CHINESE-DANISH NETWORKING ON SYSTEMIC APPROACHES TO PEST MANAGEMENT WITHOUT PESTICIDES (2012)

A project funded by
the Danish International Network Programme of
the Danish Ministry of Science, Innovation and Higher Education

Research collaboration between China and Denmark for development of systemic approaches to agro-ecological pest management without pesticides with focus on vegetable, fruit and berry crops

Proceedings and recommendations from two network workshops

International Centre for Research in Organic Food Systems (ICROFS)
University of Copenhagen
Aarhus University

China Agricultural University
Southern China Agricultural University
Zhejiang University

Edited by Lise Andreasen, ICROFS

January 2013

This report has been prepared by The International Centre for Research in Organic Food Systems (ICROFS) and a team of researchers from Danish and Chinese Universities:

Niels Halberg, ICROFS
Lise Andreasen, ICROFS
Sabine Ravnskov, Aarhus University
Tove Steenberg, Aarhus University
Annie Enkegaard, Aarhus University
Lene Sigsgaard, University of Copenhagen
Vibeke Langer, University of Copenhagen
Jørgen Eilenberg, University of Copenhagen
Lisa Munk, University of Copenhagen
Maren Korsgaard, University of Copenhagen

Wu Wenliang, China Agricultural University
Qiao Yuhui, China Agricultural University
Zhang Long, China Agricultural University
Guo Yanbin, China Agricultural University
Liu Yunhui, China Agricultural University
Zhu Zengrong, Zhejiang University
Wang Jianwu, Southern China Agricultural University

Edited by:
Lise Andreasen, ICROFS
E-mail: lise.andreasen[a]icrofs.org
Phone: +45 87157704

Table of Contents

Executive Summary 1
1. Introduction 1
1.1 Systemic approaches to pest management 1
1.1.1 Biological Control 2
1.1.2 Eco-functional intensification 3
1.1.3 Landscape perspective for pest control 4
1.2 The project approach to development of a joint framework for research in systemic approaches to pest management without pesticides 5
1.2.1 Main findings from the 1st workshop. 5
1.2.2 Different contexts – a specific challenge for development of systemic approaches 7
2. Organic and agro-ecologic (without pesticides but not certified) farming systems in China and in Denmark 7
2.1 Denmark – Characteristics of the organic production and context for developing appropriate pest management practices 8
2.2 China – Characteristics of the organic production and context for developing appropriate pest management practices 9
3. Vegetable cropping systems: towards collaborative research development of non-chemical systemic approaches to pest management 10
3.1 China: State of the art and future perspectives 11
3.1.1 Present practice for non-chemical invertebrate pest and diseases management in vegetable production in China 11
3.1.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in vegetable production in China 13
3.2 Denmark: State of the art and future perspectives 15
3.2.1 Present practice for non-chemical invertebrate pest and diseases management in vegetable production in Denmark 15
3.2.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in vegetable production in Denmark 17
4. Fruit and berry cropping systems: towards collaborative research development of non-chemical systemic approaches to pest management 18
4.1 China: State of the art and future perspectives 18
4.1.1 Present practice for non-chemical invertebrate pest and diseases management in fruit and berry production in China 18
4.1.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in fruit production in China 19
4.2 Denmark: State of the art and future perspectives 20
4.2.1 Present practice for non-chemical invertebrate pest and diseases management in fruit production in Denmark 20
4.2.3 On-going research and future perspective for non-chemical invertebrate pest and disease management in fruit production in Denmark 21

5. Research topics of mutual interest and priority between China and Denmark within the field of non-chemical systemic approaches to pest management 23
5.1 Vegetable cropping systems 24
5.2 Fruit and berry cropping systems 25
6. Recommendations for strengthening future research collaboration between China and Denmark in the field of systemic approaches to agro-ecological pest management without pesticides. 28
7. Concluding remarks on the framework for future collaboration from the Network 30
Annex 1: References 33
Annex 2: 1st Workshop on Systemic Approaches to Pest Management without Pesticides, 15-17 April, Boshan, China – Programme 35
Annex 3: 2nd Workshop on Systemic Approaches to Pest Management without Pesticides, 22-24 August, Flakkebjerg/Copenhagen, Denmark – Programme 37
Annex 4: Systemic Approaches to Pest Management without Pesticides - Chinese-Danish network members 39

Executive Summary

This report is the result of a network project which was established to discuss the potential for collaboration on development of systemic approaches to pest management without pesticides between Chinese and Danish researchers. The focus is on systemic approaches rather than input substitution of synthetic chemicals with agents of natural origin, however, the latter is considered as an integrated tool for the development and design of systemic approaches. The discussions were, furthermore, limited to management of invertebrate pests as well as diseases, while other pests such as weeds have not been included in the discussions. The discussions took place at two workshops and were based on presentations of research from the two countries and field visits in China and Denmark.

After the first workshop that took place in China, it was agreed that Chinese and Danish researchers in this particular field had mutual interests and priorities and that there was a potential for creating collaboration that could yield results beneficial for the agricultural/horticultural sectors in both countries. It was also agreed that in spite of the many differences between variation in climate and ecosystems, as well as in farming systems and their organization in China and Denmark, there were many similarities in the production of high-value crops in the two countries, such as vegetables, fruit and berries and, therefore, an obvious focus for joint research efforts. It was also agreed that joint research efforts could aim at specific crops as well as aiming at the development of specific research approaches.

Based on the observations and the agreements of the first workshop, the second workshop, which took place in Denmark, focused more specifically on the development of a research framework with specified research questions/topics. Two groups were formed – one working with vegetables and one with fruit and berries working in parallel – both looking into what kind of research is needed for development of systemic approaches to pesticide-free pest management should include both well-known practices and new practices.

