5 ±0.8[bc]	0.9 ±0.6[abc]	0.9 ±2.1[abc]	0.4 ±0.7[c]	0.4 ±0.5[c]

Means followed by the same letter were not significantly different for the multiple range test at p=0.05.

Table 11. Bait-monitoring trap B. minax catches in Kharsa orchard in June-July 1994 after applying different concentrations of PH preparate in 2 replications; (a) total male-female catches; (b) fly catch numbers over time.

Fly monitoring devices.

Emergence-monitoring bottle. Establishment of the emergence period was initially tried through catching flies in cages-over-soil with pupae. Catches varied from zero to 150 flies per m^2 and were unpredictable. Buried pupae were heavily predated upon. For example, in 1997, just 11 flies emerged from 800 pupae that were buried on eight spots one month before expected eclosion. Predation by ants, rats, and chickens made these cages unfit for establishing the emergence period. Therefore, instead, 100 pupae were mixed with sand and placed in 0.75 l transparent (beer-) bottles. During winter, about twenty bottles were kept in a barn close to Rongthong. Bottles were shuffled weekly, and water was occasionally added to avoid pupae drying out. When emergence was due, flies walked up over a tiny bamboo stick through the bottle opening into a removable plastic container placed on top. The container's open end was covered with removable mosquito net. The containers were checked every day for male and female fly emergence. Recovery of flies from pupae was 54% and 67% (in 1995 and '96 respectively). In Rongthong, in spring 1995, flies in cages over infested soil and in bottles inside a nearby barn emerged at about the same time, though temperatures in bottles and the soil were not recorded. Such *emergence-monitoring bottles* (Figure 20-a) were used to study emergence periods and to time baiting programmes in villages. Farmers used home-built *emergence-monitoring bottles* identify fly emergence periods in their particular villages.

The fruit-mimic trap. In Lyenkhar and Rongthong, early June 1994, square surfaces of 30x30 cm covered with non-drying glue coloured yellow, red, orange, green and blue (five per colour) were placed vertically in the lower canopy of mandarin trees. Few flies were attracted to the yellow trap, while other visual lures failed to attract a single *B. minax* fly. Balls of 15, 22 and 35-mm diameter coloured white, yellow, green, fluorescent green, orange, red, blue and black (fifteen balls per colour and size), pasted with non-drying glue, were tested. *B. minax* was only attracted to the green balls, while 15-mm traps were less attractive than the 22 and 35-mm traps; during later experiments sticky green balls caught typically one or two, and sometimes up to fifteen flies a day. Developing fruit pasted with non-drying glue, in particular of the earlier developing lime, was equally effective in catching flies.

The glue pasted green balls, hereafter called *fruit-mimic traps* (Figure 20-e), were useful to detect *B. minax* oviposition activity. The fruit-mimic trap was, if applied in early developing citrus species, a reliable fly monitoring device. Fruit-mimic traps revealed oviposition timing and characteristics of the fly's host searching behaviour. The fruit-mimic trap needed cleaning every few days and was difficult to handle while the non-drying glue was difficult to obtain in Bhutan. Therefore, the fruit-mimic trap proved impractical as a standard monitoring tool in village programmes, even if it was useful to show farmers the relation between *B. minax* and fruit drop.

The bait-monitoring trap and bait-splashing. Bait attractiveness was checked by stretching a cloth beneath a bait/insecticide treated tree (method suggested by A. Allwood, Fiji, pers. comm.). Some flies were caught with 90x90 cm cloths underneath treated densely foliated branches. Such traps could only be constructed in the lower canopy. A cloth of 4x4 m, stretched underneath a treated tree, with a stone in the middle for stability, gave better results. The trap was called *bait-monitoring trap* (Figure 20-b). With this trap, attractiveness of baits, the validity of bait treatments, and the effect on non-target organisms were monitored. However, fly catches with this trap were irregular; in a few occasions, up to 40 flies per trap per day were caught, but often no flies were caught at all without obvious reason. Possibly flies few away before dropping in the cloth, killed tephritid flies were found up to 25 m from trees with a bait-monitoring trap. The trap was useful to evaluate efficacy of baiting and the effect of bait-splashing on non-target arthropods. The bait-monitoring trap proved to be a powerful extension tool in village extension programmes. We never used the trap during the emergence period, when properties such as optimal bait concentration and best place to apply bait within the tree can be studied.

The application method of bait, i.e. splashing 50 ml of a watery solution of bait-poison mixture with cup or water-gun into the tree, appeared to have the potential to kill B. minax flies. This method, hereafter called *bait-splashing,* was used to apply bait for control in villages and experimental orchards.

The dry-lure trap. Following McPhail (1939), Gow (1954) and Steiner (1957) a protein lure trap was constructed. In preliminary tests traps with liquid protein baits appeared difficult to handle and did not catch any *B. minax* flies. Traps with a dry protein lure/insecticide mixture were more successful. For the standard traps cotton wicks were soaked in a watery solution of 10% PH, 0.4% malathion 50EC, and 0.1% Sandovit™ detergent. Wicks absorbed about 10 ml of the mixture so that each wick would contain about 1 g PH. Wicks were dried and mounted on iron wire. The wicks were fixed inside 2.5-l plastic jerry cans available from the market (the cheapest container available) or waste mineral water bottles through the pouring hole, which then was closed. In the upper half of the container four holes 2-cm in diameter were cut. We named such traps *dry-lure traps* (see Figure 20-c and -d). Some traps were painted green or yellow to add visual attraction, without obvious attractant effect. The dry-lure trap was cheap to construct, easy to handle, and the impregnated wicks were well protected against the frequent monsoon showers. The traps might be improved by placing an ant killer in the container.

Experiments and observations.

Adult emergence. The period of adult emergence in the Rongthong orchard was studied. Pupae obtained in autumn 1994, 1995 and 1996 were kept in about twenty emergence-monitoring bottles (@ 100 pupae/bottle) in a barn close to the Rongthong orchard. Simultaneously, flies were caught with cages over infested soil. In the following spring, the bottles and cages were checked daily for emerged flies.

Adult behaviour. Fly activity in cages. About 200 flies, which had emerged between 7 and 16 May 1996, were placed in two separate mosquito net cages of 50x50x60 cm in which they were offered food on suspended filter paper (Mauri's Pinnacle Lure, PH, sucrose, water) and fresh cucumber. The cages were placed outside in an open (but not exposed) spot. On May 17 and May 21, the flies' activity (resting or feeding) and the temperature were recorded every fifteen minutes from 5.00 am (before dusk) to 19.30 pm (after dawn).

Field observations. Behaviour observations were mainly done in the Rongthong orchard, but also by farmers in villages. Trees and bushes of citron, lime and mandarin were searched for adult fly observation. Whenever flies were spotted, their behaviour was recorded.

Trapping. Fruit-mimic trap catch-pattern. In spring 1997, after the first *B. minax* emergence, five fruit-mimic traps were hung in one lime tree; and in the upper and lower canopy of a dense mandarin tree in the Rongthong orchard. Traps were checked and refreshed three times a week. In the same period, every week, 25 fruits were collected from the lime tree and from the upper and the lower canopy of a mandarin tree, and measured. Fruit over 11-mm diameter was considered fit for oviposition (Section 5.2).

In Kharsa orchard, five fruit-mimic traps were placed in the upper and lower canopy of a bearing, dense mandarin tree and checked similarly. In Rongthong, during the main trapping period, fruit-mimic traps were placed for a few weeks in pomegranate and guave trees, and in a non-fruiting lime tree.

Bait concentration and validity. For establishing attractiveness of bait-splashes with various PH concentrations an experiment was carried out in Kharsa orchard from June 24 to July 9, 1994 (the early oviposition season). During the experiment, in the morning the weather was usually windstill, dry and hot, windy in the afternoon, with heavy showers in the evening and night.

Watery solutions of 0.0%, 0.1%, 0.5% and 2.0% PH with 0.1% Sandovit™ agricultural wetting agent and 0.1% Malathion from a 50EC formula were prepared. 50 ml of the solution was splashed into the canopy of a tree with a bait-monitoring trap. The eight treated trees stood ten meter apart. Bait was applied in the morning and traps were checked four hours later and the following days. Each treatment was duplicated.

PH-loaded dry-lure trap catch-pattern. The experiment was carried out in the Rongthong orchard in 1996. One week before expected emergence, five PH loaded dry-lure traps were placed in the canopies of fully grown dense canopy mandarin trees. Protein traps were emptied and reshuffled at least three times a week. Male and female catches were recorded separately. Catches were compared with fly emergence data.

In addition, five traps were hung in the lower canopies of the same mandarin trees, and in the upper canopy of three trees with an open canopy, during the emergence period. In the same orchard traps were placed in non-host trees peach and pear, and checked similarly.

Control. The mobile nature of *B. minax* entailed that control would have to be carried out for a complete orchard or village (i.e. the experimental unit for *B. minax* control is one isolated orchard or village). The baiting experiments were initially carried out in four orchards, out of which two appeared to be infested at irregular levels and were unfit for control experiments, so that treatments were not repeated over orchards. On the other hand, through measuring fruit drop of different trees in one orchard, one can observe the infestation level of different individual trees after bait activities (i.e. the experimental unit is one tree) and treatments were repeated over trees. Treatments repeated over years can be regarded as a repetition between orchards as well. The baiting experiment was carried out in Lyenkhar and the Rongthong orchard from 1994 to 1997. In Lyenkhar, the fly was baited in 1994 and 1995. The bait solution was a 0.5% PH, 0.1% malathion, 0.1% detergent watery solution. During sunny weather, 50 ml of this solution was splashed with a cup or bamboo water gun on to the upper canopy of every bearing mandarin tree. In 1994, bait was applied weekly after detection of gravid females, i.e. between June 19 (when oviposition had already started) and September 15. In 1995, bait was applied weekly after the start of fly emergence, i.e. between April 15 and August 20. The Lyenkhar fly population was allowed to recover in 1996 and '97. In the Rongthong orchard, the pest was not controlled, though traps were tested during these years. Trap testing probably hardly affected the fly population because the orchard fly population was only part of the entire Rongthong village population.

Fruit drop was recorded for six fully-grown trees in each orchard in 1994, '95, '96 and '97. Dropped fruits were collected from under each tree, weekly from late September to late November. The final harvest was estimated in each tree after fruit drop. In 1995, another method became available to establish the activity of the pest. Fifty fruits per tree were sampled and checked for ovipunctures (for details refer Section 5.3); obtained data fitted quite well with the (more laborious) counting of dropped fruit. Pre-1994 figures were derived from Hollands (1994) and farmer's observations, and fitted well with observations in the Rongthong orchard over 1994-1997. Variance between trees for 1991-93 were derived from the 1997 Lyenkhar data. Pre-1994 data for Rongthong were derived from the 1994-1997 data.

For future reference, specimens of B. minax are being kept at the insect collection of Wageningen Agriculture University.

Results.

Adult emergence.

Emergence of flies varied with the weather. During hot spells, more flies emerged than during cool days, resulting in fluctuation of emerging flies during the emergence period, though this relation was not established quantitatively.

Three year's emergence patterns in Rongthong are presented in Figure 21. Average temperatures of April 1995, '96 and '97 were 15.5 °C, 16.7 °C and 13.5 °C respectively. Emergence periods of 1995 and 1996 were about the same (25/4-18/5 and 23/4-17/5, the median of emergence was May 8 and May 6). The cool spring of 1997 resulted in a retarded emergence period (12/5 to 31/5, median emergence date May 23). In 1995 there was a peak in fly emergence early May, due to sudden hot and humid weather. Over three years, the median of emergence was 0.78, 1.44 and 1.34 days earlier for male than for female flies (significantly different with the paired-samples t-test for $p=0.05$). In 1996 the fraction male flies was 61% against 53% in 1995 and 1997.

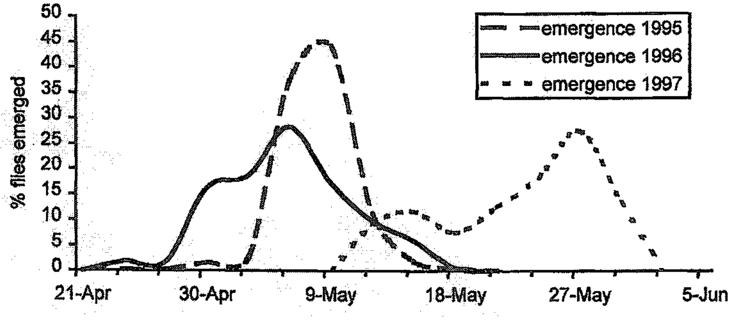


Figure 21. B. minax emergence patterns of spring 1995, 1996 and 1997 in Rongthong. April average temperatures were 15.5 °C, 16.7 °C and 13.5 °C respectively.

Adult behaviour.

Fly activity in cages. The observation of fly activity in cages gave the following results. May 17, 1996, was a cool and cloudy day; weather recordings included 2.3 hours sunshine, temperature 14-21°C (average 17°C), 0.4-mm rain, 2.9-mm evaporation. May 21 was a warm and sunny day; weather recordings included 9.9 hours sunshine, temperature 14-25°C (average 20°C), no rain, 5.5-mm evaporation.

The flies' feeding patterns during the two days are presented in Figure 22. During rest, flies mostly stayed on the underside of the cages' strips. At dawn, they started to move from the protected place and feed on sugar and cucumber. Flies moved more during the sunny day. Feeding activity took place between 7 am and 6 p.m. During the sunny day, flies fed on the average 5.4 hours, during the cloudy day 1.6 hours. Fly activity during the sunny and shady day differed significantly with the t-test for independent samples for p=0.05. Feeding activity took place during the entire day and not exclusively during the hours of sunshine.

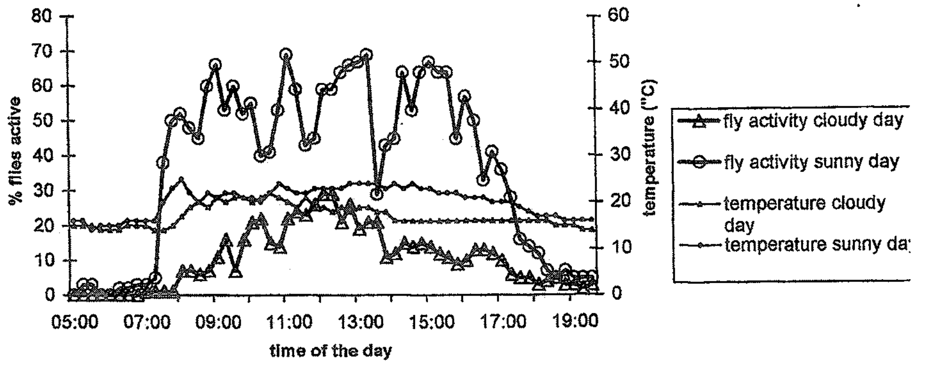


Figure 22. Feeding activity of 2-14 days old flies in cages on a cloudy and on a sunny day.

Field observations. In the field, fly emergence took mostly place between 8 and 12 am. Just emerged flies tended to walk in upward direction. Flies that reached a vertical dark place (such as the underside of a leaf) stopped walking and inflated their wings. When inflation was completed, flies flew to the closest tree and out of our sight.

Most behaviour observations were done during hot and sunny weather. During overcast weather, we could hardly detect flies, though occasionally male flies were seen resting on the underside of citron leaves. After the emergence period, on June 4, 1996, a few flies were observed in a citron bush with developing fruit. Two or three single male flies stayed on leaves around the same developing citron fruit. Competing males were chased away when coming closer than approximately 10 cm. Female flies mated and oviposited. The fly came to the citron fruit where it attempted to oviposit. The oviposition action was interrupted by a male fly for mating. Mating lasted over 20 minutes. During the following weeks the same behaviour was observed whenever the orchard was visited.

All oviposition activity took place on the underside of developing fruit. Undisturbed female flies walked circles on the underside of the developing citron fruit, probed around, and briefly inserted the ovipositor one to four times. Then the fly kept the ovipositor inserted for twelve to twenty minutes, while turning five to eight half circles, took out the ovipositor and flew away. Fruits exudated a rosin type of fluid from oviposition punctures which set hard and bristle within days. Such exudation made repeated oviposition through the same puncture unlikely.

After mid June, lime fruit developed to over 11-mm and flies appeared in the lime tree. Male flies were seen sitting close to or on fruit of over 11-mm. When fruit was about to reach the size fit for oviposition, mandarin trees with slightly bigger fruits were teeming with B. minax males while in trees with smaller fruits no flies could be detected. Later, male flies were observed on the outside of all dense canopy host trees. On sunny days, male flies flew about on the outside of upper canopies. Occasionally, female flies were seen hopping to and from leaves and fruits, staying two to six minutes on the same spot. Flies preferred to stay on the underside of leaves and fruit, where they started probing the leaf and fruit surface after landing. After mid July all mandarin fruit had developed into sizes fit for oviposition so that the fly population was diluted, and flies were only occasionally spotted. Occasionally groups of 2-4 females feeding on phloem fluid from damaged branches inside a dense canopy mandarin tree were seen. On 26 August 1994, fourty-two gravid female flies were caught in one out of six bait-monitoring traps in a village with over 1,000 bearing mandarin trees. The latest B. minax record of the fly season was a catch of two gravid females on September 12.

Trapping experiments.

Fruit-mimic trap catch-pattern. The peak catch period by mimic fruit traps was in late June and early July, when lime fruits were developing into sizes fit for oviposition (Figure 23). During the same period (of 1997), mandarins were not yet fit for oviposition while traps in the mandarin tree caught only few flies. Fruit-mimic traps in the lime tree caught in total 544 flies over the season, while in mandarin only three flies were caught. In total 18 flies were trapped during the emergence period (12-31 May), while during the main catch period (12 June to 23 July) 507 flies were caught. After July 23, when mandarin fruit became fit for oviposition, catches dropped sharply and only 12 flies were caught; the latest catch was on August 27. All caught female flies were gravid. Over the entire season, 73% of flies caught were male.

Two sets of five fruit-mimic traps placed in the upper and lower canopy of a single dense canopy mandarin tree yielded 51 and 10 flies respectively (significantly different with the two-sided Wilcoxon's matched-pairs signed ranks test at $p=0.05$). Fruit-mimic traps in non-host trees (pomegranate and guave) did not trap a single fly, but such traps in non-fruiting lime trees did catch flies in similar amounts as such traps in bearing trees.

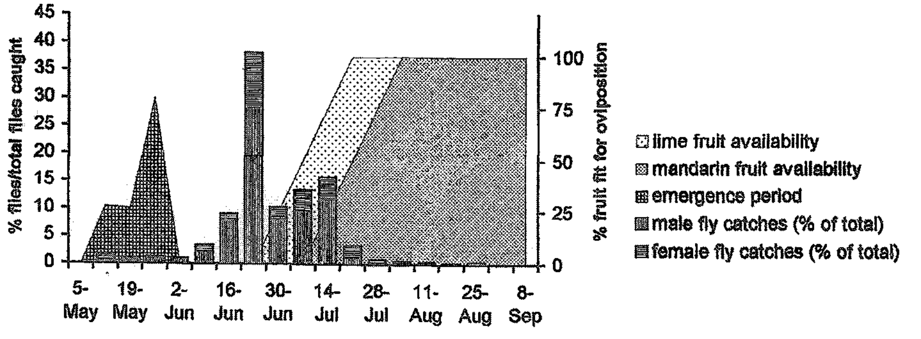


Figure 23. 1997 Fruit-mimic trap catches in a lime tree in relation to B. minax *emergence and fitness of developing fruit for oviposition.*

Bait concentration and validity. Bait-monitoring trap catches were too irregular to draw quantitative conclusions. Nevertheless, a few qualitative conclusions can be drawn from the data. Results are presented in Table 11. The control treatment (with malathion only) caught a few flies. Apparently, random touching of poison plays a role in catching flies. Catches were clumped, the all over coefficient of dispersion was 1.47 and significantly higher than 1 (t-test, $p=0.041$). Bait-monitoring traps caught flies up to five days after application of the last bait-splash, even if it had rained heavily after the bait application.