Although the discussions in the two groups took separate routes and unfolded and described the research topics in each their way, there was a clear consistency between the outputs of the work of the two groups. Each had identified three main research themes that more or less followed the same line and has been merged into three specific recommendations on themes for collaboration, namely:
1) ‘Research to provide the biological foundation and understanding of mechanisms and interactions for development of non-chemical solutions and to improve efficiency of new and existing control methods for severe pest problems’.
2) Research in ‘How best to integrate multifunctional plants (and crops) and use diversification to create a more healthy and productive farming system which is resilient to pests?’
3) Research in ‘How to design and integrate pest management in eco-functional cropping systems at field and farm/landscape level?’

This report has been prepared by a core group of 15 researchers, but the network in total includes about the double amount of researchers who all participated in at least one of the workshops, and can be mobilised for further collaboration – in informal parallel research activities or in more integrated collaborative research projects. The network recommends that the Chinese and the Danish government join forces and allocate research funds to develop systemic approaches for pesticide free management and for reduction of the use of pesticides in farming in general.

1. Introduction

This report is the result of the Chinese-Danish networking on Systemic approaches to pest management without pesticides – a project funded by the International Network Programme of the Danish Ministry of Science, Technology and Innovation.

The focus on development of pesticide free 'systemic approaches' corresponds to the holistic nature of agroecological and organic agriculture where pests are managed in an integrated manner with the farming system and based on agro-ecological practices versus a pesticide free management based on input substitution of synthetic pesticide with agents of natural origin.

The wording 'pest management without pesticides' has been used intentionally to address the pest management in organic farming systems but also to include informal/non-certified organic farming systems as well as to link experiences in the organic sector with the requirements for reducing the use of pesticides in conventional agriculture, and as such use the organic sector as a driver for development in general.

While the word 'pests' in association with crops can cover a very broad range of organisms causing damage to the plants, we are in this report referring only to 1) microorganisms causing diseases in crops and 2) invertebrates causing damage to crops, such as insects and arachnids - thus excluding mammals, birds and reptiles. Likewise when using the word pesticide in this report we refer only to chemical substances that can be used to control the above mentioned damaging microorganisms and invertebrates.

The report does not address management of weeds specifically. However, during the workshops the importance of including also management of weeds in the development of systemic approaches has been discussed. It was concluded that the interrelationship of diseases, invertebrate pests and weeds should ideally be considered in the development of systemic approaches. It has, however, not been possible to include in the objectives for the present network.

The project work has mainly been undertaken in relation to two workshops. The first workshop was held 15-17 April 2012 in Boshan, Shandong Province, China, and was supported by the local authorities in Boshan District. The second workshop was held in Denmark 22-24 August 2012 partly at Research Centre Flakkebjerg, Aarhus University and partly at Frederiksberg Campus, University of Copenhagen.

The objective of the bilateral network was to exchange knowledge on the current state-of-the-art and to provide recommendations for a joint framework for collaboration for development of systemic approaches to pest management without pesticides and with specific considerations to future challenges. The network programme has helped researchers in the two countries to better understand research priorities in China and Denmark to identify common research interests and formulate joint research problems. Recommendations for and conclusions on research collaboration between China and Denmark in the field of systemic approaches to pest management without pesticides are summarized in section 6 and 7.

1.1 Systemic approaches to pest management

Reduction of the use of pesticides in organic as well as in conventional agriculture and the search for alternative pest management approaches is a priority in Denmark and in China for food safety, environmental protection and economic reasons. To date many researches and practices are focusing on partial technology development - such as the development of a natural pesticide as a substitute for a synthetic chemical treatment – less research has focused on integrated and holistic approaches where the farming system is an integrated part of the pest management – so called systemic approaches.

Systemic approaches to pest management are characterised by an in-depth understanding of the agricultural system and require the integration of pest management decisions from planning and design of the cropping system, over monitoring and early warning of pests, to direct pest management.

The systemic approach includes consideration of the ecology and complexity of the farming system in the context of the agricultural landscape, in contrast to the more narrow focus on replacing chemical pesticides with natural or bio pesticides. This may include crop rotation and intercropping; selection of resistant crops and varieties; agro-biodiversity/functional biodiversity (diversification at genetic, crop, landscape levels); as well as giving due considerations to specific challenges and potential such as how to capture combine traditional existing innovative non-chemical pest management methods with new knowledge and advanced methodologies.

A scientific challenge in pest management without pesticides is the need for further knowledge on the biology of key pests, their interaction with plants and with their natural enemies, and of the cropping system dynamics. For arable crops covering large areas, the use of healthy varieties, crop rotation, sanitation practices, and ecological infrastructures constitute a particular focus for cultivation without pesticides.

At the workshop the discussions centred around biological control and how to upscale biological control from field to farm unit and to landscape level; so-called 'eco-functional intensification' or 'ecological engineering'; and integrated approaches at field, farm unit and landscape level. We realised that the understanding and perception of different concepts might differ slightly between groups of scientists in China and in Denmark. Therefore, we decided to clarify some main concepts and ensure our common understanding. The following three sections on biological control, eco-functional intensification and landscape perspective have been jointly prepared with this purpose.

1.1.1 Biological Control

As mentioned above biological control (=biocontrol) was a highlight topic in the workshops. In China, biological control was first recorded 2000 years ago using plants to control insects, and an early record of use of ants to control pests in fruit trees was in 880 A.D (Bao and Gu, 1998). Since then, many natural enemies of insects have been identified and several species are used in China and/or Denmark, such as parasitoids, predators, nematodes, fungi, bacteria, virus, and microsporidia (Sun, 2012). Still, however, few of the known species have been developed and are in use. Biological control of plant diseases exploits the natural competition, parasitism or antagonism of microorganisms (for instance *Trichoderma* sp.) and several products are commercialized. Besides, several extracts of plants have been commercialized in China and are widely used in organic production. The increased production of organic fruit, strawberry and vegetables calls for much more emphasis on biological control methods.

The Danish team defines 'Biological control' in accordance with the normally used definition in for example International Organisation for Biological and Integrated Control of Noxious Animals and Plants, IOBC (http://www.iobc-wprs.org/). The definition is outlined by Eilenberg et al (2001). Biological control (or biocontrol) is: *'The use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be'*. This definition does include living organisms as biocontrol agents: predators, parasitoids, nematodes, fungi, bacteria, virus and protozoa. The definition thus excludes agents consisting of plant extracts and similar. The definition is in accordance with the EU regulations on registration of microbiological control agents.

In China, definition of biological control is as follows" *utilization of organisms and their metabolic substances to control pests, the organisms including predators, parasitoids, fungus, bacterium, virus, nematode, protozoa, extracts of plants, and pheromone*". As it appears the Chinese and Danish definitions of biological control differ concerning extracts of plants and pheromones. Where needed this will be specified in the report.

Biological control can be subdivided into four main strategies:

1) Inundation biological control
2) Inoculation biological control
3) Conservation biological control
4) Classical biological control

The four strategies are outlined in Eilenberg et al (2001). Often, inundation and inoculation are together called 'augmentation', since both strategies include the release/application of commercially available biocontrol agents. Especially microorganisms used for inundation are often called 'bio-pesticides', and it should be mentioned that this term as well as the term 'biofungicides' may refer both to the use of living biological control agents as well as botanicals. Conservation biological control does not include any application, but relies solely on the effect of naturally occurring predators, antagonistic fungi etc. These three strategies are all important for Chinese and Danish efforts within biological control. The fourth strategy 'Classical biological control' includes the release of exotic organisms and will not be considered further in this report.

Considering the future development of biological control, the teams agreed that an effort is needed to explore new biological control agents from the diverse, natural resources in both countries, particularly in China, which harbours an enormous diversity of natural enemies. We need to explore new ways on one hand, and also learn from traditional methods, particularly in China, that can form part of integrated and systemic approaches, as well as investigate how the impact of the biological control can be strengthened though supporting structures (corridors, field boundaries, shelter, etc.).

1.1.2 Eco-functional intensification

The novel concept of 'eco-functional intensification' signals that the aim is to maintain or improve crop yields with less or no negative effects from pesticides or other pest management methods, at the same time maintaining, restoring or improving the resource base and the ecosystems delivering ecological services to society and to food production. One of the prevailing definitions of 'eco-functional intensification' states, that this kind of intensification – as opposed to relying on increased inputs as pesticides and fertilizers:

· *uses existing mechanisms, biological or organizational systems;*
· *is adapted to local conditions and local farmers' skills;*
· *is knowledge intensive (both local and scientific knowledge);*
· *fosters the resilience of agro-ecosystems."*

(Peter Kenmore, FAO, in GIZ (2011))

In other words, 'eco-functional Intensification' may be understood as 'more knowledge, information and organisation per hectare'. In pest management this implies that solutions may be highly context dependent and involve farmers, combining farmers' knowledge with scientific evidence in order to be applicable in practice.

Within pest management 'eco-functional intensification' focuses on system design on field, farm or landscape scale. On field scale, an example of design is intercropping which is a practice aimed at both risk reduction, nutrient management and assumed pest management effects. However, some of the scientific evidence fails to answer the crucial question whether the results seen in trials can be extrapolated to full field scale and thus be transferred to practice. On farm and local scale crop rotation in time and space is an example of system design. Rotations in space (moving crops far away from the previous crop) handle only pests with low or medium mobility, are only possible in annual crops and are often limited by land area (farm size) and location of fields. To address this, ‘landscape level rotation’ has been developed by organic vegetable farmers, who exchange land with adjacent farmers, leading to ‘increased organization per hectare’. Such a landscape rotation can be a win-win situation for participating farmers and may present an alternative to farm enlargement where land is scarce or expensive. On landscape scale, an example of system design is maintenance of hedgerows, permanent grassland, ley or other less disturbed habitats, serving as refugia (place of retreat) for natural enemies in agricultural landscapes with high proportion of arable land.

1.1.3 Landscape perspective for pest control

Landscape structure, including the spatial or temporal composition and configuration of landscape element or resource, has strong impacts on various ecological processes, including organism movement (Turner et al., 2001). In the last decades, the intensification of modern agriculture has resulted in great changes in landscape structure by expansion of agricultural land, enlargement of field size and removal of natural or semi-natural habitats. The intensification therefore drives the loss of biodiversity and deterioration of ecosystem functions associated with biodiversity. Pest control, one of the most important ecological functions, which is strongly associated with biodiversity and essential to agricultural sustainability, would also be affected by changes of agricultural landscape structure (Sigsgaard, 2010, Ouyang and Ge, 2011). Potential explanations to this impact of landscape structure on the pest control can be attributed to the following aspects. Firstly, different natural enemy species would have different favourable habitats. A decrease in habitat diversity would result in fewer habitats to sustain diverse natural enemies. Secondly, a majority of important arthropod natural enemies requires more than one habitat during their life history. Movements between habitats (for foraging, nesting, breeding, overwintering etc.) are essential to their persistence. Changes of landscape composition and configuration may prevent their migration and be detrimental for their persistence in the landscape. Thirdly, species would vary with respect to their dispersal ability and to how they perceive the landscape at different scales. Measures to conserve different natural enemies or to control pests should be made with proper consideration of this attribute accordingly.

As environmental concerns increase due to the wide use of chemical pesticides, it is a must to develop a more sustainable way for pest control, in particular for these highly intensively managed systems like vegetables, fruit and berries with high value crops, where little pest damage can be tolerated.