More female than male flies were caught. Flies were caught up to five days after application, even if during that period heavy showers occurred. After five bait-splashes in eighteen days fly catch numbers dropped, possibly because the fly population in Kharsa orchard was wiped out.

PH-loaded dry-lure trap catch-patterns. Seasonal catch-pattern. Results of the dry-lure trap catches over the adult flying season are presented in Figure 24. In 1996 flies emerged between April 23 and May 18. Flies were most attracted to protein hydrolysate during the emergence period, when both male and female flies were caught (53% female, $n=207$). Against expectation, only few flies were caught during the oviposition period, when mainly female flies were caught (93% female, $n=61$). Latest fly catches occurred late July.

Catches of dry-lure traps in different positions. Three sets of dry-lure traps were placed in open canopy trees, and in the upper and lower dense canopies of bearing trees between April 24 and May 28. Dry-lure traps placed in upper and lower dense canopy trees mandarin canopies caught 195 and 141 flies respectively (not significantly different with the Wilcoxon's matched-pairs signed rank test at $p=0.05$). This was significantly more than traps placed in open canopy trees, which caught 38 flies. A few flies were caught in dry-lure traps in peach and pear trees.

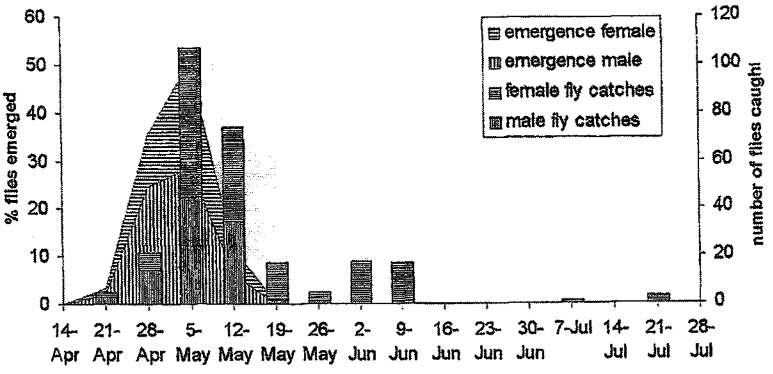


Figure 24. PH-loaded dry-lure trap catches in relation to B. minax *emergence, as recorded in the Rongthong orchard in 1996. For emergence n=1,099 (39% female); for trapping n=269 (during emergence 53% female, after emergence 93% female).*

Control.

1991-1997 fruit drop data of the 1994-1995 treated Lyenkhar orchard and the non-treated Rongthong orchard are presented in Table 14. Fruit drop in the Rongthong orchard varied from 46 to 78%. In 1997, relatively little *B. minax* activity took place, possibly due to unfavourable weather conditions during emergence and the consequent high mortality of pupae.

In Lyenkhar, the fruit drop percentage dropped from a normal 55-75% to a significantly low 17% after a bait application in June-August in 1994. In 1995, when the orchard was treated from the emergence period in April onwards, losses dropped to 9% and combined with the abnormal poor fruit setting, this meant that fruit drop was reduced to 3% of the normal average figure. Fruit fly activity recovered in the following two years. In 1996 4% of set fruits dropped (7% of the average normal fruit drop, significantly lower than Rongthong fruit drop). In 1997, 50% of the set fruits dropped (33% of the average fruit drop, not significantly different from Rongthong fruit drop). Fruit drop percentages varied from 45 to 78% before, and from 4 to 17% after control.

	average tree relative bearing (avg. 1994-97=1.00)	treatment	% fruit dropped[1,2] ± 0.95 confidence interval	relative number of fruit dropped
Rongthong	1.00 = 1516 fruits			1.00 = 890 fruits
average	1.00	0	59 %[bc]	1.00
1994	1.21	0	57 ±19 % [cd]	1.18
1995	0.88	0	78 ± 7 % [a]	1.17
1996	1.14	0	54 ± 5 % [cd]	1.04
1997	0.77	0	46 ± 13 % [d]	0.61
Lyenkhar	1.00 = 1689 fruits			1.00 = 1098 fruits
before 1994	1.00	0	55 %[cd] (1991) 75 %[ab] (1993)	1.00
1994	2.20	late bait-splash	17 ± 5 % [e]	0.64
1995	0.18	full bait-splash	9 ± 3 % [e]	0.03
1996	1.20	0	4 ± 2 % [e]	0.09
1997	0.42	0	50 ± 5 % [cd]	0.33

[1] Figures followed by the same letters were not significantly different for the Bonferroni modified LSD test at p=0.05. Variance was derived from response of individual trees to variable fruit fly populations.
[2] In number of dropped fruits per total fruits, established through counting dropped and in-tree fruits of six trees (1991-94) combined with ovipuncture density observations in in-tree fruit (1995-97).

Table 14. Fruit drop caused by B. minax *in the Rongthong and Lyenkhar orchard. In 1994 an incomplete, and in 1995 a complete bait treatment were carried out in Lyenkhar.*

Discussion.

Trapping and monitoring fly populations.
Various baits were tested for their attractiveness in dry-lure traps. Mauri's Pinnacle lure and a casein-based protein hydrolysate (PH) from the Indian market appeared to be attractive. The weak attractiveness of Di-Ammonium-Phosphate suggests that the fly is attracted to ammonia. Screening of different lures was not done up to conclusion.

Pest population monitoring tools are essential for any IPM programme, particularly if IPM is to be disseminated through participatory extension methods. In the framework of the research described in this article, various tools for catching *B. minax* were developed (Figure 20). In Figure 25 the main periods of fly observation and attraction to traps are illustrated. The tools developed allow for identification of an active *B. minax* population during most of the year. In April-May, flies can be caught during emergence, both by cages over infested soil and by PH-loaded dry lure traps placed in trees. Just after emergence, flies disperse and they return to orchards when fruits reach a size of about 11-mm diameter. In that period fruit-mimic traps catch flies. During the oviposition period, in June-August, a trained person can see male flies flying about in the upper canopies of mandarin trees. Bait-monitoring traps occasionally catch flies and ovipunctures show on developing fruit. Early October fruits with maggots start dropping, while from November onwards pupae can be found in the soil. In spring however, the pupae density in soil becomes so low that untrained people can hardly detect them.

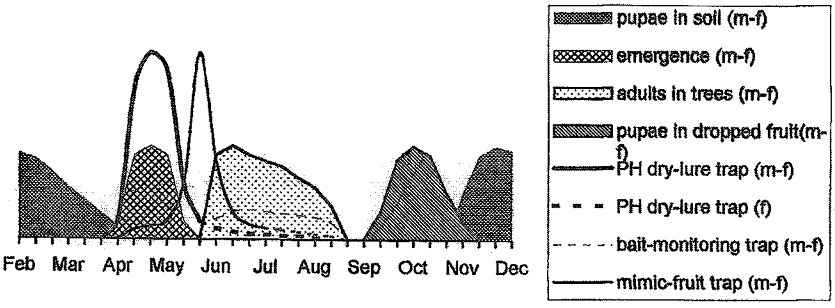


Figure 25. Schematic representation of B. minax *observation- (areas) and trapping- (lines) opportunities for male (m) and female (f) flies during the lifecycle-year.*

B. minax biology and cues for control.

Emergence period. At mid-altitudes, where high infestation orchards were common, the emergence period fell usually between April 20 and May 15, though after the relatively cold spring of 1997 emergence was delayed for about three weeks. Pupae kept at lower altitudes emerged earlier than pupae kept at higher altitudes (unpresented data). Time of emergence is probably determined by a simple temperature-sum (Wang and Lue 1995). In this *B. minax* differs from *B. tsuneonis*, which shows a pupal diapause (Yusada et al. 1993) and which emerges when its host is ready for oviposition, in June (Miyake 1919). It can be concluded that the timing of B. minax emergence is dependent on the local climate and weather. Thus, for control programmes it is best to establish the local emergence period by rearing adults in the emergence-monitoring bottle.

Flies were best attracted to PH-loaded dry lure traps during the emergence period, up to five days after the last emergence. Slightly more female than male flies were attracted (60-40% respectively, Figure 24). Thus, unlike our original idea, attraction to PH was best linked to emergence rather than to oviposition. This is in line with findings by Prokopy et al. (1992) who found that in *Ceratitis capitata,* both male and female 2-12 days old flies responded positively to PIB-7 (a standard protein attractant) droplets, and that attraction to protein increased with age. For *B. minax,* the high attraction period might be longer than the observed 5 days after emergence. Flies dispersed from the orchard soon after emergence, and we did not experiment with dry-lure traps outside the orchards. The attraction to protein lures could not be reconfirmed in cages or wind tunnels. Flies did not react to proteinaceous lures in such conditions.

Oviposition period. The earliest oviposition observed was in citron, in the Rongthong orchard, early June 1996. Citron fruited year-round, and oviposition took place as soon as females appeared. Next fruits to be fit for oviposition were fruits of lime. However, during this early oviposition period in citron and lime, the majority of flies must reside elsewhere until mandarin fruits (that represented over 95% of citrus fruit available) reached the size fit for oviposition in late June. As soon as individual fruits of different *Citrus spp.* reached 11-mm diameter, oviposition took place, and within days rather than weeks the entire fruit population was colonised (Section 5.2). The maturing time of females did not match with the development of hosts. Ten days before lime, and three weeks before mandarin fruit became fit for oviposition, female flies caught on fruit-mimic traps were all gravid. It is unlikely that the rest of the population matured slower, unless flies did not develop eggs in absence of preferred hosts, like was found in several monophagous species (Fitt 1986). The related *B. tsuneonis* in Japan is better adapted to local host availability: it emerges in June-July, and females oviposit as soon as they mature, within ten days after emergence (Miyake 1919, Zhang 1989).

During the oviposition period, the mandarin trees teemed with mostly male flies, while 30-40% of flies caught on fruit-mimic traps were female (Figure 23). Apparently, females visited mandarin fruits briefly while male flies reside much longer in the trees. Male flies were spotted in the upper half of the canopy, where mimic fruit traps caught more flies than in the lower canopy. The developing fruit was probably the place where flies met for mating, a phenomenon that is common in tephritid flies. Hendrichs and Hendrichs (1990) observed that *Ceratitis capitata* flies resided more on fruiting than on non-fruiting trees, and that male flies monopolized fruits where female flies reached for oviposition, a pattern similar to observed *B. minax* behaviour.

During the oviposition period in June-August, dry-lure traps caught few, mainly female flies (93%). Apparently, male flies lost their appetite for protein, while only few female flies fouraged in the orchard. It is also possible that bait offered in traps could not compete with natural food, as by that time the monsoon had started and plenty of natural protein sources were available. Yet, bait-monitoring traps caught relatively more males (29%) than dry-lure traps (7%). Possibly, these male flies were killed through accidental touching of the poisoned bait rather than through attraction.

During the late oviposition period, fly catches by any type of trap were irregular. Weather alone could not explain the catch patterns, and unidentified factors must have played a role. For example, a single catch of 42 females in one out of six bait-monitoring traps suggested that female flies had gregarious habits. Mid September the last flies were caught.

Control options: insecticidal cover sprays, baiting, catch crops.

Cover sprays. Despite considerable losses due to fruit drop, application of pesticides is not common practice in Bhutanese citrus cultivation. In Sikkim, cover sprays applied in September and October are reported to control *B. minax*. The reports are not very credible, as by September the oviposition activity is over, while insecticides are unlikely to reach eggs inside the fruit. Yet, blanket sprays may be effective if applied between emergence and early oviposition, i.e. between mid April and early July, even if they are difficult to implement and environmentally polluting.

Proteinaceous baiting. The strong attraction to protein during emergence allowed for control through application of poisoned bait. Such treatments had a control effect in the Lyenkhar orchard in 1994 and 1995. The 1994 reduction in fruit drop may be attributed to random touching of insecticides by the flies, as bait was applied after the main attraction period. The 1995 (and consequent 1996) figures show a convincing decrease in infestation percentages and fly activity. In fact, only a few active females had remained in the orchard. This effect was obtained through baiting with a medium-attractive bait, while pesticide use was about only 1% of the active ingredient compared to conventional cover sprays. In a few villages farmers managed to reduce *B. minax* infestation in the same way (Chapter 3). We conclude that bait-splashing bears the potential to reduce the *B. minax* population below economically important levels.

Preliminary trials suggested that the place of bait application within the tree is not very important, if the spot provides shelter (like in dense canopy trees). Flies seemed to go at least a tree distance out of their way for a suggested protein meal. Baiting during sunny days is more likely to be effective than during overcast weather days as flies are more active and bait is not washed away by possible showers.

Further research is needed to develop a more comfortable bait application method than the utilised splashing technique. Ideal would be a single time application of a slow-release bait at a fixed date. For example, in 1997 the research team experimented with bait soaked cloths and bait loaded fruit-mimic traps present during emergence and oviposition.

Trap crops. Efficacy of *B. minax* baiting in individual orchards will reduce if flies immigrate from elsewhere (Section 6.2). In such a situation, the effect of baiting flies during emergence will be reduced or undone. The migratory character of the fly could be coped with by implementing control programmes over larger areas. However, large-scale programmes are often difficult to implement. A method to catch flies just before oviposition would greatly add to an IPM strategy for *B. minax*.

In this Chapter the fly's attraction to early fruiting *Citrus spp.* such as lime has been substantiated. Growing lime trees at regular intervals, and treat them during the early oviposition period, would kill the fraction of the population that escaped earlier baiting activities. For a *B. minax* IPM programme one can think of planting lime trees for treatment scattered over citrus growing villages. The bait-monitoring trap (Figure 20a) can be used to evaluate the efficacy of trap crops. Baiting just emerged flies and trapping them in early developing *Citrus spp.* could be complementary techniques to keep fly populations at very low population levels. This strategy is yet to be explored in field experiments.

6.2. Can hygienic measures control a univoltine tephritid fly?

Abstract.

Bactrocera minax *is a tephritid fly that causes mandarin* ***(Citrus reticulata)*** *fruit drop in eastern Bhutan. The fly is monophagous and univoltine, so that cleaning orchards of maggot-loaded dropped fruits, or tilling orchards, were possibilities for controlling the fly. However, cleaning orchards did not result in noticeable control.*

To study the effect of hygiene, the puparia density in orchard soil was recorded in orchards of eight villages, some of which had been cleaned of dropped fruits, some had been tilled and some had been left untouched. Removing dropped fruit reduced puparia density in autumn from around 100 per m^2 to only a few. In spring, no such difference could be detected: puparia densities were 3-27 per m^2 both in cleaned and non-cleaned orchards. Tilling undid this natural control effect: in tilled orchards 17-65 puparia per m^2 were found.

To evaluate the control negating effect of fly dispersion, the fly population of one orchard was reduced to near eradication by proteinaceous food-baiting, while in a village at 1,200 m distance the fly population was left untreated. After baiting activities in the treated orchards stopped, we caught sizeable numbers of flies between the village and the orchard though it still took two years for the fly population to recover.

Cleaning infested orchards hardly adds to the natural control system in soils, which is probably counteracted by tilling. Fly dispersion takes place over 1,200 m, but it does not negate control measures taken in the same year. I conclude that fly control measures are more likely to be effective if they take place ***after*** *rather than* ***before*** *natural control mechanisms act.*

Introduction.

Bactrocera minax Enderlein is a tephritid fly that oviposits in citrus fruits and causes premature fruit drop. The fly is common in the eastern Himalayas (Sikkim, Darjeeling, Bhutan) and south-eastern China. In Bhutan, the fly causes 30-80% fruit drop in middle-altitude mandarin *(Citrus reticulata* Blanco) orchards. Flies emerge from puparia in soil in April-May. Adults colonise citrus fruit populations as soon as fruits reach 11-mm diameter; for mandarin this means from mid June onwards. Eggs hatch from late September onwards, and fruits prematurely ripen and drop in October and November. After dropping, maggots develop further and leave the fruit for pupation in the soil from where adults emerge the following spring.

In isolated villages of eastern Bhutan, proteinaceous baiting appeared to bear the potential to control the fly (Section 6.1). This method entailed availability of food bait and malathion, of which the supply was not very reliable. A theoretical alternative strategy is employing hygienic measures, which are sometimes recommended (e.g., Retan 1991, A. Allwood [Fiji] pers. comm.). The life history of *B. minax* suggests that hygienic measures may be feasible. The fly is univoltine (i.e. it has one generation a year) and occurs exclusively on citrus (White and Elson-Harris 1995). Fruit drop is confined to two months, and hardly any maggots escaped from fruit before dropping (Section 5.3). Collecting dropped fruit in pits and covering them with soil costs nothing but labour.

Hygienic measures to control *B. minax* are reported to have been carried out in China and Japan. The most straightforward way of control was the catching, by net, of adult *B. tsuneonis* flies in Japan (Miyake 1919). The prefecture bought flies from the villagers; in 1914 in a village called Tsugumi, 201,675 flies were caught resulting in considerable reduction of the fly population. In China in the 1950's, extensive hygienic campaigns were organised. Collectively owned orchards were cleaned from fruit with oviposition signs. Infestation was reduced [from 30-80%] to 5-0.5% in various provinces (Yang et al. 1994). Both these control methods were found to be impracticable in Bhutan.

Another type of sanitation was the collection and disposal of maggot-loaded fruit just after drop, and tilling orchards to kill remaining puparia. In Japan, Miyake (1919) reported similar efforts to control *B. tsuneonis.* Dropped mandarin fruits were collected, orchards were ploughed and poultry were used to feed on puparia in the soil. In China, orchards are ploughed and intercropped with annual crops to change the pupal environment and enhance the effectiveness of natural enemies (Yang *et al.* 1994).

In Bhutan, the collection of dropped fruit and ploughing infested orchards are indeed feasible for controlling the fly. A citrus IPM programme recommended this practice to farmers (Schoubroeck and Sharma 1994), and in some villages farmers invested days to dig deep pits for disposal of dropped fruits, while some orchards were intercropped. It was found that in villages where farmers collected fruits, fruit drop was not noticeably reduced. Similarly, Hollands (1994) had found that collection and disposing dropped fruits in research-managed orchards were not effective in reducing fruit drop. Possible explanations were the low rigidity with which hygienic measures were implemented, or the immigration of flies from nearby infested areas. This paper explores whether collection of maggot-loaded dropped fruit and soil tillage have the potential to control fly populations, and whether adult flies move from infested to non-infested orchards.

Materials and methods.

Hygienic measures.
As a preliminary experiment, one farmer collected dropped fruit from under one tree every day, while fruits from under another tree were left on the ground. After the fruit dropping period, the soil under both trees was examined for puparia.

The effectiveness of dropped fruit collection and soil tillage was further studied in four *B. minax* infested villages in Pemagatshel district, eastern Bhutan. Most farmers had regularly collected dropped fruits from their orchards and disposed them in pits, although a few of them did not participate in the programme. Thus, there were cleaned and non-cleaned orchards in the same environment. After the puparia overwintering period (early April 1994, just before fly emergence), one untreated and one treated orchard were selected and examined for puparia in four different villages. Orchards were considered treated if farmers had collected dropped fruit three or more times during the dropping season. Random sampling for puparia was not feasible as most orchards were situated on steep slopes from which fruits rolled down. Diggers for puparia tried to find places with as many puparia per sample as they could, in a competitive setting. One sample consisted of 30x30 cm infested soil. The sample was examined for puparia with a fork, and re-examined by another sampler. Maximum two samples from under a single tree were taken. Per orchard, either 15 samples with at least one puparium found were examined, or a maximum of 30 samples was taken. Possible tillage of orchards under study was recorded.