In recent years, pest control is more and more widely considered to go beyond the plot level and that a perspective of landscape is needed. Landscape planning and habitat manipulation, such as conserving or creating diverse and connected natural/semi-natural mosaics at the landscape level, establishing wildflower strips, beetle banks, field margins or intercropping systems at the between-field level, provide potential ways to enhance biological pest control for sustainable farming (Duan et al., 2012, Sigsgaard et al., *In press*). Agro-environmental schemes supporting perennial boundary vegetation and organic or low-input farming are now practiced in a wide range of European countries including Denmark as a measure to compensate the negative effects of intensive production on biodiversity and to restore the essential ecosystem function like pest control. However, these schemes have not consistently conserved biodiversity or increased pest control in the agro-landscape (Purtauf et al., 2005; Bianchi et al., 2006; Batáry et al, 2011, Veres et al., 2011). Variations in the landscape context, local habitat quality and species characteristics make it difficult to give a reliable recommendation on strategies of landscape planning and habitat manipulating to achieve a successful biological control. Future studies are needed to improve the understanding of the effects and the change of landscape structure on maintaining diversity of biocontrol agents, physiological and ecological knowledge about target species and the target species’ responses to landscape structure, interaction between natural enemies, pests and plant associated with landscape structure, values of landscape elements to pest control function, and the essential characteristics of landscape elements (area, shape, spatial, connectivity, plant composition etc.) for maintaining biological control function (Bianchi et al., 2006; Tscharntke et al., 2012).

1.2 The project approach to development of a joint framework for research in systemic approaches to pest management without pesticides

The hypothesis behind the Chinese-Danish network project is that it will be possible to follow two approaches for identification of research areas of mutual interest, namely:

- To investigate integrated systemic approaches to pest management in specific crops of joint interest (strawberries, apples, and various vegetables); and
- To investigate research methodologies for integrated systemic pest management that could be applied to different crops in China and Denmark (thus thinking more in concepts and how to conceptualize approaches to pest and disease management).

It has further been assumed that transnational collaboration would be beneficial for both countries. China can draw upon an advanced research sector with a vast number of scientists doing research in natural science and at the same time experiences from very diverse farming systems which include smallholders practicing traditional farming and having knowledge that can be highly relevant in the development of systemic approaches. In spite of its small size, Denmark has extensive experience in undertaking research in agriculture-environmental interrelations and integrated approaches and has a formalized organic research sector. Combining the experience of the researchers in the two countries for the benefit of improved agricultural systems without pesticides or with very limited use of pesticides is therefore be expected to create synergies that would not be achieved otherwise.

The network met on two occasions – a workshop in April 2012 in China and one in August 2012 in Denmark.

The purpose of the 1st workshop was to establish a common understanding of research approaches and priorities in China and Denmark and to identify common research interest. The workshop was a combination of presentations, field visits, and discussions in groups and in plenum. The findings of the 1st workshop guided the planning and implementation of the 2nd workshop. See main finding below in section 1.2.1.

The purpose of the 2nd workshop was to identify research priorities and describe selected research themes of high priority for future collaboration. The findings of the 2nd workshop are summarized in Chapter 3-5.

1.2.1 Main findings from the 1st workshop.

Similarities in trends in agricultural development - In both China and Denmark organic vegetable farmers are under economic pressure to intensify production, aiming at higher yields and larger profitability. This development takes two directions: the first pathway is farm enlargement and product specialization. In China, this is especially seen in outdoor vegetable farms in semi-urban areas, supplying the urban markets. In Denmark it is a general trend in organic vegetable farms. The second pathway is production moving from field production to protected cultivation in tunnels or in greenhouses, e.g. for strawberries, aiming at higher prices for extra quality (early products) and more secure yields. Protected production is already widespread in both the conventional and organic production in some areas in China, and is an emerging trend in both conventional and organic production in Denmark. In conventional agriculture, both of the described intensification pathways have traditionally been linked with increased demand for inputs, primarily pesticides, because of emerging problems with pests and diseases. Therefore there is a need, within the organic sector, to find alternative ways to intensify and improve systems by designing solutions on systems level, which are based on knowledge and human organization ('eco-functional intensification') and which are effective, applicable and cost-efficient in the relevant contexts.

Recent policy developments in both countries which signal an increased awareness on system design as a preventive measure towards pest and disease problems and which may promote the above ideas.

In China, organic farmers in areas with more than one crop per year face a requirement from standards for more diverse crop rotations. In EU, the 'greening of the CAP' supports the reservation of 7% of the farm area as uncropped areas as well as the implementation of increased crop diversity by requiring at least three crops in the rotation for commercial farms. These measures are mainly directed towards conventional farmers, as organic farmers are assumed to automatically comply with them. In addition, the EU directive for sustainable use of pesticides (DIRECTIVE 2009/128/EC) requires the implementation of IPM principles on all commercial farms in 2014. This will be implemented in various ways in member states, but it is certain that system designs such as use of rotation, crop diversity and uncropped areas for biodiversity enhancement can be expected to have high priority as measures to satisfy the goals. In this connection the potential of the systems approach for non-organic systems which are under pressure to implement IPM was discussed.

Broad interests, but agreement of overall perspective - Collaboration should aim at developing a holistic agro-ecological approach to prevent/control pests and to simultaneously conserve/increase biodiversity and if possible also the landscape diversity by integrating existing (in some cases 'traditional' in terms of old knowledge used by farmers in the past but now in danger of being forgotten) and new knowledge. The efficacy of 'Old knowledge-methods' should be tested to evaluate whether these methods can be employed in modern organic agriculture. New knowledge must be obtained after identifying possible gaps in our knowledge concerning methods that are currently available for non-chemical control of pests, diseases and weeds. This does not only include the methods presented at the conference (e.g. augmentative releases of natural enemies, use of antagonists, mechanical and cultural weed control) but must include 1) diversification of the organic cropping systems and the landscape using e.g. intercrops, flower strips and other types of habitat manipulation, and 2) the application of a diversity of pest control methods as well as methods to prevent pests. A key element will be the integration of different research disciplines into multidisciplinary projects, where all major problems related to a particular cropping system are addressed.

Cropping production systems versus individual crops - A focus on intensive cropping systems seemed to be the obvious choice with focus on vegetable and fruit and berry production systems as crops within these categories were frequently brought into the discussion. The discussions were intended to focus on 'cropping production systems' in general, however discussions on specific crops, such as tomato, cucumber, strawberry and apple, added to the mutual understanding of systems in the two countries.

Some key issues for full implementation of sustainable pest management for all crops:

- Monitoring and forecasting are indispensable tools for the full implementation of sustainable pest control (including implementation of diagnostic tools)
- Deeper understanding of the basic biology of the organisms involved
- Attention to changes of pest (invertebrates) and disease pressure which may be caused by climatic changes
- Diversification as a means of disease control should be considered
- Fundamental studies of the microflora and fauna in soils are needed together with the effect of plant protection activities of the functional biodiversity

Broad scope for collaboration versus limited project resources - Based on the discussions at the first workshop it became clear that the network project needed to limit its scope due to the limited time available for the network as well as the limited number of experts to be involved. Other cropping systems that could be relevant for collaboration between China and Denmark, but were decided to be omitted from the network at present time, would be systems where wheat, potatoes and maize are important crops. These crops cover large areas in relative terms in the two countries, so elimination of pesticides in these crops would have a major impact on food safety and environmental health.

1.2.2 Different contexts – a specific challenge for development of systemic approaches
In addition to the above findings referred in 1.2.1, it also became clear that there was a need to be aware of the very different contexts in the two countries.

Both in China and Denmark demand for high value products produced without the use of pesticides is increasing driven by health and environmental concerns, but conversion to non-pesticide management relies on available alternatives to pesticides and different applicability of possible system design solutions. Such alternatives and their applicability will depend on the specific context locally or nationally concerning farm structure, land use and land ownership and organisation management, resulting in highly different applicability of possible system design solutions.

Developing appropriate pest management methods in the two different contexts of China and Denmark calls for great attention to the importance of context: what are exactly 'the systems' we are dealing with?

Firstly, to apply systems approaches we need to know 'the system' on various scales:
a. The crop itself (inherent properties of the crop, e.g. varieties)
b. The crop field (crop + its associated plants, e.g. flower strips, intercropping)
c. The cropping system as part of the farm system (crop diversity, balance between high-risk and low risk crops, land availability, etc.)

When the focus moves from the inherent properties of the individual crop to the cropping system, the demand for contextual knowledge increases. This means that the actual context for implementing pest management methods in terms of farm practices, farmer competences and socio-economic drivers and barriers must be understood. Some information on the farming systems and context is provided in 2.1 and 2.2; however, contextual considerations should be an essential part of future research collaboration.

Secondly it is necessary to define whether the focus of the research is solely on certified organic agriculture or whether we also see organic agriculture as a development arena for mainstream agriculture. In that case success criteria for pest management methods or practices emerging from this Chinese-Danish research cooperation could be identified as:

1. The method or practice has the potential to improve the management of pests of considerable importance in organic agriculture – in China, Denmark or both;
2. The method or practice has the potential to improve the management of pests of considerable importance in some conventional systems;
3. The method or practice has the potential to demonstrate to policy makers that system approaches/ system design can reduce the use of pesticides in non-organic agriculture – and in that way 'push' for changes.

2. Organic and agro-ecologic (without pesticides but not certified) farming systems in China and in Denmark

The area of Denmark is 4.3 million ha. The agricultural area is 2.64 million (61%). In 2011 almost 1.5 million ha were cultivated with cereals (56% of cultivated area). The average size of a farm in Denmark is 65 ha and the total number of farm households 40,661. Most farms are privately owned.

With Denmark being a small country in the temperate region, China covers several climatic zones, lowland as well as mountainous regions, and compared with Denmark a more diverse nature.

The area of China is 959 million ha, of which 120 million ha are arable (12%). The main crops are rice (25%), wheat, corn, vegetables, oil rapes and fruits. Due to the diverse nature condition, the farm type and management is different from north to south. In North China, the farms are large with monoculture and with more than 1 ha per household mainly used for wheat –corn rotation, sometimes farmers have more than hundreds of ha in Heilongjiang and Xinjiang Province; mainly for rice and bean production. In South China the farms normally have only a small piece of land - especially in mountain areas - with less than 1 ha per household. Here the small farm households plant different crops such as rice and upland crops.

2.1 Denmark – Characteristics of the organic production and context for developing appropriate pest management practices

Organic farming in Denmark covers 7% of the agricultural area and is practiced by 6% of farmers (2011).

Historically, the state has played a large role in the development of organic agriculture in Denmark. Certification and control is managed by the Ministry of Agriculture, and the organic label is recognized by more than 95% of all consumers. The advisory service is integrated with the conventional extension service, typically with specialized organic advisors but with a large degree of professional collaboration. The growth of the sector in numbers of farms and area has been stagnating, with new farms converting and other farms returning to conventional production. However, government supported efforts to increase the market through minimum requirements for public kitchens' proportion of organic products are expected to increase conversion, especially in products for fresh consumption.

The development of organic agriculture and the support from the Government is strongly related to a desire to minimize the environmental impacts of pesticides, particularly the protection of groundwater and the aquatic environment. Organic farming has, however, developed into a viable sector.

In 2011 the export value of organic products from Denmark was approx. USD 0.18 billion. The export is mainly for the rest of Europe.

Farm size distribution among organic farms is similar to that of conventional farms. Like conventional Danish farms, organic farms enlarge their enterprises, especially within livestock farms. In conventional agriculture large farms with highly intensive pig production dominate the sector, while large dairy farms dominate the organic sector. Most organic dairy farms are full time farms with a few employees, marketing their milk through dairies, which are either small and exclusively processing organic milk or are large and process milk from both the organic and conventional dairy producers. Other farm types which are overrepresented in the organic sector are vegetable and egg producers.