Dispersion of the adult fly population.
The fly movement study was conducted along the Tashigang-Kanglung highway, on the east slope of the Drangme-chu river valley in eastern Bhutan. The area is characterised by a mixture of wetland area, fallow dry land, and subtropical forest on steeper elevations. There are a few isolated orchards on the slope *(Figure 26)*, such as the Lyenkhar orchard and Rongthong village situated 1,200 m apart. Both orchards consisted of about thirty 25-35 years old mandarin trees and five lime trees, and natural fruit drop ranged from 54 to 78% (Hollands 1994 and own observation). Fruit drop and bearing were recorded in 1994-1997. In Lyenkhar in 1994-1995, proteinaceous food-baiting was used to reduce the fly population to near extinct.

Manidangre is the area between Rongthong and Lyenkhar. Along the road there were a few wild fruiting lime trees (*Citrus aurantifolia* Swingle). The very poor road workers always harvested the lime fruits before *B. minax* maggots could develop, so that any observed *B. minax* must have immigrated from either Rongthong or Lyenkhar. These lime trees made dispersal studies between the two orchards possible. In 1996 and 1997 *B. minax* infestation amounted 70-80% (observed by checking fruits for ovipunctures, Section 5.3).

On May 5, 1997 five fruit-mimic traps (green balls with non-drying glue, Section 6.1) per tree were hung in one lime tree in the Rongthong and one in Lyenkhar orchard, and in three solitary lime trees in Manidangre. Traps were checked three times a week until mid September.

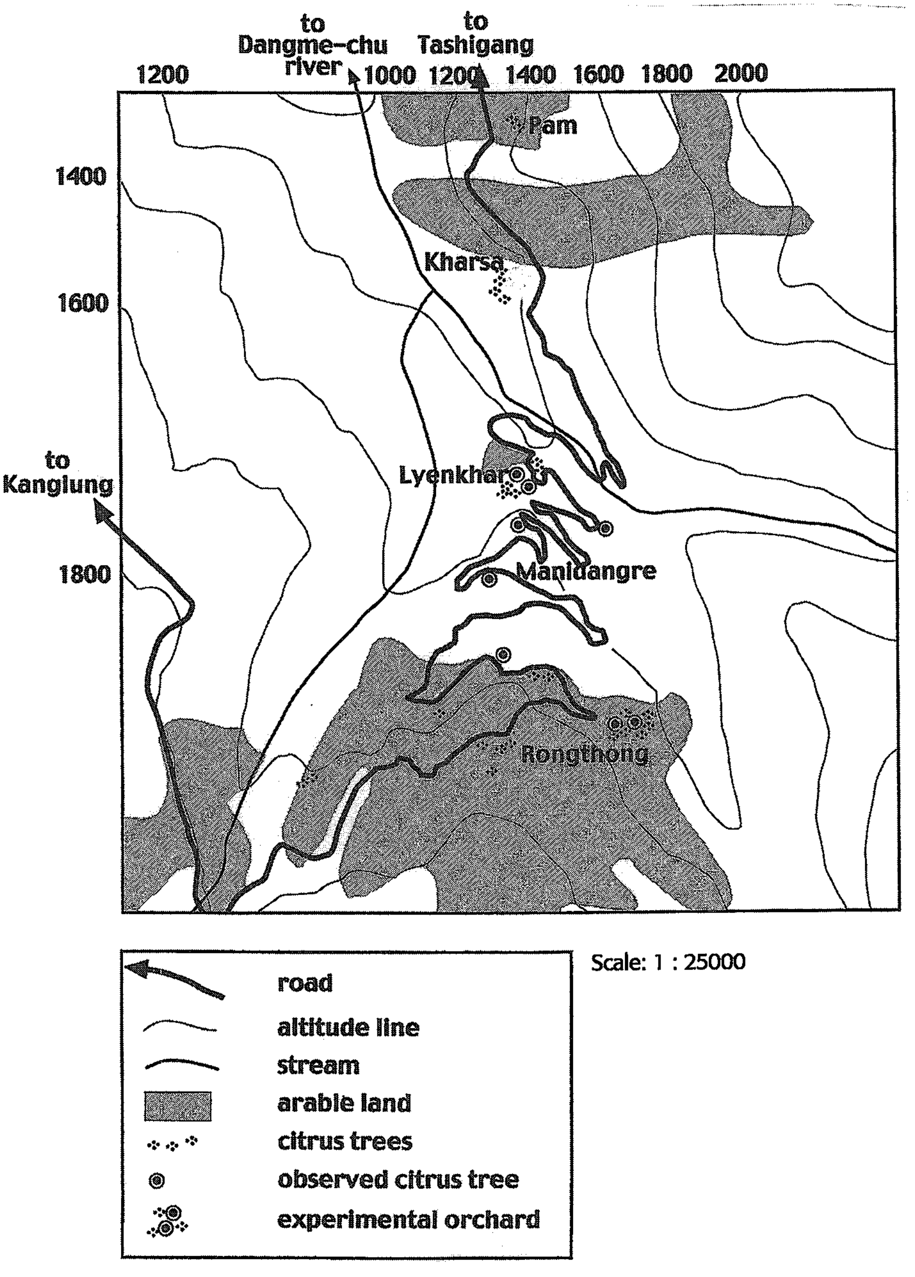


Figure 26. The Lyenkhar and Rongthong experimental mandarin orchards and their surroundings.

Results.

Hygienic measures.

Soil was checked for presence of puparia just after fruit drop in autumn. About 25 m^2 of non-cleaned soil yielded 2,300 puparia, and the same area of daily cleaned soil yielded six puparia. Thus, carefully implemented hygienic measures were capable of reducing puparia populations in autumn.

In spring however, samples varied greatly in number of live puparia found. Even after a few days of practice, samplers had difficulty in locating high concentrations of puparia. In (unploughed) orchards where fruits had been collected, up to 12 puparia per (30x30 cm) sample were found. In unploughed and ploughed orchards where fruits had not been collected, up to 17 and 32 puparia per sample were found. The results are summarised in Table 13. Through testing with the GLM test of Between-Subject-Effects, the effect parameter of dropped fruit collection was not significantly different from zero at the 5% error level. The effects of tillage and village were significantly different from zero. This means that samples from tilled orchards yielded significantly more puparia than samples from untilled orchards. Samples from treated orchard yielded fewer puparia than samples from untreated orchards, although the difference was not significant over four villages.

Village	*Lyenkhar*		*Burna*		*Chemung*		*Dungmin*		*Dena Wung*		*Nangma-lang*	
*30*30 cm sample size n*	30	15	26	18	30	30	15	30	24	30	15	18
Infested fruits collected	no	no	no	yes	no	yes	no	yes	no	yes	no	no
soil tilled	no	yes	no	no	no	no	yes	no	yes	no	no	yes
Puparia per m^2	7^a	65^b	27^a	23^a	13^a	6^a	40^a	12^b	17^a	7^a	3^a	54^b

Sample means from the same village followed by the same letter were not significantly different for the LSD test at p=0.05.

Table 13. Number of B. minax puparia m^2 in spring in orchards where hygienic measures (collecting dropped fruit, ploughing) were carried out or not.

Population control in an orchard close to an infested area.

Lyenkhar orchard was treated with proteinaceous baits in 1994-1995 while Rongthong village was left untouched. In 1996 and 1997 the Lyenkhar fly population was allowed to recover. The result of the experiment is given in Figure 27. In 1996, when no control was carried out in any of the orchards, the fly activity in Lyenkhar remained low, even if it tripled from near zero in 1995. (Fruit setting in 1995 was low and 4% fruit drop in 1996 was equivalent to about 30% fruit drop in 1995). The data show that it is well possible to reduce a fly population in one orchard if an infested citrus area is present at more than 1-km distance.

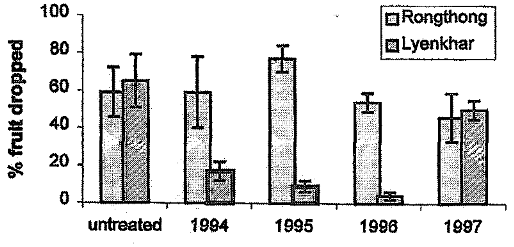


Figure 27. Fruit drop induced by B. minax *measured in six trees in the Lyenkhar and Rongthong orchards, situated at 1,200 m apart. In Lyenkhar orchard in 1994 and 1995 the pest was bait-poisoned (bold columns); in 1996-97 the fly population was allowed to recover. Error bars indicate the standard deviation over years ("untreated") and 95% confidence intervals.*

Dispersion of the population.

Fruit-mimic trap catches between Rongthong and Lyenkhar are summarised in Table 14. The first catch was in Rongthong on May 16; up to June 10 only 27 flies were caught. In Lyenkhar, only four flies were caught up to June 10, an indication that the local population was not very large. During the entire season, 549 and 175 flies were caught in Rongthong and Lyenkhar respectively. Despite the fact that no local population was present in Manidangre, in total 294 flies were caught on fruit-mimic traps in three solitary wild lime trees. These flies must have originated from either Rongthong or Lyenkhar orchards.

location	*trapping period*	*total flies caught*	*first catch*	*flies caught up to June 10*	*main catch period*
Rongthong orchard	5 May-15 Sep	549	16 May	27	12 June- 23 July
Manidangre	5 May-15 Sep	294	12 June	0	12 June- 28 July
Lyenkhar orchard	5 May-15 Sep	175	28 May	4	23 June-18 July

Table 14. Fruit-mimic trap catches in lime trees on the Rongthong-Lyenkhar traject during the fly emergence and ovipostion period of 1997.

Discussion.

Hygienic measures.

Puparia density observations in cleaned and non-cleaned soil in autumn suggest that collecting dropped fruits considerably reduces puparia densities in autumn. Just after the fruit drop period, puparia were found in densities between 100 and 200 puparia per m^2, while in carefully cleaned places hardly any puparia were found. Fruits were disposed of in pits, and farmers could see that maggots died of suffocation or predation by ants, which were apparently able to find their prey if in such high concentrations (unpublished data). In our experience, very few flies emerged from fruits disposed in a pit, and the application of insecticides to kill maggots or puparia in such pits (as recommended by Subba *et al.,* undated) was not necessary (unpublished data).

The high mortality of concentrated maggots and puparia did not exclusively occur in disposal pits. In spring puparia densities had vastly reduced to typically 5-10, or up to 27 puparia per m^2. Natural enemies such as ants, hens and rats grazed spots where puparia were concentrated and predated on over 90% of the puparia population (own observation). I am not aware of detailed studies on predators of *B. minax* puparia. C. van Achterberg (in prep.) reported the isolation of a new parasitoid *Diachasmimorpha feijeni* (Hymenoptera: Braconidae), from eastern Bhutanese *B. minax* puparia, which seems of little importance. Newell and Haramoto (1967) reported 75-87% mortality of *B. dorsalis* puparia by ants in about one month.

Thus, it seems that natural control brought the puparium population to 5-30 puparia per m^2, an infestation level that one to seven infested fruits per m^2 can result in. Therefore, the fly population can only be reduced if hygienic measures are implemented rigidly i.e. if dropped fruit density is brought below seven fruits per m^2, while fruits that roll down slopes into bushes should be collected also. The latter is an impossible task in steep villages bordering forest, and obviously the method is not feasible in Bhutanese conditions. This explains why, after the winter period, cleaned and non-cleaned orchards showed no difference in puparia populations, and why collecting dropped fruits did not result in reduced fruit drop (Hollands 1994, and unpublished observation).

In ploughed orchards in spring, puparia densities were higher than in unploughed orchards (Table 13). This observation was inconsistent with practices in China, where reportedly 65-100% of puparia is killed through ploughing orchards; in fact, Chinese orchards are intercropped with the objective of controlling puparia in the soil (Wang and Lue 1995). I speculate that in Bhutan, in ploughed soil, a good shelter opportunity for pupariating maggots was combined with a breakdown of the natural control system. Deep burying of puparia hardly works, as Miyake (1919) found that if puparia were buried up to 45 cm deep, still flies emerged. Thus, soil tilling has minimal or no controlling effects.

Adult population dispersion.

Figure 27 shows that it is possible to control *B. minax* in orchards situated at more than one km distance from infested areas. Thus, dispersion of the fly population is not a major factor in the ineffectiveness of hygienic measures (or other control methods). In between the two orchards, where flies could not reproduce due to premature harvesting of fruit, flies were still caught on fruit-mimic traps, though later than in Rongthong and Lyenkhar. Moreover, in Rongthong 549 flies were caught in one tree, while in Manidangre and Lyenkhar each tree caught between 89 and 115 flies per tree. Apparently, flies did not massively move away from Rongthong area. Flies caught in Manidangre must have come from at least 600-m during the dispersion period. This is consistent with the findings by Wang and Zhang (1993) who showed that in flat orchards that *B. minax* adults dispersed mostly 500-1000-m (maximum 1500-m). Miyake (1919) found that *B. tsuneonis* dispersed up to 720 m within a citrus growing village over three days. Thus, it seems that part of the adult population disperses, even if most flies stay within 600 m of their orchard of origin. This notion bears importance for eradication programmes. If fly populated areas lie close to cleaned orchards, the influx of flies from areas at 1 km distance requires that fly control needs to be continued.

Conclusions.

A closer look at the life table characteristics of *B. minax* can clarify the potential effect of a control measure. Female flies produce between 80 and 700 eggs (Wang and Lue 1995, Section 5.3), and about half of the eggs must be female. Thus, in a fly population stable over longer periods, only between 0.3 and 2% of the female eggs result in an egg-laying female in the following year. Therefore, considerable fractions of eggs, maggots, puparia and adults must die in the course of the season. In Rongthong orchard, the usual within-fruit mortality of eggs and maggots is less than 50% (Section 5.3), which does not account for the vast mortality between generations. Therefore, natural mortality in pupal or adult stages must be an important population regulation factor. A control measure such as collection of dropped fruit reduces puparium populations *before* natural control mechanisms take place. If natural control is higher in soil with high pupal densities, collection of fruit reduces its effectiveness.

Thus, for control options, it is relevant whether control takes place before or after life history stages in which substantial natural control takes place. Farmers better invest in proteinaceous food-baiting during fly emergence (after puparia are preyed upon) or trap cropping (after flies have dispersed and located fruit) as they act *after* major natural mortality mechanisms. It is concluded that the discussed hygienic measures are not a practical option to contribute to an IPM strategy for *B. minax*.

Part III. Conclusions.

7. How to research the interaction of technology and sociology?

This chapter briefly discusses how socio-technological innovations can be built, mainly referring to Chapter 3 on the village research process.

7.1. Village research programmes allow for studying the interaction of social and technical processes.

Experimenting in villages as working hypothesis.

Chapter 3 started with showing that in the late 1980's IPM was mainly defined in technical terms, and that farmers were rarely in a position to apply technology developed on-station. It looked at the case of Farmers Field Schools for rice IPM in Indonesia, and found that the curriculum of those field schools dealt with not only control technology, but also with technology that made pest development processes visible to farmers. Research and extension staff and farmers are to join hands to sort out any problems occurring when applying IPM. The introduction of IPM that needed communal action would be extra difficult as in that case the classic diffusion of innovation mechanism does not apply.

As a working hypothesis, research and extension staff and farmers were to develop control of the chinese citrus fly in two isolated citrus growing villages. The idea was that combined knowledge of the three stakeholder groups could help in thrashing out problems in the application of IPM. Simultaneously, on-station research provided technological ideas to be applied and adapted in the villages. Although the programme objective was originally defined in technical terms, soon the including of research sites in villages overhauled the originally intended contents of the research programme. The presence of various stakeholder groups such as the district administration, farmers and extension staff challenged the idea of exclusive technical development. Pressure and wishes from various groups and the limitations of their capabilities determined priorities for technical development. On the other hand, technical possibilities had their impact on the social configuration in which they were applied. For citrus fly IPM to work, the relations between farmers, research and extension staff had to be reconsidered. Farmers were not "recipients" of technology anymore; instead ideas from on-station research (usually in the shape of a tool) were handed over to farmers, who immediately moulded it and used it for their purposes, usually far beyond the imagination of the staff. Part of the subsequent research then became figuring out whether the adaptations farmers had made were technically sound or not and so research again embarked upon many a useful notion for innovation. When the farmers community was not in a position to organise itself for the sake of the experiment, the extension staff had to facilitate the process until technology was successfully applied, leading to practical knowledge on community organisation etc. This network of stakeholders was successful in developing technology applicable in the particular villages, providing a pattern for citrus IPM as well as for the implementation of socio-technological research.

In what type of village is research best carried out?

The IPM development programme has been carried out two villages that, for the sake of the argument, are being labelled "innovative" and "conservative". In the innovative village, a group of active farmers grabbed any technological trick the researcher came up with, and moulded it further into technology that they applied all over the village. Even if not all households were aware of technical developments, they happily let the group decide on the management of their individual orchards. During programme implementation the researcher observed that activities needed better timing and so the village showed that it needed monitoring tools for setting the agenda of its activities. More than critical users of technology, the community was charmed by the idea of experimenting itself, and soon it set its own agenda for further experimenting activities.

In a more conservative village for a long time the community remained for a long time divided on whether it wanted to carry out the inherent sinful programme. Thus, the community had difficulties in organising the baiting activities, and the extension staff took up a role of facilitator to try to introduce knowledge for application at community level. This led to development of knowledge on the organisational intervention in communities. The researcher observed that the community found baiting a complicated procedure, and it became clear that a simpler procedure was needed. Individuals in the community kept on experimenting with technology, to be able to get the same profits at less organisational costs.

A comparison of the case shows that the knowledge the programme generated in both villages differed vastly. In one village, the emphasis laid on technical development, in particular the use of monitoring tools, while the results in the other village covered the social configuration of pest control activities and the development of simpler control methods. This shows that the programme in both villages led to particular knowledge, according to the problems encountered during programme implementation. Which is not to argue that the resulting technology or organisational patterns in one village could not be used in the other one. Experimenting in both villages yielded technological developments, and insight in the role of each stakeholder in such programmes. More progressive communities can serve as working partners to make theoretical control options operational, while more conservative villages are a nice arena for processes of simplifying technology and observing the dynamics of knowledge change within communities. Thus, both types of villages serve a different research objective. There are many more variations possible, such as variability in climate, in the relative importance of the crop under study, in the size and structure of the community, etc. This implies that we cannot expect to have sorted out all possible IPM problems for hundreds of citrus growing villages based on an experimental programme in just two of them. I expect that in southern or western Bhutan, where the social configuration of villages and the relation with extension services are different, another socio-technological set-up will be needed for citrus fly control. Generally spoken, one should select communities for specified socio-technological development objectives. In practice however, research objectives are rarely defined so specifically and villages are selected following more arbitrary criteria such as accessibility or presence of influential people's relatives, etc.

7.2. *The need to maintain support from farmers, extension staff and policy makers.*

The generation of socio-technological knowledge can only be carried out if different stakeholders co-operate. Farmers, research and extension staff implement such programmes with support from administrators, the Ministry of Agriculture and donors. In this Section I would like to discuss possible motives of each stakeholder to participate in such programmes. It must be noted however, that during this first village level experimenting programme, even direct implementers mixed up the generation of knowledge aspect with the direct effects on the village's economy, for reasons explained.

Farmers support experimental programmes for the promise of better profits.