Because the dairy farms have only few pest management problems due to their focus on forage crops, the main pest problems are found in intensive crops like fruits, vegetables and seed crops. This production structure means that from a pest management point of view, organic vegetable producers (responsible for 15% of the total Danish vegetable production) and fruit producers will be important stakeholders for new practices on systems level. Important vegetable crops are different cabbage crops, onions and carrots, whereas apple and strawberries are the dominating fruit crops.

2.2 China – Characteristics of the organic production and context for developing appropriate pest management practices

By the end of 2010, there were about 1.09 million hectares organic certified arable lands in China, it accounts for about 0.9% of the total arable land. In addition 0.89 million hectares are certified for wild collection. Certification is undertaken by private and governmental certification bodies. In 2010 there were 21 certifiers. There were 4,390 organic enterprises[1] involved with 5,439 certificates and 3,976 production bases and 2,018 processing factories.

The main driver of organic agriculture has been the market demand, initially by the international market especially Europe (54% by value) and North America (33%), but after 2000, the domestic market is booming, especially in large cities. Special food stores, community supported farms for home delivery and relaxation are developing very fast. National demonstration areas for organic productions are promoted by governments CNCA, Ministry of Environmental Protection, and Ministry of Agriculture. Some local governments with good conditions have their own policies for promotion such as payment for certification fees.

According to the survey of certified projects[2] by certifier ECOCERT, there are 78 projects for certified organic vegetable. The size of the majority of the organic vegetable farms is less than 46.83 ha; only 25% of farms are larger than 90.8 ha. About 86% of the farms are operated by companies, 8% of them by farmer cooperatives; and 6% farms are co-operations between companies and small householders. Normally in vegetable production, farmers know well how to apply intercropping and crop rotation to increase bio-diversity and also meet the demand of the standards.

In a study in Zhejian it was found that the main residues found in conventional vegetables were insecticides and fungicides and with mid-high toxicity pesticide (Ye et al. 2012). These insecticides are mainly for controlling whiteflies, lepidopteran caterpillars, and spider mites. High toxicity and high residue insecticides are still applied illegally in vegetables. Pepper, cucumber, cowpea, cabbage and tomato are the main vegetables from which pesticide residues were detected. There is, thus, a strong need to reduce the use of pesticides and minimize the level of residues - particularly the high toxicity insecticides in these vegetables.

For fruit production, there are 47 projects. In general, the farms are bigger than the vegetable farms, about 79 ha on average, and more than 25% of farms are larger than 242 ha. About 53% of the farms are operated by companies, 2% of them by farmer cooperatives; and 45% are in cooperation between companies and small householders. Intercropping in younger plantings is common.

Organic production is normally located in the region with favourable environment and climate conditions where even conventional farmers seldom use chemicals such as in the high mountain remote areas or Northeast China area. The most popular used measures for pest & disease control are yellow boards, traps, net cover, lamps, hormones, sugar-vinegar or Bordeaux mixture, Lime sulphur for spraying.

Some of the constraints in pest and disease control in organic production are:

- Control mainly depends on bio-pesticide (biological control agents) and other certified agents (commercial products),
- System control methods for pest and diseases may require some areas for wild vegetation/ ecological infrastructures, but farmers want to make full use of the land for food production,
- There is a lack of professional guidance and literature.

[1] Enterprise means the applicant of the certification. This may be an individual producer who has or rents land from farmers, or who organizes a group of farmers to produce organic products.
[2] Projects mean a certified programme applied by enterprise.

In order to facilitate the pest and disease management, it is necessary to train operators in the ethics of organic farming and to develop integrated and practical system measures for implementation. Furthermore, demonstration is very important for dissemination of appropriate and good practices.

3. Vegetable cropping systems: towards collaborative research development of non-chemical systemic approaches to pest management

The major Danish greenhouse vegetable crops are cucumber, tomato and lettuce grown on a total area of 120 ha. The major vegetables grown as field crops in Denmark are pea, carrot, onion, cabbage and lettuce totalling an area of 11,150 ha of which about 14% are organic. The pesticide use index in conventional vegetable production is rather high, corresponding to 3.8 per area unit. Approximately 34 % of the pesticides used in vegetable production are fungicides to control diseases.

The pests and diseases occurring in Danish vegetables depend upon the crop and the growing conditions (indoor, outdoor). In greenhouses the major pests are spider mites, whiteflies, thrips, aphids, and leafminers whereas outdoor vegetables suffer from infestations by root flies, aphids, Lepidopteran caterpillars, nematodes, beetles, thrips and slugs and snails. The most severe disease problems in vegetables are caused by air-, seed- and soil borne fungal pathogens, whereas diseases caused by bacteria, virus and nematodes are of less importance in Danish vegetable production.

China has the largest vegetable production in the world producing 49% of the global vegetable production (FAO 2010). Greenhouses play an important role in vegetable production - 80% of greenhouses in the world are in Chin. 37% of the vegetable production in China are from greenhouses (Zhang 2010, Yu 2011).

Vegetables cover the fourth largest area in China, 19 million hectares each year (China MOA statistics). Since 2000, the land area for vegetable production has been stable, while the unit yield and total production increase, which might be attributed to germplasm and production facility improvement, and manpower and energy inputs.

The main kind of vegetables are *Cruciferae* (cabbage etc.), which is the most predominant vegetables occupying 5.22 million ha (m ha) and a production of 185 million tons (m t) yearly; *Solanaceae* 1.52 m ha and 58 m t; *Leguminosae* 1.32 m ha and 21 m t; *Cucurbitaceae*, *Umbelliferae* and *Leguminosae*, each covers 1 m ha, with a production of 38, 33, 22 m t, respectively.
There is a total of 109,900 ha of organic vegetables (56,000 ha certified organic and 53,800 ha in conversion). This equals 0.6% of the total vegetable production area.

Organic vegetable production mainly takes place in the Eastern part of China such as Shandong (9,300 ha, 8.5%) and Zhejiang Province (8,350 ha, 7.6%) with perennial vegetables, Yaro class vegetable, Chinese cabbage, melon vegetables etc.

Both in Denmark and in China biological control in tomato and cucumber is used and has already contributed significantly to a reduction in pesticide use, yet there are many challenges in order to fully explore and implement biological control.

3.1 China: State of the art and future perspectives

3.1.1 Present practice for non-chemical invertebrate pest and diseases management in vegetable production in China

Invertebrate pests

Lepidopterous caterpillars, Coleopteran worms and beetles, whiteflies, leafminers, aphids, spider mite, thrips, beetles, are the main insect pests of vegetables. In China, non-chemical pesticide practices in vegetable pest control are increasing. The main methods used are as follows:

Cultural methods: rotation of cucurbits and beans with pepper, onion, garlic or parts of leaf-vegetables will reduce the infestation level of leafminers. General sanitation and removal of insect harbored crop residues have been used to decrease the initial infestation of over-wintered or over-summered insects such as lepidopteran insects. Vegetables intercropped with maize would interrupt the immigration of winged-aphids.

Physical methods: Black-light traps (365 nm) are effective to attract mole crickets, cockchafers, beet armyworm adults. Plastic mulching is used for killing the pupae of leafminers, and prevents the cucumber seedlings from oviposition by cucurbit leaf beetle (*Aulacophora femoralis*), and the silver-grey color plastic on soil surface would reduce the infestation by aphids and their vectored virus diseases. Yellow board sticky traps for aphids, thrips, whiteflies are seen frequently in vegetable fields. Net screening isolation indicates a good way to prevent crop infestation from whiteflies, lepidopterans, beetles etc.

Plant extracts, natural compounds: Several kinds of plant extracts have been available in the market for insect pest control. Matrine (including quinolizidin, dipiperidinetype etc.) extracted from *Sophora flavescens* (Order: Fabales, Family: Fabaceae) has been widely used against many species of vegetable crop pests, such as aphids, green leafhoppers, mites, cabbage worm (*Pieris rapae*), with efficacies from 40% to 80% (Wang et al. 2007). Azadirachtin and neem insecticide from Azadirachta indica with a series of effective mechanisms such as insecticidal, antifeeding, deterrent, growth regulator, are used for suppression of the insect herbivores populations. These plant-based insecticides are relatively safe for the cabbage worm (*Pieris rapae*) and the diamondback moth (*Plutella xylostella*) larval parasitoids (*Apanteles glomeratus*, *Diadegma semiclausum*) (Chen et al. 2010).

Natural chemical lures: mole crickets can be attracted by sweat volatiles and horse manure, cabbage root flies by garlic extracts, the cotton bollworm and oriental tobacco bud worm moth by sugar solutions, and the slug *Limax flavus* by leaves of trees, weed and vegetable leaves, respectively, during night time and can be collected in the morning.

Pheromone lures: several pheromone products have been commercialized in Chinese vegetable pest control. In 2010 a total of about 110,000 ha vegetable fields used pheromones in China. The pheromones are mainly used to control moths and beetles. Artificial insect pheromone lure and traps have been widely utilized to catch male moths of armyworms *Spodoptera litura*, *P. exigura*, etc.

Bio-pesticides: Many entomophagous fungi have been used in relation to vegetable pests, such as Verticillium, Beauveria, Metarhizium, and Paecilomyces to control whitefly, aphids, moths and beetles. Bacillus thuringiensis is the most popular bio-pesticide used in China for the control of cabbage worms and diamondback moths. Many entomophagous viruses have been developed as commercial products for the control of moths in vegetables. Bt-wettable powder (WP) (10 billion spores/gram WP) has been used as a spray for controlling *Pieris rapae* and *P. brasssicae*, diamondback moth (*Plutella xylostella*) larvae since the 1980s. Pieris rapae granular virus (GV) and Plutella xylostella GV have been applied and Metarhizium anisopliae is effective against lepidopteran pests (*P. rapae*, *P. xylostella*, noctuids). Recently, *M. pingshaense* (CQM132) and *M. guizhouense* (CQM135) were found highly effective to control the white grubs (*Holotrichia parallela Motschulsky* and *Holotrichia corpulenta Motsch*) (Shen et al. 2012).

Conservational biocontrol: Conservation of naturally occurring predators and parasitoids by avoiding the broad-spectrum toxic chemical pesticides is widely recognized by growers. Mass releases of *Encarsia formosa* Gahan in greenhouses to suppress the population of whiteflies, *Bemesia tabbaci* and *Aleurodes vaporariorum* are applied in northern China. Chrysopa, ladybird beetle, and predator mites are used to control aphids, whiteflies and spider mites. Wasps, such as Encarsia spp. are widely used for the control of aphids and whitefly; Trichogramma spp. used in control of moths.

Diseases

In China, as well as in other countries, diseases are a big problem in vegetable production, and about 10-30 % losses of vegetable products are caused by diseases.

There are a lot of practical measures for non-chemical disease management in vegetable production in China, such as rotation, intercropping, grafting, resistant varieties, biofungicides or mineral fungicides, and monitoring or modification of environmental factors applied in vegetable production without chemicals.

Resistant varieties: The farmers will use resistant varieties in the vegetable production. Some vegetable varieties which showed high activities of root knot nematode resistance, virus disease resistance, or fungi disease resistance were selected by the Chinese Academy of Agricultural Sciences and other research institutes.