Some farmers are interested in experimenting as such. Such "innovative" farmers are usually of relatively high social status (Rogers 1995), they usually do not have peer experimenters in their village, and for such farmers the presence of government staff as discussion partners is a reward in itself. The in-village experimenting component of our early extension programme (cf. Chapter 2) was completely carried out by innovative farmers. An average community does not have the same interest in experimenting as its individual innovative farmers. Most farmers within a community are not interested in experimenting as such; the majority of farmers participate in experimenting for the promise of material benefits. Now, an essential element of experimenting is its trial-and-error character. Benefits can not be guaranteed, and it thus follows that the support for experimental programmes by an entire community is problematic. In the Bhutanese set-up, in the first year of experimentation, for reasons of politeness the farmers' community co-operates with any new programme. If after that year farmers do not obviously benefit from experiments, if staff does not address this problem usually one or two vocal farmers use their influence to block the carrying out of further experimental activities. There are a few options to be able to continue experimenting. One can start personal relationships with opinion makers in the village, which may stretch the span of polite support for one or two seasons. One can use administrative force, which obviously does not result in proper motivation and is not likely to develop sustainable application of technology. This option is often applied, for example for the abandoning of slash-and-burn cultivation or when communities are instructed to build latrines. Another option is to implement different activities at a time, some with proven technology, some as an experiment. The "successful" activities then make a good show to ensure support for the experimental activities. Yet, the best way to get support from the farmers' community is achieving a success that is widely acknowledged in the farmers' community. Therefore, in a village programme the period of experimenting should be kept as short as possible. As a preparation one should develop a broad overview over available technical possibilities. Things that can be sorted out on-station should be sorted out on-station. A community's genuine support for experimenting is difficult to achieve, particularly if the time span of polite support is exceeded without resulting in material benefits.

Extension staff acts as facilitator and scaling-up agent.

Experimental programmes rarely pay to extension staff in the shape of material benefits. Staff's salary is usually fixed, successful implementation of such programmes does not result in better chances for promotion, and material benefits are therefore restricted to incentives such as daily allowances for incidental training activities. Thus, the motivation to experiment in villages should be invoked in another way. Some extension staff is genuinely interested in experimenting. The involvement of research staff provides supervision, a discussion partner and personal interest to extension staff that all too often work in an isolated and poorly supported fashion. But also the experimental work as such may provide a nice distraction from the routine activities. In research villages, apart from innovative farmers, also extension staff started to experiment with provided monitoring tools and enthusiastically showed various tricks to farmers' communities outside the research villages. However, such enthusiasm usually resulted in a "dead end", as staff was rarely in a position to support village level activities to an extent that they led to recognised reduction of fruit drop. Thus, as long as experiments were on going, and research staff was intensely involved in the programme, support from extension staff was ensured; after that, extension staff could not sustain scaling-up activities. Similar mechanisms were found by Matteson and Galagher (1994) who found that the dissemination of IPM took place as long as it was a learning process; after standardisation the dissemination process stopped.

Research staff initiates, defends and documents the experimental programme.
The citrus IPM programme was initiated by a research institution. The change of research site invoked a series of changes that re-defined the role of research staff. In villages technical developments can not be regarded isolated from the social context, which calls for skills that not all researchers are equipped with. They need to be sensitive to "tacit knowledge" (Nonaka and Takeuchi 1995) of farmers and extension staff and provide them with tools and possibilities for action. As long as researchers are educated in technical rather than social skills, it depends on the personality of the researcher whether he or she can deal with such tasks or not. Some researchers will find the involvement of farmers in their research set-up an irritating disturbance; others see farmers' practices as a source of inspiration and enjoy involvement in organisation building and sharing of knowledge.

An extra dimension of in-village research appeared to be the exposure of the village research programme to village communities and to administrators. The support of such actors has a dynamics of its own. They usually go for short-term objectives such as better yields rather than for objectives such as creating organisations or socio-technological knowledge. When carrying out village level experiments, the researcher has a hard time steering a middle course between long-term objectives and short-term demands by farmers and administrators. This is particularly difficult for researchers who are not in a position to defend their programme to administrators (such as younger national staff) and who, as a result, can not develop technology up to a level that is applicable in villages. For example, in the citrus fly programme, the technology with the best potential has not yet been thoroughly tested because the attention span of donors, administrators and farmers was less than the time needed for development of technology. This while the research period allowed in this case was exceptionally long for Bhutanese standards. Even if village experimental programmes considerably speeded up technological development, still quite a few individuals in the stakeholder groups meant that the researcher carried out his "hobbies" rather than doing useful research. Expectations of research are often overstretched, and researchers are rarely in a position to spend more than a few years on one topic.

In the citrus IPM programme the role of the researcher was bigger than strictly necessary. He was responsible for initiating and sustaining the experimentation process in villages. An alternative set-up could be that the district agriculture section initiates a similar research programme, occasionally calling in assistance from research staff. In this set-up the district would be in a position to determine programme priorities, in co-operation with farmers and research staff. For a programme such as the citrus IPM programme this would probably have led to more emphasis on making socio-technological knowledge fit for routine scaling up activities and less on the social dynamics of one particularly difficult community.

District administrators support the programme for poverty alleviation.
The interest of the District Administration in the programme was similar to that of the majority of farmers, be it that it was concerned about district development and not individual household or village development. The district administration regarded improved citrus yields as a way to improve farmers' incomes, and allowed for village experimenting because it expected it could result in improved yields over a short period. However, some district staff had difficulties comprehending the experimental character of the programme. During agriculture workshops the researcher usually briefed district staff about the experiments to be carried out. Staff often regarded the strategies-to-be-tested as final recommendations to be spread over the entire district area so that many villages were confronted with changing recommendations over the years. For

the district, the knowledge developed had its value only as far as it could meet the objective of improved citrus yields and the process of knowledge development in itself had little value. The district administrator was clear in his demands for fast results that led to a fast development of technology, although at times expectations were high and the programme could not meet the demands. Chapter 4 briefly discusses the scaling-up programme in the district.

MoA and donors support the programme if it fits their dynamic policies.
The support for the experimental programme by farmers, the district administration and research could be well understood from the objectives of each stakeholder. Their objectives were stable and could be built into the programme goals. The programme was however dependent on the policies of the Ministry of Agriculture and donors, institutions in which policy makers formulate new policies. Part of these policies are based on ad-hoc programmes formulated as and when there is political pressure for action. When in 1993, 1995 and 1996 the mandarin harvest was poor, fruit drop was pointed out as a major cause and the Ministry supported the village experimenting programme (presented as a national programme) to show its swift action in response to the problems. For the longer term one depends on policies formulated in five-year plans, etc. in which a variety of policy lines is formulated. Cash crops and food security were explicitly mentioned in the seventh five-year plan, and most policy makers could see that the citrus IPM programme resulted in the felt needs of farmers. This resulted in support for the programme for as long as the original staff was around. However, in the mid-1990's the Ministry adopted a policy of integration of agriculture, livestock and forestry services, and the citrus IPM programme was regarded a highly specialised programme that did not fit in this policy. Thus, once staff left, the programme came to an end.

This stresses one particular characteristic of small-scale research programmes in which researchers try to get things work for later scaling-up. Researchers are almost always people with a technical or sociological background, with little interest in policy making. On the other hand, policy makers take the work of researchers at best as marginal inputs in their work. For scaling-up programmes, commitment of both parties is necessary, while the two groups are rarely in a position to understand each other's point of view. No doubt, for scaling-up programmes to have a chance for success the two stakeholder groups must link much more closely, just like in this study farmers, extension staff and research staff carried out joint programmes.

The same "division of worldviews" could be seen in the donor environment. The turnover in policy guidelines went even faster than in the national policy guidelines: mainstream policy changed two or three times during programme implementation. Respective mainstream policies of poverty alleviation, adoption of a "process approach" and addressing gender were swapped for a policy of reciprocity of development aid, conservation of the local culture and rural enterprise development. Thus support for the citrus IPM programme was discontinued. Chapter 4 briefly discusses the interaction of policy and programme progress in the framework of scaling-up of pilot successes.

7.3. Organisation and knowledge for the application of technology.

The introduction of "group level knowledge" and organisational structures.
Now that programme support by the community as a whole has been discussed, it is time to consider what community level support means in terms of activity and social configuration. Douglas (1986) argues that groups develop a common understanding, and in this argument I wish to take this "group cognition" as a (community level) awareness resulting in the skill to be able to apply technology at village level. In the village experimenting programme we wanted pests to be controlled, and for that group level activities were needed, and therefore group level knowledge or group cognition were essential components. The technical need for such a group level activity had two consequences. On one hand, by showing and explaining about flies flying about, all stakeholders understood the need for communal activities. This resulted in farmers trying to organise their community for fly control. In the Dungmin programme awareness of the majority of farmers did not lead to something like "community level knowledge" (Box 14). While farmers knew that communal action was a necessity to sustain the high yields, there were always reasons why not to implement the programme. Thus I deduct that the necessary "group cognition" about IPM has not been effectuated. Definitely, the original definition of the problem in technological terms veiled the need for specific expertise for community organisation. The need for success in 1995 forced the programme to take an organisational shortcut by staff involving in the organisation of fly baiting activities rather than taking a more distant stand, i.e., involving in organisational development alone. During the programme implementation organisational expertise was out of our reach, despite brief visits of a casual stray consultant who would emphasise that organisational development was "of upmost importance". I figure that this is a main reason why the programme in the Dungmin community never developed an organisation to sustain citrus fly IPM. In Am Shing, such an organisational pattern was already there and technical awareness was immediately translated into communal level activities. Thus, also in Am Shing it was not the programme that instilled social cognition (in this case for citrus fly control); it was already there, although the utilisation of the know-how alone reconfirms the capacity and need of such (local) expertise.

The field of relations between technology and organisation shows an interesting dilemma. The involvement of technological expertise in villages reveals the need for social action, leading to technical people involving in the organisation of villages. Agronomists however rarely avail of the explicit expertise needed to introduce organisational patterns; they usually stay focussed on technology and regard social organisation as a side-activity in their technically defined research. On one hand, when addressing technology alone, a sustainable organisation is difficult to develop, even if technology provides not only the notion of the need of social cognition, but also the tools to make this need visible and to build intuition on the problem the organisation is supposed to address. On the other hand, invoking organisations that lack an explicit (technical) objective serves no goal if they do not have a task outside the creation of the organisation itself. Thus we can conclude that the Dungmin programme suffered from the classical division between the bèta and gamma-disciplines, as only the combination of both domains of expertise can result in sustainable citrus IPM.

In the irrigation sector in Bhutan, this dilemma was recognised and an irrigation policy was formulated and adopted in which communities were trained on how to organise joint maintenance of channels (Blok, undated). In the drinking water sector the same problem never led to an adjustment in the national policy (Prakke, Thimphu, pers. comm.). In agriculture, just like in the drinking water sector, at times the problem emerged but was never addressed at policy level. I think that we are embarking on a problem that is equally important in the developing and in the so-called developed world (e.g., Röling and Wagemakers 1998). Social cognition can be regarded as a resource. The lack of the recognition of the complementing social and technical component of village-based development in Bhutan accounts for a gross ineffectiveness of village level programmes resulting in scepticism on the side of farmers and a general sentiment that extension staff is poorly motivated and generally ineffective. If the integration policy of the Ministry of agriculture would not only be technically defined, but would also include social fields of expertise, it would be a revolutionary expansion. Subsequent programme formulation and attraction of proper expertise would make a few pilot (scaling-up) successes possible and such programmes are likely to pay back in years rather than decades. I hope that this study provides inspiration towards such a policy.

Social constraints for application of available technology.
One of the obvious examples in which (the lack of) social cognition hampers progress is the case of mistletoe infested orchards. Mistletoe is one of the major pests in hundreds of eastern Bhutanese villages, even if control is simple and known to farmers, even in villages in which mandarin is extensively traded and the main source of local income. Similarly, in many villages a devastating pest such as trunk borer is rarely controlled, even if individual farmers often requested extension staff for a solution to problems observed. When trying to figure out why farmers would not control mistletoe, we failed to find any reason valid in either farmers' or staff's worldview. Farmers did not control such pests because they did not control them. The reason might be historical: until a few decades ago, each house needed mandarin only for the exchange of the yearly ration of salt as the market was difficult to access. Since then, the "social cognition" that mistletoe was to be controlled to make orchards more vigorous has just never been introduced, even if in most villages individual farmers kept on requesting extension staff to solve such pest problems. The point is, that changing the knowledge and attitude of a single individual is relatively easy, but to do the same at group level (i.e., to introduce "social cognition" on the topic) is a much more complicated task. In most communities, the adaptation to new circumstances (such as opening markets) is not initiated from within the communities itself. A social cognition, a new morale has to develop and for that most communities need assistance from outside. In such circumstances, it is not investments in information dissemination that is needed, but a facilitating role by the extension service (or any other party). Such facilitators should look why the particular community does not apply such obvious measures, and, if desirable, figure out how the community can be supervised to acquire the social cognition underlying such work. A changed role of the extension service, which would include a "programme approach" in villages (DoeDoe 1997), entails a different focus and training of extension staff. In The Netherlands, similar desirable changes in the role of extension staff have been identified as needed for the large-scale introduction of more environmental-friendly farming (van Weperen et al. 1998). Such a different focus is now accepted in programmes promoting participatory methods (e.g., Razaak et al. 1999). By 1997 the extension service in Bhutan was not in a position to just discuss the possibility of a social role of staff in villages. The initiating of research in pilot areas such as a single watershed area (P.M. Pradhan, Khangma, pers. comm.) will probably eventually lead to the same conclusion.

7.4. The development of technical IPM knowledge.

Technical experimenting in a social context emphasises both pest control and monitoring strategies.

Norton and Mumford (1993) present an extensive toolbox to clarify pest management mechanisms to researchers and farmers. Their technology is for the greater part developed on-station and that should somehow be made palatable to farmers. This study shows how through placing part of the research in farmers' communities, the need emerges to not only develop "control tools", but also "monitoring tools" for decision making, allowing for the building of an IPM strategy. In our example, an IPM strategy for the citrus fly consists of monitoring emergence of flies and application of bait accordingly, and monitoring of ovipunctures in early developing catch crops and treating the catch crop accordingly. This strategy is then to be applied by a community that is aware of the meaning of all signs, and able to translate it into communal level activities.

In the previous Section we saw how "social cognition" was an essential aspect of the application of technology in communities. Here I want to argue that the development of an appropriate set of tools is only possible through the experimental use of actors for whom the tools are meant. For IPM development, technical research needs the confrontation with analytical and organisational needs of farmers. Through a trial-and-error application of technology, one can develop both the social cognition aspect, and the technical tools needed for an IPM strategy. A similar approach to technology development can be found in various IPM programmes in the world. In an IPM project in Zanzibar, a skilled phytopathologist worked on adapting the FFS-curriculum to situations where diseases were the main plant protection problem. Farmers were given the opportunity to master concepts like diseases so that they knew how and when to implement hygienic measures (Gerard Bruin, Wageningen, pers. comm.). Another example is the development of cotton IPM in Sudan in which a wide variety of expertise was employed for this goal (Dabrowski 1997).

Village programmes indicate which technical notions need to be developed into tools.

Chapter 3 showed how investments in in-village and on-station-research were complementary in the presented case. Village programmes showed how general notions obtained from literature or on-station research could possibly be developed into practical tools. This was mostly a mental process carried out by the active users of the tools. The farmers used monitoring tools to minimise their investments in control, thus internalising the information that monitoring tools yielded. We have seen only few farmers using damage assessment tools to evaluate their efforts; farmers usually evaluated control efforts through a rough estimation of dropped fruit compared to other years. The researcher however needed exact loss figures for the scientific reporting purposes and developed the detection of ovipunctures to a pre-drop damage assessment routine. Similarly, extension staff used traps to show the presence of the particular pest to farmers. Such was the case for the development of monitoring and control tools for the chinese citrus fly, for which a relatively sophisticated technology is needed. In other pests, no station-led research was needed at all. For example, individual innovative farmers could figure out the control of trunk borer (Box 3) and for this particular pest no station-led research appeared to be needed.

The implementation of about twelve IPM village research programmes by the entire plant protection service in Bhutan in 1993-1997 provides a nice collection of various pests and the need for station-led and in-village experimentation. Some pests occurred exclusively in villages and their management would have no meaning in station-led experiments. Such pests included wild boar (DoeDoe and van Aaken, pers. comm.). In various pests of apple, research was done in farmers' orchards. The study of the phenology of pests and their consequent control was mainly carried out by station-led research; the application of its results was carried out in a community environment (Chencho Dorji, Thimphu, pers. comm.). In the study of late blight control in potato, station-led research appeared ineffective because experimental plots were too small and too variable in the rough Bhutanese terrain (Hollands 1994). The effect of planting a more resistant variety combined with the use of protective spraying was figured out by farmers' groups in a research village. In fact, this research revealed few technical secrets, and resulted mainly in an idea on how to introduce such spraying technology in eastern Bhutanese villages, thus addressing the social cognition component of late blight control (DoeDoe, pers. comm.). In an experiment to control chilli blight in villages, experiments yielded no significant effect of planting chilli plants on ridges. The experiments should have been carried out on-station simultaneously to be sure that the technology had disease prevention effects. Now, the programme failed to yield presentable data and such experiments need to be repeated to be sure whether the technology can be effective in the particular conditions (M.M. Kool-de Rie, Khangma, pers. comm.)

This list is not exhaustive and can be complemented with many more examples, also outside the field of plant protection. It shows that the relation between on-station and in-village research is highly dependent on the subject of research. And it shows that the failed application of many technologies that work so well on-station or in theory is a matter of cognition at the side of the farmers rather than of availability of technology.

The official programme is only a start for further experimenting by farmers.
Interestingly, once curiosity for technology is instilled in farmers' minds, their experimentation becomes an autonomous process. This shows that programmes, be them research programmes as ours, or extension programmes introducing socio-technological knowledge, represent only the start of new socio-technological dynamics. In that sense, the formation of experimenting groups is very important. In Am Shing, after having introduced various technological tools, experimentation with those tools continued and new areas of interest were explored. Because technology was shared within the group, this led to a different application of technology all over the community. Even in Dungmin the experimentation of individual farmers shaped the communal programme, although I am not aware to what extent the programme was supported by the community. This notion is to stress that the development of technology in a social context does not stop when the government-supported programme backs out. More in general, there are numerous examples of programmes that continued after outside support stopped; although often in a very different shape than originally intended, particularly if social organisation around the technology was an essential aspect of the original programme.

Documentation of village experiments.
Scientific activity must be documented so that future workers do not need to reinvent the wheel and can build on past experiences. If village experimentation is to be a scientific activity, it should be documented in an accessible way, and experiments need to be understandable and repeatable. But, even if village research programmes do not result in scientific reporting, one can not deny that village experimenting generates socio-technological knowledge and that it has great socio-economic impact. If such programme's results are not presentable in scientific terms, then it is high time to reconsider the scientific paradigm and find a way to have this kind of knowledge documented.

The story of Dungmin and Am Shing showed that the production of technical scientific data was not a very strong aspect of both programmes. When working out the technical results for this report, it appeared that the quality of data collected from villages was usually too poor for scientific presentation, mainly through the great variation of relevant parameters over the villages and the consequent difficulty to establish the relation between treatment and result. Moreover, often data collected by farmers were incomplete as farmers usually observed relevant processes for building an ad-hoc theory on the processes relevant to them and then stopped observing. It appeared difficult to collect village-level non-treatment data as in non-treated villages (necessarily close to treated villages) the communities always wanted to be included in the treatment samples. Therefore, most of the data on which the technical reports (Chapter 5 and 6) are based have been collected in station-led research (carried out in farmers' orchards). In short, village experimenting isolated from station-led research is not likely to produce data that can be used for technical presentations.

In a way, the same counts for the sociological knowledge we collected. Although the study yielded a wealth of information on the organisational structure within the various communities, this information was only collected insofar it was useful for the programme. By initiating organisations for doing experiments the programme in fact interfered in the social set-up in the village, which made observations a kind of invalid in objective scientific terms. Moreover, for the purpose of the programme, sociological knowledge as such was not very interesting: it was the action perspective emerging from the combined sociological and technical knowledge that the programme was interested in.

During programme implementation, the main objective of the programme was to have the chinese citrus fly controlled for which a variety of aspects were addressed. This resulted in a conglomerate of anthropological, sociological, political, economical and technical knowledge that had a natural shape when working in the field, but that had little coherence in academic terms. This integrated knowledge had to be deconstructed to be able to write this report. In a way this is a painful and disappointing process, on the other hand, the process of conforming to discipline-organised scientific traditions yielded a lot of insight in mechanisms that we did not notice when implementing the work. Now, the question is whether the paradigm-segregated reporting gives due acknowledgement to the integrated character of the work itself.

In a way it does. The behaviour of the fly seems so simple at observation; yet, its documentation demands large tables and graphs based on thousands of figures that look impressive to the reader. Similarly, when we stood in the middle of Dungmin village and discussed activities, the choices seemed so simple to make; yet, when documenting such self-explanatory choices they make many pages of boasting literature. On the other hand, the integrated way of thinking that is so natural in the field needed to be changed to a continuous shifting from the technology perspective to the social perspective and vice versa during this report writing.

I would never have noted down this consideration if it were not for the enormous potential that is waiting to be explored through this integrated type of thinking. People that are incredably poor can make money and live in a sustainable way. Yes, through technology alone, i.e., pesticide cover sprays the chinese citrus fly can be controlled. This is the uni-paradigm thinking that leads to excessive use of pesticides and degradation of our environment. This study tries to contribute to a solution to these excesses by providing a simple and economically viable alternative, in this case the socio-technological complex of organised baiting that allows for double yields for an excellent cash crop. And, at the documentation stage one can see how difficult it is to write down this knowledge in an integrated way, i.e., how far scientific paradigms have drifted from the objective they were originally intended for: to provide humanity a thinking tool for keeping the world a liveable place. I think that multi-paradigm scientific thinking (under whatever name) justifies investments in agricultural (and for that purpose: environmental) science for the decades to come. For multi-paradigm thinking to be able to enter mainstream thinking, a reporting method must be available that appreciates the multi-paradigm environment in which we live. I needed to write a Ph.D. thesis to justify the interplay between the two paradigms. Yet, I can see how institutions such as the Bhutan extension service as well as the Wageningen Agriculture University (to name a few) are lost between paradigms, and continue to adhere to unnecessarily ineffective thinking systems.

7.5. What remains to be done.

Citrus IPM in Bhutan.

Based on this study, a first thing to do would be to evaluate simple citrus fly control strategies (baiting through loaded cotton wicks and catch crops) in villages and on-station. Such an evaluation would take one, at most two seasons, and would give opportunities for a very simple and cheap way of citrus fly control. Moreover, the chinese citrus fly is not the only pest causing fruit drop. At lower altitudes it is the citrus green stink bug (Box 2) that inflicts up to 90% damage. Other important pests include small suckers and mildew. Such pests need to be researched in a way similar to the chinese citrus fly, i.e., taking local knowledge and organisation potentials into account. Such research is likely to result relatively fast in tangible achievements as the research pattern has already been developed.

Consequences for the extension practices and education of staff.

In fact, the research set-up presented in this study shows how to develop a curriculum for FFS, even if during programme implementation the direct benefit to farmers was considered pretty important. It is now the extension service that should initiate a programme to further develop it into socio-technology applicable at large scale. The extension service will have to think how such knowledge is to be spread among relevant groups of farmers. This would on the short term involve pilot extension programmes (Chapter 8), preferably with research involved to see where technology is yet to be further developed. Moreover, extension staff needs intensive supervision of people thorough in village level social processes, to ensure that the social component of the socio-technological complex is not neglected. Enabling extension staff carry out such programmes would take a year or two. For the longer term, one can think of a training programme in the national agriculture training institute, in which the dissemination of socio-technological knowledge can be part of the curriculum. This would result in sizeable numbers of staff knowledgeable about the principle. If such activities prove more successful than the present practices, next step would be to consider the organisational configuration of the extension service, and the incorporation of many more socio-technological opportunities in such an extension set-up.

The support by authorities and donors and the presence of expertise in various layers of the governmental hierarchy make out whether socio-technological opportunites will be identified, explored and put to production or not. The example of citrus IPM, and many more, show that investments in these opportunities will result in sustainable technology that will easily pay back in a few years. This stands in shrill contrast to the integration of technical services that has been so popular among policy makers even if it is yet to identify economical opportunities farmers can explore. I hope that this study contributes to a pool of knowledge for the exploration of socio-technological opportunities that, after all, value crores of Ngultrums each year to be earned by large groups of semi-subsistence farmers in Bhutan. The next Chapter presents ideas on how to implement such a programme in practice.

8. How can farmers' communities learn to control the citrus fly?

The previous chapter showed that for citrus fly control, not only an applicable, proven technology is needed, but also the social cognition to apply this control. This chapter gives a brief outline of programmes through which communities can acquire the skill of citrus fly control.

8.1. The socio-technological construct of citrus fly control.

The citrus IPM programme that has been described in this thesis started with technical research on pests. When the programme tried to develop citrus fly control in villages, it soon found that technology alone did not suffice to control the fly. The farmers' community needed to understand proposed measures as a group; a recepy-type of control implementation always failed somehow. Chapter 4 shows that, at a time when technology was already proven to be effective, extension staff was not in a position to introduce citrus fly control to villages. The extension staff introduced technology, while farmers and staff were unable to develop a *group cognition (or: group intuition)* about the technology in the farmers' community. Some technology may be applicable even if it is not understood; for IPM a thorough understanding of the pest biology and principles of control is a sheer necessity.

But, if group intuition on fly control is an essential component of citrus IPM, how can the extension system help farmers' communities developing such an intuition? Lecturing to farmers that they should develop social cognition on citrus fly control obviously does not work. The extension methodology should be adapted in order to be able to put farmers in a position in which they can build intuition.

The programme found that there are a few basic rules that govern the successful introduction of socio-technological knowledge. First, the programme should be confined to one solid subject that can make a significant difference, in this case citrus fly control. Nobody can learn many different subjects at a time, and for that reason addressing a variety of subjects in one go is bound to induce confusion and therefore apathy with regard to the particular programme. Moreover, if an individual extension staff addresses many subjects, it is unlikely that he has a better knowledge on any of the separate subject than farmers have. Such a problem that is less likely to happen if he is well experienced in a few subjects in which significant effect can be sorted.

Secondly, farmers should individually experience processes that lead to damage. This means that whenever training is given, the contents of the lecture is also shown in practice, or even better, farmers should observe and carry out practices for themselves. After doing all kinds of observations on citrus fly, farmers should discuss the findings within a small group of peers, for social cognition to get a chance to develop. Farmers should not only know about the pest and its control, but also build an idea on why the fly acts the way it does, how its activity can be monitored and how it can be controlled. Based on such ideas, farmers can then again look into their orchards and see whether the ideas fit new observations or not. The Farmers Field School extension methodology has been developed to deal with such "building of knowledge" though it should be adapted according to the subject of study.

Third, training should be adapted and repeated. Repetition of training is to reconfirm and refine the earlier acquired knowledge, but also to learn from earlier shortcomings and consequently act. This enables both the community and the extension staff to learn and continuously improve the quality of training and discussion.

Current extension practice in Bhutan is weak in particularly the first two principles. Yet, they are necessary ingredients for an extension programme, not only to introduce citrus IPM in villages, but to introduce any technology in which the farmers' intuition is an essential element for appropriate implementation.

8.2. Implementing a programme to introduce citrus fly control in villages.

This section shows how confinement of subject, experiential learning and repeated training are the corner stones of community programmes that aim to introduce citrus fly IPM and the social cognition that goes along with it in citrus growing villages.

Preparation of a citrus fly control programme.
If one wants to introduce citrus fly IPM to villages, the programme must be well prepared. If one starts working on citrus fly IPM without realising that communities must enter a learning process rather than follow a series of instructions, the technology is bound to fail and will leave both staff and farmers behind in disappointment. Preparation starts at two levels: at the administrative level, and at the village level. At the village level, extension staff should carry out a rapid appraisal exercise, preferably in mid-October when the peak of fruit drop takes place. In a meeting, extension staff should discuss with the community whether it wants to implement a citrus fly control programme or not. Farmers and extension staff should make a tour and visit all orchards in the village to see whether fruit drop is indeed caused by the citrus fly (for a method to check whether individual fruits drop is caused by the citrus fly, see Section 5.2). If no fly infestation signs can be found, the citrus green stink bug is the likely cause of drop. Extension staff should preferably visit a few villages, and discuss the possibilities for a programme. The final choice for the programme should depend on two criteria: is the community as a whole (and not just a few individuals) ready to commit itself to a citrus fly control programme? Are all households ready to pay for its inputs? And: is citrus fly indeed the most important cause for fruit drop in the village? Only if both criteria are met, a village programme to control the fly has a chance for success. For staff trying to introduce citrus fly control for the first time, it is best to take a small village of 15 to 20 households, or a village in which organisation for production purposes is already strong.

Preparations at the district level are equally important. Of course, the extension staff him or herself should be willing to implement a citrus fly control programme. He or she should be willing to invest time in preparation, implementation and evaluation of the programme, and should ensure to be available during critical times in the life cycle of the citrus fly, i.e., in April-May, in September and October-November. During each period the village should be visited for at least a full day; in April-May even two or three times, to make sure that bait splashes are properly carried out. Extension staff must be sure that he can carry out the full programme, preferably two years in a row, and must seek support from superiors and be sure that the activity is taken up as a special programme in relevant plans. At unexpected interruptions, colleague staff must back up the programme, otherwise either the control activities are unlikely to be carried out properly and in time, or the results are not appropriately measured. Another essential element in the programme is the availability of inputs. District staff must make sure that inputs are available at least a month before the programme starts. Late starting of activities make that the programme is unlikely to be effective and in that case it is better not to carry out a programme at all.

The fly life cycle and the technical learning process of farmers.
Biological processes take place irrespective of bureaucratic agendas, so that in all agricultural programmes the bureaucracy must be adjusted to the seasonal calendar. This is equally valid for the monitoring and control of the chinese citrus fly: its phenology determines to a great extent the community training agenda. Therefore, I start this Section with an exposure of the

fly's life cycle and critical periods for control activities.

In April-May, adult flies emerge from pupae in the soil. This is also the period that flies are best attracted to proteinaceous food-bait, and when control must be carried out. The emergence period varies from year to year and village to village, and therefore it is best to monitor the period by keeping pupae in emergence-monitoring bottles (Figure 20a) at various places in the village, and observe when the first flies emerge. At the first fly emergence, bait should be prepared and applied in bearing trees all over the village, for the month to follow every week, during sunny days. Timing of activities is essential: if baiting flies starts a week after emergence actually started, some flies already disappeared in surrounding areas and can not be caught by baiting anymore (though they could be intercepted by trap crops at the early fruit development season).

When the fly emergence period is over, flies fly away and reappear when fruits develop up to sizes of over 11-mm. Male flies detect such fruits first, and early growing citrus species, such as lime, teem with flies in the early oviposition season. During this period, usually one month after emergence, such crops can be used as trap crops by spraying them. Farmers should monitor the (potential) efficacy of such crops through the fruit-mimic trap (if not sprayed, Figure 20e) or a cloth-trap (if sprayed, Figure 20b). At the time fruits are developing caught female flies are fat with eggs. The fruits of lime, if over 11-mm, can be checked for ovipunctures to build an idea about fly activity and when fruits are still small, farmers can try to spot fly eggs at the end of the ovipuncture, in the pulp. Throughout the summer, female flies continue puncturing fruits. Farmers can watch male flies flying about around the upper canopies in dense mandarin trees, female flies will only briefly visit trees to oviposit.

September is the best month to establish the fly activity and the expected damage in the particular year. Farmers should collect fifty big fruits, fifty medium sized fruits and fifty small fruits from all over the village, and check each fruit for ovipunctures. Three quarters (76%) of punctured fruits is likely to drop. Thus, the damage the fly causes can be estimated by taking the percentage of punctured fruits, and multiply this percentage with 3/4. In the last days of September maggots in heavily infested fruits will start develop and through damaging the fruit the latter turns orange and drops. Farmers can collect all dropped fruit in their orchards, see maggots that turn into pupae, and calculate the number of baskets that dropped as well as the monetary loss. It is essential to collect fruits daily; otherwise the fruit drop will be highly underestimated. During the harvest period when people's pockets are thick with cash, they should collect money for the following year's baiting activities.

Fly control is unlikely to be effectively carried out in one season. Ideally, farmers should monitor the fly's life cycle for one season, and control the fly the following season. One can also think of an arrangement in two neighbouring villages, where in one village the fly is controlled, and in the other farmers monitor the fly and its activities. It is suggested that the extension staff takes farmers from one village to the other, to see the difference of control and no control, and combine this with calculations on profits, if staff can promise to carry out similar programmes in other villages.

The learning process to build the community's social cognition.

The technical learning process as suggested in the previous Section needs another round if it is to lead to a robust organisation of fly control. In fact, it is best to meet two times during each critical period: first to understand the technical aspects of the particular period, second to discuss the action to be taken and to establish an organisational pattern to make sure that activities are indeed carried out. Here, extension staff and farmers must make a "social contract": each of the stakeholders must point out if the other one failed to carry out the promised activities. It is this process in which trust and friendship between stakeholders are essential. If the extension staff fails to supply materials in time, or fails to be there when the first communal bait splash is to be carried out, farmers should be able to hold him responsible. Similarly, if the community does not take information that monitoring tools yield seriously, the extension staff should ask them to do so. When a community carries out such activities for the first time, usually many hick-ups appear and the technology is often hardly effective. When the community and staff are able to learn from things that went wrong in the first year, they are likely to be able to carry out fly control appropriately in the second year. Nevertheless, one remark must be made. The fly's behaviour is highly dependent on the weather. In very wet springs, the fly can not be lured, while it is unsure whether catch crops alone can control the fly. Farmers and staff must be prepared for such calamities and, should weather be unfavourable in one year, extend the programme for another year.

Extension staff acts as a facilitator and learns from the community.

The above given outline shows that for a fly control programme the role of the extension staff is quite different than during the earlier training-and-visit routine. Extension staff should be thoroughly versed in technology and be able to provide farmers with tools through which they can learn about the citrus fly. On the other hand, staff should not lecture all the characteristics of the fly to farmers, but allow them to learn from the observations they do. There will always be some innovative farmers that take the monitoring tools and build their own idea on the citrus fly's activities. This is no problem, and in fact such ideas are best discussed in small groups and in village level meetings. Extension staff may be thoroughly trained in technical terms; farmers are definitely more knowledgeable about their own community. Extension staff should allow farmers to build their own organisation around citrus fly control, although certain pitfalls can of course be discussed. If farmers select one "volunteer" to carry out control over the entire village, one can be sure that this does not lead to communal "intuition" and that, should this person fall sick, activities are properly carried out. In such cases extension staff may discuss the impractical arrangement with the community. The nice thing about this approach is that each village is different, and that staff must be flexible about the arrangements each village makes. Therefore, each village programme has its own flavour, and staff does not get bored with the communal arrangements, even if he or she works for many years in citrus fly IPM. Extension staff in general gets bored with their own knowledge, which they often have been promoting for years.

It is an illusion to think that staff can learn to carry out such programmes independently. In particular at the beginning, staff needs back up, both technically, and in terms of the process of learning he or she is to initiate in villages. If, at particular moments, difficulties emerge, staff should be able to fall back on a supervisor who supports rather than reprimands him or her. Regular visits of colleague staff to each other's programme villages will definitely be a useful method to share experiences and learn from each other. Similarly, farmers can visit other programme villages and discuss the organisation procedures and problem solving. I think that staff should be supervised by one researcher who is knowledgeable about citrus fly IPM, and one district official, with access to the district policy making process, and (if available) someone who is knowledgeable about the dynamics of social mobilisation.

Finalisation and follow-up of the village programme.

After the programme is finalised, it should be evaluated with farmers, extension staff and a supervisor of the extension staff. Positive and negative points should be noted down, such as the success in terms of fruit drop reduction, moments of tension, the building of a social cognition in

the village, the course of the programme, and possible improvements. Such reporting can be taken up in the district annual plans, and followed up in the district planning.
Summarising the village curriculum to introduce citrus fly control.

Table 15 presents the seasonal calendar to introduce citrus fly control in villages. The learning cycle is linked to the phenology of the citrus fly. Critical periods in the fly life cycle must be established for each village separately by farmers using monitoring tools. By the time activities must be carried out the support extension staff gives to the farmers' community must be ready. For that, staff must act two months before actual control activities must be carried out in the village.

Table 15. The curriculum to introduce citrus fly control in a village is related to the fly phenology. Farmers and extension staff must act upon the happenings of the season.

act by:	*Oct-Nov*	*Dec-March*	*April-May*	*June*	*July-Aug*	*Sept*	*Oct-Nov*
Citrus fly	maggots develop: fruit drop	pupae rest in soil	emergence	early oviposition	oviposition	eggs rest in fruit	maggots develop: fruit drop
farmers: monitoring	observe fruit drop & calculate losses; collect pupae for emergence monitoring	dig up pupae for emergence monitoring	monitor emergence for timing control	monitor oviposition in early developing fruit	observe fly behaviour in trees	observe fly infestation level in fruit samples	observe fruit drop & calculate profits; evaluation
farmers: fly control		prepare programme: meetings	bait flies all over the village	treat catch crops	optional: bait females in upper canopies		
extension staff	appraisal: -fly infesta tion; -communi ty will for fly control programme	prepare programm: -administr. support -meetings -inputs	supervise baiting activities	supervise catch crop treatment		supervise fly infestation level observing & report	evaluation; appraisal: follow-up activities

8.3. District level organisation of village programmes.

The previous Section shows that the village programme is related to the fly's life cycle and to the learning process of the farmers' community. Moreover, extension staff should intensively follow the village's learning process and organising capability, and in fact enters a learning process him or herself. Both changes have considerable consequences for the planning of activities at district level. First, activities should be planned according to the season, rather than according to the administrative year. A failure to follow up training in April, when fly control must start, disturbs the programme for an entire year. Thus, it must be ensured that the activities indeed start when flies emerge. Another consequence is related to the stationing of staff: when starting a programme, a farmers' community must be sure that the staff will indeed stay in place to be able to finalise the programme. If staff changes halfway the process, the programme is likely to be disrupted and fail. On the other hand, staff must be able to work in villages over the entire district, because the specialised experience developed may be needed outside his block of stationing.

The Agriculture Officer must support village level staff in more than one way. He must make sure that inputs are available in time. Then, when problems emerge in village programmes, the officer must make sure that this is a learning moment rather than a reason to back out. For this, the Agriculture Officer must maintain appropriate links with the district administrator and with research services to be sure that staff is supported when needed. Particularly staff that is not experienced with participatory programmes need intensive supervision of knowledgeable people. For example, during the facilitation of village programmes, staff often falls back in an autocratic role, which is unlikely to result in communities acquiring ownership over the programme. When farmers themselves do not feel responsible for the proper implementation of control measures, they are rarely if ever carried out completely and in time. Staff must be corrected, and village initiatives must get a chance to grow, for citrus fly technology to become a part of the community knowledge

8.4. Policy implications of incorporating the process of learning into extension practice.

Policy based on opportunities rather than comprehensive theories.

During the implementation of various IPM programmes in villages we, various staff of the eastern regional plant protection service, often wondered why general policies were so little geared towards simple opportunities in villages rather than grand comprehensive ideas. This proposal sticks to the idea of planning as a dynamic, "ecological" activity. The starting point of such planning is not a far-fetched objective that can hardly be verified, nor an elaborated logical framework-type of planning which, in its rigidity, often lacks possibilities for learning and thus hampers the development of social cognition. Although I stick to the example of the citrus fly, for most other technologies that proved successful at small scale similar programmes can be designed.

For constructing a citrus fly scaling-up programme, it should be acknowledged that agricultural production is an ever-changing activity that can neither be understood nor governed. Some ideologies, such as farming system approaches (including RNR-integration) claim that understanding the system is a prerequisite for purposeful intervention; however, I think that such comprehensive theoretical policies paralyse innovation by not supporting programmes that do not address the system as a whole. Instead, I feel programmes should start with an opportunity as developed in village research programmes, such as the control of citrus fly. The extension programme should look for technically demarcated, achievable innovations that can contribute to "better" or "sustainable" production (such as cash crop management, soil conservation, channel building etc.). In my view, the core of such development can be technology as farmers apply it, or can be subjects like group formation, rural credit, etc., provided that if such a programme starts at one end of the socio-technological spectrusm, expertise of the other end is involved soon. In a country like Bhutan, where rural problems are defined in exclusive technological terms, a technological start of programmes is best. An experimental area approach combined with on-station experimenting as discussed in Chapter 3 has proven a good method to develop technology with a meaning in the farming community's context.

For the large-scale introduction of a socio-technological construct such as citrus fly IPM, different stakeholders in the Agriculture Knowledge System need to co-ordinate activities. Only if components such as a survey of the problem, technology, input supply, availability of extension staff and support to staff have been put into place, a socio-technological construct can be successfully scaled up. Such an arrangement can never succeed if not properly planned, and it can only be planned if national policies do support such programmes.

Co-operation between institutions based on activities rather than policies.
Engel (1997) and Engel and Salomon (1997) developed a tool to systematically analyse the activities different stakeholders in the Agriculture Knowledge System have to carry out for a particular task (this tool is called RAAKS). A particular problem is discussed from the perspective of different stakeholders who jointly identify activities they should carry out to address the problem. For the district scaling-up programme to actually result in the control of fruit drop, problems as listed in Table 4 must be addressed simultaneously. In Bhutan, first, technology should be further developed, particular an IPM method for the control of the citrus green stink bug. Farmers must be aware that the implementation of IPM involves a learning process and they must be ready to invest in the methodology rather than wait and see what the government comes up with. Input supply for the implementation of activities in villages should be ensured. Extension staff must be familiar with the process of learning rather than the activity of teaching, and they need to be trained and coached in that end. Policy makers must understand and support this set-up. All relevant stakeholders should develop something like a group cognition across all stakeholders, so that when individual stakeholders fail to carry out certain tasks, others back them up or are in the position to correct the particular stakeholder.

Village pogrammes rather than training programmes.
This has quite a few consequences for the extension service. Extension staff should be in a position to supervise farmers that want to experiment with innovative technologies. Generally spoken, it is an illusion that extension staff have more knowledge on the farming system than farmers. Extension staff must specialise to be able to add to the farmers'general knowledge. Integrating technology into the farming system is not the task of extension staff; farmers are well capable of doing that themselves (e.g., Guenat 1991). I imagine that extension staff, after a general education, specialises on-the-job in certain crops or certain subjects, such as "orchard management", "soil conservation" or "the transition process from shifting cultivation to permanent agriculture". Possible specialisation should depend on the policy issues of the particular five-year plan and may extend from a few years to an individual staff's full career. Staff then carries out programmes in particular villages after an initial training in a successful village research programme. Such staff should have report to a researcher, who support such staff in particular in the early stages of programme implementation in villages. When a particular programme is finished in a particular block, the staff moves on to another block where his services serve a need. This makes that extension staff builds experience and confidence, and gets a career perspective rather than muddle on the same track for most of their professional life. After a village programme is successfully finalised in a few villages, staff moves on to another place where his skills are needed, and the villages where a particular programme was finalised may choose for another specialised input. The system should in no way replace the existing system, it can be partially introduced, specialised input can grow and shrink, as per the need and availability of concrete innovations from village experimental programmes. If, in such a set-up, a joint

programme of the three RNR-sectors emerges to be necessary to achieve goals felt by communities, this may lead to a temporary co-operation of the involved sectors and as such they form a justified RNR-integration programme rather than an imposed one.

Identifying and carrying such flexible programmes to villages has consequences for the institutional set-up of the extension service. Staff transfer should follow a programme rationale rather than an institutional one. The number of successful village extension programmes then may result in marking for staff's promotion. Allocation for training abroad should be in line with individual's specialisation (or the other way around), rather than being a general incentive where skills are little used. An essential aspect of such programmes is the possibility to experiment. If particular activities fail to work the first year, the actor network should jointly analyse the failure and implement an adapted programme in the following year. Administrators should be aware of the experimental character of any intervention, and stimulate learning rather than issue punishing measures.

I think that such a set-up will enable the farming community to improve farming practice through small, significant steps. In this way, the Royal Government can help farmers to fully explore the rich natural environment of Bhutan in a sustainable way.

References.

The Bhutanese names are placed by the first name in appearance, i.e., Kinlay Dorjee can be found under K. Spelling of Bhutanese names is according to the spelling on the original publication, which occasionally varies for the same person. Dutch names starting with "van" are placed, following the Dutch tradition, under the first letter of the family name that is written in capitals; thus "van de Fliert" is placed under F.

Achterberg, C. van, in prep. The Palaearctic species of the genus Diachasmimorpha Viereck (Hymenoptera: Braconidae: Opiinae). Zoologische Mededelingen Leiden.

Aluja, Martin, Mario Cabrera, Jorge Guillen, Hilario Celedonio and Feliciano Ayora (1989). Behaviour of *Anastrepha ludens, A. Obliqua* and *A. serpentina* (Diptera:Tephritidae) on a wild mango tree *(Mangifera i ndica)* harbouring three McPhail traps. Insect Sci. Applic. Vol. 10, No 3, pp. 309-318, 1989.

Aluja, Martin, and Andrea Birke, 1993. Habitat use by adults of *Anastrepha obliqua* (Diptera: Tephritidae) in a mixed mango and tropical plum orchard. Annals of the Entomological Society of America, 86(6), 799-812.

Ashby, J.A., 1987. The effects of different types of farmer participation on the management of on-farm trials. Agricultural administration and extension, 24: 235-252.

Auerbach, Raymond, 1999. Design for participation in ecologically sound management of South Africa's Mlazi river catchment. Dissertation, Wageningen University and Research Centre.

Averill, Anne L. and Ronald J. Prokopy, 1987. Residual activity of oviposition-deterring pheromone in *Rhagoletis pomonella* (Diptera: Tephritidae) and female response to infested fruit. Journal of Chemical Ecology, 13(1), 167-178.

Averill, A.L., and R.J. Prokopy, 1993. Foraging of *Rhagoletis pomonella* flies in relation to interactive food and fruit resources. Entomol. exp. appl. 66: 179-185.

Back, E.A., and C.E. Pemberton, 1915. Susceptibility of citrous fruits to the attack of the Mediterranean fruit fly. Journal of Agricultural Research, Vol. III, No. 4, pp. 311-330.

Bateman, M.A., and T.C. Morton, 1981. The importance of ammonia in proteinaceous attractants for fruit flies (Family: Tephritidae). Australian Journal of Agricultural Research, 32: 883-903.

Bierbaum, T.J. and G.L. Bush, 1990. Host fruit chemical stimuli eliciting distinct ovipositional responses from sibling species of *Rhagoletis* fruit flies. Entomologia Experimentalis et Applicata, 56:165-177.

Bigger, M., D. Padgham, N.K. Pradhan & Chencho Dorji, 1988. A check list of insects and mites of Bhutan. Department of Agriculture, EEC Plant Protection Project, P.O.Box 119, Thimphu, Bhutan. 54 pp.

Biggs, Stephen, and Grant Smith, 1998. Beyond methodologies: coalition-building for participatory technology development. World Development, Vol. 26, No 2, pp. 239-248.

Blok, Kees, undated (1997?). Effects of the National Irrigation Policy on sustainability of irrigation systems in Bhutan. Report of the Training Co-ordinator of the Irrigation Section of the Royal Government of Bhutan.

Cao, Y.S., 1987. The two species of fruit flies on oranges in China. Tech. Bull. Inst. Plant Quarantaine Press, Beijing. (In Chinese, with English abstract)

Chen, S.H., 1940. Two new Dacinae from Sechwan. Sinensia, 11: 131-135.

Chen, F.J. & F.P. Wang, 1943. Study on citrus maggot in Jianjing County. Agricultural science, 46-59. (In Chinese)

Chencho Norbu and Phuntsho Lodey, 1995. Orange fruit drop problems in five Dzongkhags. A tour report: November 28 to December 6 1995. Ministry of Agriculture, Thimphu. Internal report.

Crins, Riki, 1998. Bhutan. Mensen, politiek, economie, cultuur. Koninklijk Instituut voor de Tropen, Amsterdam, 88 pp.

Dabrowski, Z.T., 1997. Integrated Pest Management in Vegetables, Wheat and Cotton in the Sudan: a participatory approach. FAO/Government of the Sudan Cooperative Project, Wad Medani, Sudan.

DoeDoe, 1997. Sustainability - an issue on farm and not of farm! Internal report, Regional Plant Protection Centre, Khangma, eastern Bhutan.

McDonald, R.E., P.D. Greany, P.E. Shaw and T.G. McCollum, 1997. Preharvest applications of gibberellic acid delay senescence of Florida grapefruit. Journal of Horticulture Science 72(3), 461-468.

Doorenbos, J. & A.H. Kassam, 1979. Yield response to water; Citrus. FAO Irrigation and Drainage Paper 33: 81-87. FAO, Rome.

Douglas, Mary, 1986. How institutions think. Routledge & Kegan Paul Ltd, London.

Dowell, R.V., and L.K. Wange, 1986. Process analysis and failure avoidance in fruit fly programs. In: Mangel, M., J.R. Carey and R.E. Plant (eds.). Pest control: operations and systems analysis in fruit fly management. NATO Advanced Science Institute Series G: Ecological Sciences, 11, 43-65. Springer Verlag, Berlin.

Economopoulos, A.P., 1989. Use of Traps Based on Color and/or Shape. In: Robinson, A.S., and G. Hooper

(Eds.), 1989. Fruit flies their biology, natural enemies and control. World pests, vol. 3b. Elsevier Amsterdam - Oxford - New York - Tokyo.
Enderlein, G., 1920. Zur Kenntnis tropischer Frucht-Bohrfliegen. Zool. Jb. Syst. 43: 336-360.
Engel, Paul G.H., 1997. The social organisation of innovation. A focus on stakeholder interaction. Royal Tropical Institute, Amsterdam, 242 pp.
Engel, Paul G.H., and Monique L. Salomon. Networking for Innovation. Windows and tools. Royal Tropical Institute, The Netherlands, 82 pp., including worksheets.
FAO, 1966. Report of the FAO symposium on integrated pest control. Rome, Italy, October 1965.
Galagher, Kevin DeWayne, 1988. The 'Model'. Yogyakarta, IPM secretariat. Unpublished paper.
Granovetter, Mark S., 1994. The strength of weak ties. American Journal of Sociology 78:6, pp. 1360-1380.
Fitt, Gary P., 1984. Oviposition behaviour of two tephritid fruit flies, Dacus Tryoni and Dacus Jarvisi, as influenced by the presence of larvae in the host fruit. Oecologia 62: 37-46.
Fitt, G.P., 1986. The influence on the shortage of hosts on the specificity of oviposition behaviour in species of Dacus (Diptera, Tephritidae). Physiological Entomology, 11:133-143.
Fletcher, B.S., 1989. Life history strategies of Tephritid fruit flies. In: Robinson, A.S., and G. Hooper (Eds.), 1989. Fruit flies their biology, natural enemies and control. World pests, vol. 3b, pp. 195-208. Elsevier Amsterdam - Oxford - New York - Tokyo.
Fliert, Elske van de, 1993. Integrated Pest Management: farmer field schools generate sustainable practices. A case study in Central Java evaluating IPM training. Wageningen, WAU, The Netherlands, published dissertation.
Fliert, E. van de, and J. Proost, 1999. Women and IPM, crop protection practices and strategies. KIT press, Amsterdam.
Fullerton, R.A., 1988. Citrus production in Bhutan: a practical guide to improved husbandry and increased production. EEC consultancy report, Thimphu, Bhutan. 34 pp.
Goldsworthy, Peter, and Frits Penning de Vries, 1994. Opportunities, Use, and Transfer of Systems Research Methods in Agriculture to Developing Countries, pp. 127-138.
Goldsworthy, Paul, 1995. Integrating Agricultural and Natural Resources Research: Bhutan. ISNAR, The Hague.
Gow, Paul L, 1954. Proteinaceous Bait for the Oriental Fruit Fly. Journal of Economic Entomology, Vol. 47, No. 1, 153-160.
Greany, P.D., S.C. Styer, P.L. Davis, P.E. Shaw and D.L. Chambers, 1983. Biochemical resistance of citrus to fruit flies. Demonstration and elucidation of resistance to the Caribbean Fruit Fly, Anastrepha suspensa. Entomologia Experimentalis et Applicata 34:40-50.
Greany, Patrick D., 1989. Host plant resistance to Tephritids: an under-exploited control strategy. In: Robinson, A.S., and G. Hooper (Eds.), 1989. Fruit flies their biology, natural enemies and control. World pests, vol. 3a, pp. 353-362. Elsevier Amsterdam.
Guenat, 1991. Study of the transformation of traditional farming in selected areas of central Bhutan: the transition from subsistence to semi-subsistence market-oriented farming. A dissertation submitted to the Swiss Federal Institute of Technology, Zürich.
Gutierrez, A.P., 1987. System analysis in Integrated Pest Management. In: V. Deluchi, ed. Integrated pest management: quo vadis? An international perspective. pp. 71-82. Parasitis, Geneva, Switzerland, 416 pp.
Hamilton, N.A., 1995. Learning to learn with farmers. A case study of an adult learning extension project conducted in Queensland, Australia 1990-1995. Wageningen, WAU, published dissertation.
Hartmann, J. Dr. et al. Report on the baseline-surveys for the Integrated Pest Management Development Project (July to August 1993); Integrated Pest Management Project (IPMDP), National Plant Protection Centre (NPPC), Department of Agriculture, Simtokha, Thimphu, September 7, 1993.
Hasrat, Bikrama Jit, 1980. History of Bhutan, Land of the Peaceful Dragon. Education Department, Royal Government of Bhutan, Thimphu, Bhutan.
Hendrichs, J, B.S. Fletcher, and R.J. Prokopy, 1992. Feeding Behavior of *Rhagoletis pomonella* Flies (Diptera: Tephritidae): Effect of Initial Food Quantity and Quality on Food Foraging, Handling Costs, and Bubbling. Journal of Insect Behavior, Vol. 6, No. 1, 1993, 43-65.
Hendrichs, Jorge and Martha A. Hendrichs, 1990. Mediterranean Fruit Fly (Diptera: Tephritidae) in nature: location and diel pattern of feeding and other activities on fruiting and nonfruiting hosts and nonhosts. Ann. Entomol. Soc. Am. 83(3): 632-641.
Hess, M.D, W.G. Abrahamson and J.M. Brown, 1996. Intraspecific competition in the Goldenrod Ball-gallmaker (Eurosta solidaginis): larval mortality, adult fitness, ovipositional and host-plant response. The American

Midland Naturalist, 136:121-133.
Hollands, J., 1994. Research on pests and diseases of crops in east-Bhutan. Final report of the Plant Protection Research Adviser. Regional Plant Protection Centre, Khangma, Eastern Bhutan. 23 p. + annexes.
Hutchins, Edwin, 1995. Cognition in the wild. MIT Press.
IIE, 1991. Bactrocera minax (Enderlein) = Tetradacus citri (Chen), Callantra minax (Enderlein), Diptera: Tephritidae, Chinese citrus fly. International Institute of Entomology, distribution maps of pests, Series A (Agricultural), (526), 1-2. CAB International, London.
ISNAR, 1992. Review of the Bhutan National Research System: The Renewable Natural Resource Sector. The Hague, The Netherlands: International Service for National Agricultural Research.
Kapoor, V.C., 1989. Indian Sub-Continent. In: Robinson, A.S., and G. Hooper (Eds.), 1989. Fruit flies their biology, natural enemies and control. World pests, vol. 3a. Elsevier Amsterdam - Oxford - New York - Tokyo.
Kinlay Dorjee, 1995. An analysis of comparative advantage and development policy options in Bhutanese agriculture. A dissertation submitted to the Swiss Federal Institute of Technology, Zürich.
Kinlay Dorji, Dely P. Gapasin, Pirthiman M. Pradhan, 1992. Integration of research: Bhutan's Renewable Natural Resources Sector. Background paper for the International Workshop on Management Strategies and Policies for Agricultural Research in Small Countries, Eduit, Mauritius, 20 April – 2 May 1992.
Kleinheerenbrink, P. and F. van Schoubroeck, 1993a. The Pemagatshel Citrus Programme. An effort to involve farmers in spreading knowledge on citrus management. Video production. Sharchopkha, English subtitled, 13 min. Available from: SNV-Bhutan, P.O. Box 815, Thimphu, Bhutan.
Kleinheerenbrink, P. and F. van Schoubroeck, 1993b. Citrus growing in Eastern Bhutan. Portrait of a family. Video production. Sharchopkha, English subtitled, 30 min. Available from: SNV-Bhutan, P.O. Box 815, Thimphu, Bhutan.
Kleinheerenbrink, P. and F. van Schoubroeck, 1994. A plant protection pilot village programme. Video production. Sharchokpa, English subtitled, 18 min. Available from: SNV-Bhutan, P.O. Box 815, Thimphu, Bhutan.
Kleinheerenbrink, P., 1996. Citrus Pest Management. Video production. English, 18 min. Sharchokpa, Dzongkha and Nepali versions are also available. Available from: SNV-Bhutan, P.O. Box 815, Thimphu, Bhutan.
Kolb, David A., 1984. Experiential learning. Experience as the Source of Learning and Development. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
Krohn W., and J. Weyer, 1994. Society as a laboratory: the social risks of experimental research. Science and Public Policy, June 1994, pp. 173-182.
Laborda, R., E. Santaballa, F. M. Garcia, 1990. Development of the fruit fly *Ceratitis capitata* Wied. on Spanish lemons. Boletin de Sanidad Vegetal, -Plagas, 16:3, 613-618.
Lee, Kai N., 1993. Compass and gyroscope. Integrating science and politics for the environment. Island press, 246 pp.
Leeuwis, Cees, Niels Röling and Gerard Bruin, 1998. Can the Farmer Field School replace the T&V system of extension in sub-Saharan Africa? Some answers from Zanzibar. Unpublished paper.
Leyva, Jorge L., Harold W. Browning and Frank E. Gilstrap, 1991. Development of *Anastrepha ludens* (Diptera: Tephritidae) in Several Host Fruit. Environmental Entomology, Vol. 20, no. 4, pp 1160-1165.
Loevinsohn, Michael, Gerdien Meijerink and Beatrice Salasya, 1998. Developing Integrated Pest Management with Kenyan Farmers: Evaluation of a Pilot Project. Paper presented at the International Seminar on Assessing the Impact of Using Participatory Research and Gender Analysis, Quito, Ecuador, September 6-9, 1998.
Long, Norman, and Ann Long (eds.), 1992. Battlefields of knowledge. The interlocking of theory and practice in social research and development. Routledge, London and New York, 310 pp.
LUPP (Land Use Planning Project), 1995. LUPP Dzongkhag Data Sheets for Bhutan. Ministry of Agriculture, Thimphu, Bhutan.
Maas, Paul W. Th., 1994. Plant parasitic Nematodes in Bhutan. IPO-DLO Report nr. 94-06. NPPC, Semtokha, Bhutan.
Matteson, P.C., K. Galagher and P.E. Kenmore, 1994. Extension of Integrated Pest Management for Planthoppers in Asian irrigated rice: Empowering the user. In: Renno, R.F. and T.J. Perfect (Eds.). Ecology and Management of Planthoppers. London, Chapman and Hall, pp. 656-685.
Miyake, T., 1919. Studies on the fruit-flies of Japan. Contribution I. Japanese Orange-Fly. Bulletin of the imperial central agricultural experiment station in Japan, vol. II, No. 2, pp. 85-165. Nishigahara, Tokio.
Nath, D.K., 1973 (dated 1972). Callantra minax (Enderlein) (Tephritidae: Diptera), a new record of a ceratitinid

fruitfly on orange fruits (Citrus reticulata Blanco) in India. Indian Journal of Entomology, 34: 246.
Newell, I.M., and F.H. Harimoto, 1967. Biotic factors influencing populations of Dacus dorsalis in Hawaii. Proceedings of the Hawaiian Entomological Society, 20:81-139.
Nonaka, Ikujiro, and Hirotaka Takeuchi, 1995. The knowledge-creating company – How Japanese companies create the dynamics of innovation. Oxford, Oxford University Press.
Norton, G.A., and J.D. Mumford eds., 1993. Decision tools for pest management. CAB International, 288 pp.
Norton, 1993. Philospohy, concepts and techniques. In: Norton, G.A., and J.D. Mumford, eds., 1993. Decision tools for pest management. CAB International, 288 pp.
Papaj, D.R., 1990. Fruit size and clutch size in wild Ceratitis capitata. Entomologia Experimentalis et Applicata 54:2 pp. 195-198.
Papaj, D.R., B.D. Roitberg and S.P. Opp, 1989 (a). Serial effects of host infestation on egg allocation by the Mediterranean fruit fly: a rule of thumb and its functional significance. Journal of Animal Ecology, 58, 955-970.
Papaj, D.R., S.B. Opp, R.J. Prokopy and T.T.Y. Wong, 1989 (b). Cross-induction of fruit acceptance by the medfly Ceratitis capitata: the role of fruit size and chemistry. Journal of Insect Behavior 2:2, pp. 241-254.
Parker, Chris, 1992. Weeds of Bhutan. National Plant Protection Centre Simtokha, Royal Government of Bhutan. 236+VI pp.
McPhail, M., 1939. Protein Lures for Fruitflies. Journal of Economic Entomology 32(6): 758-761.
Planning commission, 1991. Seventh five-year plan (1992-1997). Planning commission, Royal Government of Bhutan, Thimphu, Bhutan. Vol. 2. Project profiles (210 pp.).
Pommaret, Françoise, 1990. Odyssey illustrated guide to Bhutan. The Guidebook Company Limited, Hong Kong, 232 pp.
Pradhan, P.M., K. Dorjee and P.R. Goldsworthy, 1994. Bhutan's research needs and priorities for the management of natural resources: a small country's perspective. In: Goldsworthy, Peter, and Frits Penning de Vries. Opportunities, Use, and Transfer of Systems Research Methods in Agriculture to Developing Countries, pp. 127-138.
Prokopy, R.J., D.r. Papaj, J. Hendrichs and T.T.Y. Wong, 1992. Behavioral responses of Ceratitis capitata flies to bait spray droplets and natural food. Entomol. exp. appl. 64: 247-257.
Prokopy, R.J., T.A. Green and R.I. Vargas, 1990. Dacus dorsalis flies can learn to find and accept host fruit. Journal of Insect Behavior 3:5 pp. 663-672.
Prokopy, Ronald J., P.D. Greany and D.L. Chambers, 1977. Oviposition-deterring pheromone in *Anastrepha suspensa.* Environmental Entomology, 6(3) 463-465.
Prokopy, Ronald J., 1972. Evidence for a marking pheromone deterring repeated oviposition in apple maggot flies. Environmental Entomology, 1(3), 326-332.
Razaak, Navaratne and van Schoubroeck, 1999. Report of the evaluation mission of PMHE. Netherlands Embassey, Sri Lanka, 1999.
Retan, A.H., 1991. Walnut husk fly. Extension bulletin, Cooperative Extension, College of Agriculture and Home Economics, Washington State University, 3 pp.
Roessler, Yoram, 1989. Insecticidal Bait and Cover Sprays. In: Robinson, A.S., and G. Hooper (Eds.), 1989. Fruit flies their biology, natural enemies and control. World pests, vol. 3b. Elsevier Amsterdam - Oxford - New York - Tokyo.
Rössler, Y. and P.D. Greany, 1990. Enhancement of citrus resistance to the Mediterranean fruit fly. Entomologia Experimentalis et Applicata, 54:89-96.
Rogers, Everett M., 1995. Diffusion of innovations. Fourth edition. The Free Press, New York, 526 pp.
Röling, N. and H. de Zeeuw, 1983. Improving the quality of rural poverty alleviation. Report of the working party "The small farmer and development cooperation." Wageningen: IAC.
Röling, 1992. The emergence of knowledge systems thinking: a changing perception of relationships among innovation, knowledge process and configuration. Knowledge and policy: the international journal of knowledge transfer and utilisation, spring 1992, Vol. 5, No. 1, pp. 42-64.
Röling, Niels and Annemarie Groot, in prep. Het maakbare van innovatie. Basisboek Voorlichtingskunde. Amsterdam: Boom.
Röling, N.G., and M.A.E. Wagemakers (eds.), 1998. Facilitating Sustainable Agriculture. Cambridge University Press.
RGoB (The Royal Government of Bhutan), 1992. Bhutan research strategy plan: the Renewable Natural Resources sector. Ministry of Agriculture.
Royal Government of Bhutan, 1993. Inception Report, Integrated Pest Management Development Project. NPPC, Simtokha.

Schoubroeck, F.H.J. van, Cheki Wangmo and B.B. Acharya, 1999. Gender aspects of a citrus IPM programme in eastern Bhutan. In: Fliert, E. van de, and J. Proost. Women and IPM, crop protection practices and strategies. KIT press, Amsterdam.

Schoubroeck, F.H.J. van, and L.N. Sharma, May 1994; The eastern Bhutan citrus programme. An effort to involve farmers in extension and research activities on citrus cultivation.

Steiner, Loren F., 1957. Low-cost plastic fruit fly trap. Jour. Econ. Ent. 50: 508-509.

Steiner, Loren F., 1952. Fruit fly control in Hawaii with poison-bait sprays containing protein hydrolysates. Journal of Economic Entomology 45(5): 838-843.

Stonehouse, J.M., J.D. Mumford and G. Mustafa, 1998. Economic losses to tephritid fruit flies (Diptera: Tephritidae) in Pakistan. Crop protection 17:2, 159-164.

Straw, N.A., 1989. The timing of oviposition and larval growth by two tephritid fly species in relation to host-plant development. Ecological Entomology, 14:443-454.

Subba, J.R., 1984. Agriculture in the hills of Sikkim. Sikkim science society, Gangtok, Sikkim.

Subba, J.R., Dr. R.C. Upadhyaya, Dr. D.K. Gupta ans Dr. S. Ray. Crop Calender For Scientific Management Of Orange Orchards In Sikkim. Department of Agriculture/Horticulture, Government of Sikkim, 9 pp, undated.

Sun, Z.Y., 1961. The study and control of Dacus citri Chen. In: Chinese plant protection science, pp. 912-921. Scientific publishing house. (In Chinese)

Veldhuizen, Laurens van, Ann Waters-Bayer and Henk de Zeeuw, 1997. Developing Technology with Farmers: A Trainer's Guide for Participatory Learning. Zed Books Ltd, London, 230 pp.

Vincenot, D, 1994, Report of a mission to Bhutan by the consultant for the citrus pathology and deficiency problems. Integrated Pest Management Development Project, Simtokha, Bhutan, 28 pp.

Wagemans, M.C.H., 1987. Voor de verandering. Een op ervaring gebaseerde studie naar de spanning tussen de theorie en de praktijk van het besturen. Wageningen: WAU, published doctoral dissertation.

Wang, Huasong and Heqin Zhang, 1993. Control of the Chinese Citrus Fly, Dacus citri (Chen), using the sterile insect technique. Proceedings of an international symposium on management of insect pests held in Vienna, 19-23 October 1992. International Atomic Energy Agency, Vienna.

Wang Xing-Jian and Lue Luyi, 1995. Research Progress in the Chinese Citrus Fly. Entomological knowledge. Chinese academy of zoology 32 (5) p. 310-315, Beijing. (In Chinese)

Weperen, Willem van, Jet Proost and Niels G. Röling, 1998. Integrated arable farming in the Netherlands. In: N.G. Röling and M.A.E. Wagemakers, Chapter 6. Cambridge University Press. (op cit), pp. 102-120.

White, I.M., & Wang, X.-j., 1992. Taxonomic notes on some dacine (Diptera: Tephritidae) fruit flies associated with citrus, olives and cucurbits. Bulletin of Entomological Research, 82: 275-279.

White, Ian M. and Marlene M. Elson-Harris, 1992. Fruit flies of economic significance: their identification and bionomics. CAB International, 601 pp.

Wit, Ton de, and Tenzin Choeda, 1996. Slowly getting strong. A study on economic development opportunities of Zhemgang district. Consultancy report, Zhemgang, Bhutan.

Wu, Z.C., 1958. A preliminary report on the bionomics of Dacus citri Chen. Kunchong Zhishi, 4: 216-217. (In Chinese)

Yang, P., 1988. Status of Fruit Fly Research in China. Research Institute of Entomology, Zhongshan (Sun Yatsen) University, Guangzhou, China.

Yang, Pingjun, James R. Carey, and Robert V. Dowell, 1994. Tephritid fruit flies in China: Historical background and current status. Pan-Pacific Entomologist 70(2):159-167.

Yasuda, T. et al., 1994. Thermal responses in the citrus fruit fly, *Dacus tsuneonis*: evidence for a pupal diapause. *Entomologia Experimentalis et Applicata* 71(3), 257-261.

Zhang, W.Q. (ed.), 1981. Agricultural entomology. Agriculture Publishing House. (In Chinese).

Zhang, Yu-An, 1989. Citrus fruit flies of Sichuan Province (China). EPPO-Bulletin 19:649-654.

Zwölfer, H. and W. Völkel, 1997. Influence of behaviour patterns of adult insects on resource utilisation and population dynamics: a model of population control by three major components. Entomologia generalis, 1(3):129-144. (In German)

Summary.

The chinese citrus fly (Bactrocera minax) is one of the key pests in Bhutanese mandarin orchards that lays eggs in developing fruit that cause pre-mature fruit drop. In this study it is used as a "model subject" to explore the integration of technical, social and administrative domains of knowledge. The confinement of the study to control of the fly leads to the study addressing a broad set of issues that are linked through their relevance to control the pest. Citrus fly control and its consequent doubling of the mandarin harvest is relatively easily measured and could serve as an indicator for effectiveness of technology development, farmers'organisation, government services and policies.

Part 1 deals with the socio-economic aspects of the study, and deals with the link between technology, learning processes and organisation. Chapter 1 gives the socio-economic and historical background of the area of study. The area falls under Pemagatshel and Samdrup Jongkhar districts in Bhutan, it is mountainous and borders Assam (under India) in the south. The inhabitants are Sharchok-pa or eastern Bhutanese people with an Indo-Burmese origin, they speak a distinct language that is not written. The local religion is dominated by the Nyingma-pa sect of the Mahayana Buddhism that heavily draws upon Tibetan traditions. The "Dzongda" or District Administrator is the representative of the Royal Government of Bhutan in the "Dzong", the District Administrative centre. Forestry, livestock and agriculture sections represent the Ministry of Agriculture and carry out the developmental programmes in the district. Districts are divided in blocks headed by a kind of mayor, blocks consist of five to fifteen villages with village headmen. The food situation in the area is relatively good, only in a few blocks shortages of food occur in particular seasons. Maize is the main staple crop and farmers turn excessive produce into drinks so that in the present marketing structure, improvement of staple food production is not likely to improve the local economy. Mandarin is the main cash crop that is mostly sold to Assam and Bangladesh with a huge population of potential consumers. The market can easily absorb any increase in Bhutanese mandarin production, although monopolies and trade restrictions often influence prices farmers get negatively. Even then, in terms of money, mandarin is the most voluminous export crop in the country, which still has a vast potential for further expansion in production both in acreage and per unit. The local variety is seed-multiplied, robust and well adapted to the local conditions. So far, there are no major virus problems, although a growing flow of germplasm in the country increases risks. In Nepal for example, the introduction of virus by developmental programmes wiped out citrus cultivation in large areas. Individual trees yield the equivalent of 40 tonnes per hectare, which shows that the average production of 2 to 6 tonnes can be substantially improved. Bhutan can capitalise upon this large potential for production by improving management through local seed selection and better planting practices, minor irrigation, manuring, and pest control. The major pests include mistletoe, trunk borer, the citrus green stink bug and the chinese citrus fly. The stink bug causes premature fruit drop in summer in low-altitude orchards and the citrus fly does the same, in autumn, in middle and high altitude orchards. Both pests result in fruit drop varying from up to 90% damage by the stink bug, to 35-75% damage by the chinese citrus fly.

Chapter 2 starts with an exposure on experiential learning theory, in relation to Integrated Pest Management (IPM) as used by the Farmers Field Schools (FFS) in Indonesia. In conventional learning, science is the source of knowledge and the extension system brings knowledge from science to farmers. In experiential learning, each individual goes through a learning cycle in which apprehension and comprehension follow each other. In this study experiential learning is taken as a process of experiencing, formulating the experience in words (that can be communicated) that shape the interpretation of the following experiences. Thus there is a feedback loop between

knowledge and experience, rather than a teacher telling about reality as formulated by scientists.

For a citrus IPM programme, the modified training-and-visit extension routine as used in Bhutan was taken as a starting point and gradually experiential learning elements were introduced in the programme. In stead of giving training on a variety of subjects, training was confined to citrus, the training site was swapped from in-door to orchards, training activities were followed by farmers interviews in their orchards so that their actual effectiveness could be established. Then, in the same village training was repeated to make useful additions if farmers did not follow up recommendations. Examining the follow-up of training with farmers in orchards revealed that this training programme led to a better adoption of recommendations in comparison with the earlier more general extension programmes. More surprisingly, monitoring farmers' practices revealed that quite a few recommendations given over the last few years had been impracticable or erratic. For example, the recommendation to plug trunk borer holes with kerosene appeared to be ineffective, as many of such holes were larva escape holes rather than entry holes. Following such observations, recommendations were modified according to experiences of successful farmers. Similarly, station-developed research outcomes were monitored for their usefulness. For example, research came up with the concept of natural enemies preying on pests which was taken up as a subject in training. This idea originated from areas in which calendar pesticide applications were the norm, however, Bhutanese farmers hardly used pesticides and such ideas had few, if any, practical consequences.

A shortcoming of the programme set-up was its poor potential to effectuate more fundamental technological innovations. For example, the theoretical notion that the chinese citrus fly could be controlled through food-baiting and hygienic measures needed to be examined in practical conditions, and the on-going research did not yield enough information to effectuate relevant shifts in practice. Another shortcoming originated in the fact that control of pests such as mistletoe and citrus fly needed to be carried out over entire villages. If an innovator farmer experiments with such technology at individual scale, it is bound to fail, and thus it is likely to be rejected even if it holds a great potential to improve yields. Transfer-of-technology extension was not effective in introducing such a village-wide application of control methods. This made clear that the current link between farmers, extension and research had to be reviewed. This led to a major shift in the set-up of IPM research. In 1993 the national plant protection service decided to have research carried out in village research programmes (locally referred to as "pilot village programmes"). In Chapter 3 it is argued that IPM was originally a technically defined methodology but that, for farmers to properly carry out IPM, they must have the learning capability to follow the ecological processes in their crops. In this end, processes must be visualised so that farmers can build intuition on processes leading to damage. Thus, both monitoring and control tools need to be developed to make IPM possible in practice. These tools can be developed through a Participatory Technology Development (PTD) programme, although most literature on PTD shows more concern for "empowerment" of farmers than for technological development as such. The observation that pests are often to be controlled at appropriate scale had substantial theoretical repercussions. Here I mention the social scale at which innovations take place. I take social cognition as a kind of "intuition" at group level. Social cognition theory observes that groups of people create a reality by sharing vocabulary and common interpretation of phenomena, resulting in a self-referential worldview. This social cognition essential for the implementation of activities at communal level, such as citrus fly control.

The citrus IPM programme set out to experiment with citrus fly control in two eastern Bhutanese villages, while on-station research continued under the same programme. Technology developed on-station was utilised in the village programmes, while technological needs felt in the villages, such as traps to monitor the fly population, were developed on-station. The programme success in villages appeared highly dependent on the social organisation of the two villages. In one village, farmers immediately formed a robust organisation that carried out the experiment over the entire village. In the other village various sources of resistance developed, such as the poor will to implement fly baiting in view of the inherent sin in religious terms. After three years, fly control in both villages succeeded and yields hit historical records that greatly enhanced the socio-economic development of the respective communities. In retrospect, the programme had difficulties in maintaining support during the period that the farming community had not yet acknowledged success. In one village the success led to farmers wanting to go further, and build a minor irrigation scheme for mandarin. For citrus cultivators and the extension service, the outcome of the programme was a combination of sociological and technological knowledge useful in a curriculum for Farmers Field School type of extension programmes in which complete villages learn how to implement citrus fly control. For the agricultural research practice, the programme showed how technology and socology can be combined into a practical blend of the two domains of knowledge.

After the village research programmes had been successful, policy makers wanted to capitalise on developed knowledge and scale-up the technology. So far, social cognition and experiential learning theory had been applied to farmers and a few individual staff. For the scaling-up programme, the same theory was applied to the extension service and the group of policy makers. Scaling-up of the socio-technological set-up appeared easy by extension staff who had been involved in the programme: he had four villages adopt the method within two seasons. Other agriculture staff appeared incapable of introducing citrus fly control in villages of their respective blocks. This was caused by particularities in the staff reward system, an inhibited learning process regarding implementing village programmes, and the fact that the input supply system could not supply the (inherent to IPM) small amounts of chemicals. These problems were poorly addressed because mainstream national agricultural and developmental policies were inspired by developments outside Bhutan rather than by successful initiatives inside the country. It is concluded that for a future scaling-up programme of locally successful technology, various actors in the Agriculture Knowledge System should interact to build a common understanding of the problems at stake so that they can co-ordinate their efforts to have large groups of farmers benefit from economically highly viable technology. In village programmes farmers and staff should try to induce small and measurable changes rather than carrying out broad programmes in order to learn from previous experiences rather than carrying out activities for the sake of doing them.

Part two of the thesis deals with the biology and control of the chinese citrus fly *(Bactrocera minax).* The data collected in village research programmes were often not complete, and the technical articles are mostly based on station-led research activities. Although the chinese citrus fly is a member of the family of fruit flies, its biology is quite peculiar in a few aspects. The fly has one generation per year and employs two rest periods (rather than only one in most other tephritid species): both as pupa in soil and as egg in fruit. The female's long ovipositor enables it to lay eggs in the pulp rather than in the peel of citrus fruits (where most other tephritid flies oviposit), thus avoiding contact of eggs with toxins in the skin. The fly oviposits early in the fruit development season (rather than during fruit ripening). After May, female flies puncture fruits of over 11-mm diameter. Fruits that develop earlier into critical sizes attract more ovipuncturing than later developing fruits. This mechanism explained uneven ovipuncture distribution over fruit

populations within trees, between trees, as well as between different citrus species. Moreover, it allows for trap cropping, as in the early season an orchard's fly population flocks on a local lime species that develops its fruits weeks earlier than mandarin. The oviposition season lasted until September. The development of eggs into active maggots took one to four months, in October and November maggots started feeding and induced early ripening and premature fruit drop. In all four years of observation the median of fruit drop was in the third week of October, and was slightly earlier in a high-altitude than in a mid-altitude orchard. Possibly, the period of hatching related to shortening light periods, which may explain the uniform timing of fruit drop over the years.

Fruit populations could be checked for ovipunctures, which allowed for pre-drop quantification of oviposition activity. Through such checking the effectiveness of food baiting activities in villages was evaluated. Not all punctured fruits dropped; comparison of in-tree pre-drop and post-drop puncture density suggested that 76% of ovipunctures contained viable clutches. In high-altitude orchards puncture density of fruit just before fruit drop appeared a reliable measure for damage, more so if post-drop density was established as well. In lower-altitude orchards, non-tephritid fruit puncturing agents blurred the evidence of oviposition activity.

In theory, the disposal of infested fruits from orchards could be part of an IPM strategy to suppress the fly population. However, monitoring puparia densities in soil revealed that disposing infested fruits hardly adds to the natural control system in soils. If the soil is not disturbed by tilling, natural enemies, mostly ants, prey upon puparia. Various traps were developed to establish critical periods in the fly's life cycle such as the fly's emergence and oviposition period and the best period for proteinaceous food-bait attraction. The chinese citrus fly is best lured during the emergence period in April when flies of both sexes are attracted, unlike in most other tephritid flies, in which baiting is usually carried out just before the oviposition period when mainly female flies are attracted. In one experiment in one isolated orchard, proteinaceous food-baiting during the emergence and oviposition period controlled the fly; after two years of bait application the fly was near extinct. Influx of flies from orchards at about 1,200-m distance made that the population recovered in two years. This results in a recommendation to combine proteinaceous baiting during fly emergence with the use of catch crops in the early oviposition season. Part 1 of the thesis then showed how fly monitoring and tools can be used to enable farmers to identify critical periods of the fly life cycle and build a social cognition for a joint effort to implement fly control activities.

Samenvatting.

Bactrocera minax of de chinese citrusvlieg is een belangrijke plaag in Bhutanese mandarijnenboomgaarden. De citrusvlieg legt eitjes als vruchten nog klein zijn zodat deze, als de eitjes een paar maanden later uitkomen, vroeg rijpen en uit de boom vallen. In deze studie is de citrusvlieg een "modelplaag" waaraan de samenhang tussen technische, sociale en bestuurskundige kennis bekeken wordt. Vanuit het perspectief van het probleem dat de vlieg veroorzaakt worden verschillende onderwerpen behandeld. Schade van de vlieg kan dan als een indicator beschouwd worden voor de effectiviteit van onderzoek, organisatie van boeren, en van overheidsdiensten en hun beleid.

Deel een van het proefschrift behandelt het sociaal-economische deel van de studie, dus de samenhang van technologie, leerprocessen en organisatie. De studie vond plaats in zuid-oost-Bhutan, in Pemagatshel en delen van Samdrup Jonkhar district. Het gebied is bergachtig en grenst in het zuiden aan Assam, een deelstaat van India. De bevolking is Indo-Burmees van origine en spreekt een ongeschreven taal, Sharchokpa of Oost-Bhutanees. De locale godsdienst is de Nyingmapa-secte van het Mahayana Buddhisme dat stamt uit Tibet. In de districten wordt de Bhutanese regering vertegenwoordigd door de "Dzongda", een soort "commissaris van de koning" wiens kantoor huist in de "Dzong", een kasteel vanwaaruit districten worden bestuurd. Akker- en tuibouw-, veeteelt- en bosbouw-diensten vertegenwoordigen het ministerie van landbouw en voeren districtontwikkelingsprogramma's uit. Districten zijn verdeeld in gemeenten met een gekozen burgemeester, iedere gemeente bestaat uit vijf tot vijftien dorpen met een dorpshoofdman. De voedselsituatie in het gebied is vrij gunstig, enkele seizoensgebonden uitzonderingen daargelaten. Het belangrijkste voedselgewas is mais en eventuele overproductie wordt vergist tot drank. Mais wordt nauwelijks verhandeld zodat onderzoeksinvesteringen in mais niet zoveel bijdragen aan een verbeterde sociaal-economische positie van de boeren. Mandarijn, het belangrijste handelsgewas, wordt vooral verkocht aan Assam en Bangladesh waar tientallen miljoenen potentiële consumenten wonen. Deze markt is nog lang niet verzadigd en kan makkelijk elke productieverhoging uit Bhutan opvangen. Alleen protectionisme (van India en Bangladesh) en monopolies (aan de Bhutanese kant van de grens) bederven nogal eens de prijs voor Bhutanese boeren. Desalniettemin is mandarijn verreweg het belangrijkste handelsgewas van het land. Het areaal groeit gestaag, en de productie per boom kan enorm verbeterd worden. De locale mandarijnenvarieteit is een ongeënt landras dat via zaad vermeerderd wordt. Het is een robuust gewas dat goed is aangepast aan de locale omstandigheden. Er zijn nog geen virusproblemen, hoewel een varieteit-verbeteringsprogramma, niet gehinderd door enige kennis van de risico's met betrekking tot virusziekten, materiaal het land in brengen. In het nabije Nepal bijvoorbeeld heeft de introductie van virus in een aantal gebieden de mandarijnencultuur weggevaagd. De huidige bomen in Bhutan kunnen wel 400 kilo mooie mandarijnen opleveren, maar de gemiddelde productie ligt tussen de 20 en 60 kilo. Dit gemiddelde kan verbeterd worden door betere selectie, lichte irrigatie, bemesting en gewasbescherming. Belangrijke plagen zijn maretak, een boktor, de gedoornde Djeroek-wants en de chinese citrusvlieg. Beide laatste plagen veroorzaken voortijdige fruitval. De Djeroek-wants veroorzaakt tot 90% fruitval in laaggelegen boomgaarden in de zomer, de citrusvlieg 35–75% in boomgaarden in hogere gebieden in de herfst.

Hoofdstuk 2 behandelt het citrusvoorlichtingsprogramma zoals zich dat in Pemagatshel district ontwikkelde, bekeken vanuit een leerperspectief. In de traditionele visie is wetenschap de bron van kennis. De voorlichtingsdienst is dan de instantie die de kennis van de wetenschap naar boeren brengt. In Indonesië is een bepaalde voorlichtingsmethode ontwikkeld, de Farmers Field Schools, waarin ervaringsleren een belangrijk element vormde. In de visie van het ervaringsleren is de bron van kennis anders dan in de traditionele visie. Ieder individu "ontdekt" kennis weer opnieuw via een leerproces waarin ervaring en het formuleren van ervaringen in taal elkaar opvolgen. Er is dan ook een terugkoppelingsproces waarin de persoon dan iedere keer weer kijkt of zijn of haar kennis wel overeenkomt met de ervaring, en ervaring genereert om meer kennis te bouwen.

Deze theorie werd toegepast in het voorlichtingsprogramma over citrus. De traditionele training-and-visit routine werd langzamerhand verrijkt met allerlei elementen uit de ervaringsleertheorie. In plaats van het geven van informatie over allerlei mogelijke onderwerpen werden dorpstrainingen toegespitst op citrus zodat informatie ook waarneembaar effect kon hebben. Eerder werden trainingen vooral binnenshuis, in tempels of andere grote ruimtes gegeven, maar later meer in boomgaarden zelf. Na training interviewden trainers boeren om te kijken of ze inderdaad hun practijk veranderden. De uitkomsten van dit soort interviews werden gebruikt om de daaropvolgende training aan te passen aan de noden in het getrainde dorp. Daarop bleken boeren aanzienlijk meer aanbevelingen op te volgen dan gedurende eerdere, meer algemene programma's.

Een meer verrassende uitkomst van het zoeken naar terugkoppeling was dat veel aanbevelingen die al jaren gedaan werden verkondigd weinig effectief bleken te zijn. Bijvoorbeeld, de bestrijding van de boktor werd ter hand genomen door watjes gedrenkt in petroleum in gaten van de boomstronken te proppen. Bij nader inzien bleken de meeste gaten *uitgangen* te zijn en niet gaten waardoor de larven naar binnen waren gekropen. Vooral boeren met bovengemiddeld mooie bomen bleken zulke technieken toe te passen en het programma nam veel van hun practijken over als aanbevelingen. Op dezelfde wijze werden de resultaten van onderzoek onder de loep genomen. In die tijd legden onderzoekers zich graag toe op onderzoek naar de grote rol van natuurlijke vijanden, immers door kalenderbespuitingen werd het natuurlijke vijandensysteem vaak aangetast. Maar in de dorpen waar het voorlichtingsprogramma werd uitgevoerd werd helemaal niet gespoten en daarom had het idee om natuurlijke vijanden te sparen daar weinig of geen betekenis.

Ondanks de aardige successen was het citrusvoorlichtingsprogramma niet helemaal compleet. Bijvoorbeeld, in de literatuur hadden we gevonden dat citrusvliegen waarschijnlijk wel door een combinatie van sanitaire maatregelen (onschadelijk maken van vliegenmaden in gevallen vruchtjes) en lokken door eiwitlokstoffen konden worden bestreden. Zo'n idee moet je natuurlijk uitproberen en het voortgaande onderzoek gaf te weinig informatie voor practische aanbevelingen.

Een ander probleem was dat zo'n bestrijdingsmethode niet door een innovatieve boer alleen kon worden uitgeprobeerd. Vliegen uit onbehandelde boomgaarden zouden in dat geval de behandelde boomgaard alsnog zouden kunnen binnenvliegen. Ook maretak is een plaag die zich verspreidt binnen dorpen zodat deze op dorpsnivo moet worden bestreden en niet op individueel nivo. Met de klassieke voorlichtingsstrategie gebaseerd op kennisoverdracht kan zo'n probleem niet worden aangepakt. Er moest dus iets gebeuren aan de link tussen boeren, onderzoek en voorlichting.

Deze overwegingen leidden tot een radicale verandering waarop het gewasbeschermings-onderzoek werd aangepakt. Onderzoekers voerden vanaf 1993 onderzoek vooral uit dorpen in plaats van alleen op de onderzoeksstations. Dat onderzoek wordt behandeld in Hoofdstuk 3. In eerste instantie was geïntegreerde gewasbescherming vooral een technisch begrip. Maar als boeren de techniek goed willen uitvoeren hebben ze toch ook inzicht in de processen die tot schade leiden nodig. Voor geïntegreerde plaagbestrijding heb je dus zowel bestrijdingsmethoden als procesobservatiemethoden nodig. Zulke methoden kunnen ontwikkeld worden door participatieve technologieontwikkeling, ook al is de meeste literatuur over dit onderwerp erg gericht op een versterking van de machtspositie van boeren, terwijl we in dit programma meer in de technologie zelf geïnteresseerd waren.

Het feit dat plagen vaak op een bepaalde schaal moeten worden bestreden heeft allerlei theoretische en practische gevolgen. In dit stuk gebruik ik het voorbeeld van theorie over "intuitie op groepsnivo" ("social cognition"). Deze theorie beschouwt de vorming van een gedeelde realiteit door groepen. Groepen ontwikkelen een gezamelijke woordenschat en geven een zelfde betekenis aan bepaalde fenomenen, wat resulteert in een wereldbeeld dat continu naar zichzelf verwijst. Zo'n groepsintuïtie essentieel voor het goed uitvoeren van bestrijdingsactiviteiten met een hele groep.

Daarop begon het citrusprogramma met het experimenteren met de bestrijding van de citrusvlieg in twee dorpen in oost-Bhutan, terwijl het onderzoek op het onderzoeksstation werd voortgezet. Technologie ontwikkeld op het onderzoeksstation werd meteen toegepast in de dorpen, terwijl het programma in de dorpen weer het onderzoek in de proefboomgaarden bepaalden. Het succes van de dorpsprogramma's hing erg af van de manier waarop de twee dorpen georganiseerd waren. In een van de dorpen wisten boeren al gauw een goed geoliede organisatie te creëren die de nodige behandelingen meteen over het hele dorp toepaste. In het andere dorp ontstond hier en daar verzet tegen het programma, niet in de laatste plaats omdat vliegen lokken het doden van levende wezens met zich meebracht wat in religieus opzicht niet goed lag. Na drie jaar proberen slaagde de boeren er toch in om de vlieg te bestrijden zodat de dorpen een aantal recordoogsten achter elkaar haalden. Achteraf gezien was het wel erg moeilijk geweest om gedurende die drie jaar steun voor het programma te behouden. Maar toen het doel een keer bereikt was was iedereen er toch erg blij mee. In een van de dorpen wilden boeren al meteen verder gaan en zijn ze, met hulp van de irrigatiedienst, een klein irrigatiesysteem voor hun mandarijnenteelt gaan aanleggen.

Het dorpsonderzoek leverde kennis voor verschillende groepen mensen. Voor citrusboeren en voor de voorlchtingsdienst leverde het een combinatie van technische en sociale kennis op die gebruikt kan worden om een Farmers Field Schools-achtig programma in elkaar te zetten, zodat dorpen als geheel kunnen leren hoe je gezamelijk zo'n beest moet bestrijden. Voor de practijk van landbouwkundig onderzoek laat het programma zien hoe je techniek en sociologie kunt combineren tot een mix waardoor, als deze juist wordt toegepast, onderzoek veel relevanter gegevens voor boeren kan opleveren.

Nadat de onderzoeksprogramma's in de dorpen zo aardig verlopen waren wilden beleidsmakers de ontwikkelde methode wel op grote schaal laten toepassen. De theorieën over groepsintuïtie en ervaringsleren hadden we tot dusverre eigenlijk alleen nog maar op boeren en op enkele individuele voorlichters en onderzoekers toegepast. Maar voor het toepassen van de technologie op grote schaal kun je de theorie ook aardig gebruiken om het gedrag van voorlichters en beleidsmakers mee te analyseren. Staf die eerder met het onderzoeksprogramma had meegedaan kon de technologie makkelijk in andere dorpen introduceren. Maar andere staf bleek dat helemaal niet te kunnen wegens allerlei redenen. Voorlichtingsstaf werd nauwelijks beloond voor dit soort activiteiten. Als er iets mis ging met het programma in dorpen hield de staf het snel voor gezien en bleek zo nauwelijks in staat van de fouten te leren. Bovendien bleken de hoeveelheden chemicaliën nodig voor het programma zo klein te zijn dat niemand geïnteresseerd was ze te leveren. Het ministerie kon nauwelijks flexibel reageren op de problemen omdat het zich bezig hield met het formuleren en uitvoeren van grote beleidslijnen ingefluisterd door instanties van buiten het land zoals ISNAR. Het bleek onmogelijk de beleidsmakers als groep werkelijk voor de successen op dorpsnivo te interesseren. We trekken hieruit de les dat, om het soort technologie in de dorpen ontwikkeld grootschalig toe te passen, allerlei partijen in het landbouwkennissysteem gezamelijk betrokken moeten raken bij zo'n programma. Pas dan kunnen ze een soort groepsintuïtie ontwikkelen om grote groepen boeren toegang te verschaffen tot allerlei economisch zeer aantrekkelijke en duurzame technologieën. Bovendien zou men niet bedrijfsstijlen als geheel moeten willen begrijpen, maar kleine componenten daarin. Effecten aan zo'n component kun je meten, en je kunt daarin van je fouten leren. Bij het doorvoeren van alomvattende veranderingen mis je de mogelijkheid om te leren.

Het tweede deel van het proefschrift gaat over de biologie en bestrijding van de chinese citrusvlieg. Omdat de datasets die we in dorpen verzameld hadden vaak incompleet waren is het technische gedeelte van dit proefschrift bijna helemaal gebaseerd op onderzoek op het onderzoeksstation. De chinese citrusvlieg is lid van de familie van Tephritidae (fruitvliegen). Toch is de biologie van het beest nogal anders dan die van de best onderzochtte soorten. De vlieg heeft twee rustperiodes (en niet maar een, zoals bij de meeste andere fruitvliegen): als pop in de bodem, zowel als als ei in de vrucht. Omdat vrouwtjes een lange legboor hebben kunnen ze eitjes leggen in het vruchtvlees. Andere fruitvliegen in citrus leggen eitjes in de schil waardoor ze in contact komen met allerlei toxinen die mortaliteit veroorzaken. De vlieg legt eitjes als vruchten net groot genoeg zijn, d.w.z. als ze groter dan 11 mm in diameter zijn. Vruchten die eerder die maat bereiken worden intensiever geprikt dan vruchten die pas later zo groot worden. Dit mechanisme verklaart veel van de ongelijke verdeling van eiboorgaatjes tussen verschillende vruchtenpopulaties. De gaatjesdichtheid kon zodoende nogal verschillen binnen groepen vruchten van eenzelfde boom, van verschillende bomen en van verschillende soorten bomen. Bovendien komen vliegen massaal op vroeg ontwikkelende citrussoorten af, zoals een locale soort limoen en sucade. Deze zouden als vanggewassen kunnen fungeren. Het seizoen dat eitjes gelegd worden duurt tot september. De eitjes blijven lang in rust, een tot vier maanden, voordat de eersten in october uitkomen. De maden eten dan aan het mandarijntje en veroorzaken schade en voortijdige val van de vruchten. De mediaan van fruitval viel vier jaar achter elkaar in de derde week van october, in een hoge boomgaard ietsje eerder dan in de lage boomgaard. Misschien wordt het uitkomen van de eitjes afgestemd op de korter wordende dagen, wat de ongewoon lage spreiding in de gemiddelde datum van fruitval zou kunnen verklaren.

Je kunt populaties van vruchten nakijken op eiboorgaatjes, net voor het seizoen dat de vruchtjes gaan vallen. Zo kun je meten hoeveel vruchten ongeveer gaan vallen en kun je de effectiviteit van eventuele behandelingen meten. Niet alle vruchten met een boorgaatje vallen uit de boom. Als je de dichtheid van gaatjes in mandarijnenpopulaties meet voor en na de periode van vruchtval blijkt dat ongeveer 76% van alle gaatjes inderdaad een of meer levende eitjes bevatten. Deze meting van de activiteit van citrusvliegen ging alleen op in hooggelegen boomgaarden. In lage boomgaarden zijn er meer beesten die in de vruchtjes prikken waardoor het beeld verstoord wordt.

Het opruimen van besmette vruchten zou in theorie een van de componenten van een bestrijdingsprogramma kunnen zijn. Toch bleek dat weinig zinvol. Als de bodem niet geploegd wordt grazen meest mieren de bodem af tot een bepaalde poppetjesdichtheid waar je met het opuimen van gevallen vruchten moeilijk onder komt.

Met allerlei vallen kun je de verschillende levensfasen van de vlieg volgen, zoals het uitkomen, de periode van eitjes leggen en de periode dat de vliegen het best op lokstoffen af komen. De citrusvlieg kan het best gevangen worden tijdens de periode dat deze uit de grond komt. Dan komen zowel mannetjes als vrouwtjes op de lokstof af. Andere fruitvliegen worden meestal gelokt net voor ze eitjes gaan leggen, dan komen er enkel vrouwtjes op de lokstoffen af. In één boomgaard zijn we er in geslaagd het lokken van vliegen de populatie zo goed als uit te roeien. Nadat de behandelingen gestopt waren duurde het twee jaar voordat de populatie weer terug op het oude nivo was, waarschijnlijk omdat er immigratie uit een boomgaard op zo'n 1200 m afstand optrad.

Technisch is de vlieg dus te bestrijden door het toepassen van vergiftigde eiwitlokstoffen in de periode dat vliegen uit de grond komen gecombineerd met met het toepassen van vanggewassen als de mandarijnenvruchten nog net te klein zijn. In het laatste deel van de dissertatie wordt samengevat hoe boeren valletjes en dergelijke kunnen gebruiken om inzicht te krijgen in de correcte toepassing van die lokstoffen, zowel op individueel nivo als op communaal nivo.

Curriculum Vitae.

Mr Frank van Schoubroeck was born in 1961 in Geldrop, The Netherlands. He did his MSc in Phytopathology at Wageningen University from 1980 to 1988 for which he took courses at the departments of Phytopathology, Theoretical Production Ecology and Organic Agriculture. He was one of the authors of a book on pest management for small landholders and worked as a crop modeller at the International Rice Research Institute. From 1990 to 1998 he worked in eastern Bhutan at the Regional Plant Protection Centre in Khangma, for the Integrated Pest Management Development Project. This project was implemented by the Royal Government of Bhutan and financed by the European Commission, while the Netherlands Development Organisation (SNV) employed him during that period. In 1998-1999 he wrote a Ph.D.-thesis about his work on citrus IPM in Bhutan. At present he is working for the Praja Community Development Project in central Nepal.