Crop rotation and intercropping: Lots of vegetable rotation or intercropping systems are applied in recent years, such as kidney bean-celery-cucumber, tomato-celery-cucumber, and cucumber-wheat rotation systems, and pepper-cabbage, Chinese date– vegetable, and green Chinese onion–tomato/cucumber intercropping systems. Several studies show that rotation or intercropping systems could significantly decrease powdery mildew, downy mildew and leaf blight of vegetables (Cui and Wu 2009; Yu 2009).

Grafting: Grafting is a very popular technology in vegetable production in China. Cucumber was grafted onto fig-leaf gourd, and pepper, tomato and eggplant can be grafted onto original species. Grafting can control root diseases of vegetables as well as it can strengthen the tolerance to pathogens.

Biofungicides: Most of the biofungicides applied in vegetable production come from Chinese herbs. Some of these have been commercialized such as berberine, baicalin, vegard, and osthol.

Biological control with beneficial microorganisms:
Bacillus spp., *Pseudomonas* spp. *Streptomyces spp.* and *Trichoderma* spp. are the most common microorganisms used in biological control of vegetable diseases in China, such as grey mildew, anthracnose, verticillium wilt, and phytophthora light. Some beneficial microorganism strains were commercialized. People can use them to treat soil, coat seeds, or spray on leaves.

Physical methods: In China, if a soil borne disease is serious in greenhouses, the tillage layer soil of the greenhouse will be replaced by soil that has not been used for vegetables in the past 5 years. Further, the farmer will monitor the temperature, moisture and vegetable disease symptoms in the greenhouse in order to investigate the diseases of vegetables. The diseased leaves and plants will be removed from the greenhouse.

3.1.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in vegetable production in China

Invertebrate pests

Use of the crop's own resistance to control pests is an ideal approach for invertebrate pest management. Both crop resistant varieties and induced defence could be applied for invertebrate pest management. Use of agricultural biodiversity is another choice.

In China some on-going research projects focus on the conservation of natural enemies and habitat manipulation to enhance the establishment of natural enemy populations in the early season of vegetables, by growing nectar flowering plants such as sesame, sun-flowers, okra *(Abelmoschus esculentus)* to provide supplementary food for parasitoids, lacewing flies. Some artificial "gas stations" in which some natural compounds were used as attractors for parasitoids and predators, and honey solutions or other nutritional elements were set up as food for the natural enemies to increase their survival and fecundity.

In the current launched Agro-Industrial R&D projects of the Ministry of Agriculture, at least 5 of 20 projects are directly related to insect pest management in vegetable crops, tobacco whitefly in horticultural crops, gluttonous insect pests, root flies and insect transmitted viruses of vegetables (Chinese chive pest control (from Ministry of Agriculture, 2012-2015); Biological control of vegetable pests (from Ministry of Agriculture, 2007-2013); Integrated management of vegetable pests (from Ministry of Science and Technology, 2013-2017)), key techniques for argumentation of excellent natural enemy resources. All of these projects include the ecological, non-chemical approaches for insect pest management in out-door and protected lands.

Future perspectives: with the increase of the public concerns in relation to food safety and environment, particularly pesticide residues in agro-products, the demand for organic agro-products (also non-certified) with non-chemical management is expected to rise significantly. Thus, detailed non-chemical approaches for different vegetable crops sorely need to be developed urgently. Luckily, many large-scale producers (governmental-owned enterprises, farmers, cooperatives, etc.), extension experts, local government officers, and pest management scientists are paying attention to the technical development. Chine Agricultural University, Zhejian University as well as other institutions are engaged in these aspects.

However, only few make use of the full range of non-chemical methods in organic agriculture, and examples of systemic approaches to non-chemical pest control such as design of healthy and resilient ecosystems for agricultural production are rare.

In China the size of vegetable fields are very small and the work depends on human labour. The small field sizes make it difficult to release and multiply natural enemies/predators. At the same time the availability of human labour on farms is decreasing. Therefore, in order to develop pest management systems that do not depend on chemicals, we need to be innovative and change our traditional way of thinking to find new ways that at the same time protect our environment, strengthen the eco-functionality of the farming system and does increase the need for human labour.

Diseases

Ongoing research projects focus on green[3] and organic product production, processing and quality control at Yili in Sinkiang Province and at Boshan District in Shandong Province.

We use grape-alfalfa, grape-white clover and grape-lavender intercropping systems to control diseases in organic grape production in Xinjiang Province, China, and use Sichuan pepper seeds, a kind of spice plant, to control root diseases in organic strawberry production in Boshan Distric in Shandong Province.

The disease control efficiency of botanical fungicides (Berberine, Osthol, Vegard, and Baicalin) in relation to vegetable diseases (downy mildew, gray mold, powdery mildew) was detected in both Yili and Boshan. Moreover, we isolated plant beneficial bacteria in soil which could produce antimicrobials, phytohormone, and solubilization mineral phosphate including *Rahnella aquqtilis* HX2, *Arthrobacter globiformis* CK19, and some *Pseudomonas* spp. strains. These bacteria could be applied to organic farming as biofertilizers or biofungicides.

In the future we plan to establish a vegetable-spice plants/Chinese herb plants intercropping system, and apply volatile oils of spice plants/Chinese herb plants to control vegetable diseases. The effect evaluation of the intercropping system used to control vegetable diseases, and the impact analysis of spice plants/Chinese herb plants to insects and the soil microbe community will be the key task of our research.

In tropical and subtropical areas, banana (*Musa* spp.) is one of the most popular fruits. Panama disease (Fusarium wilt) of banana caused by *Fusarium oxysporum* f. sp. *cubense* (FOC) is a devastating soil-borne fungal disease causing extensive failure of commercial plantations of banana throughout the banana producing areas of the world. Intercropping and rotating banana with Chinese chive (*Allium tuberosum* Rottler) have been used as an effective method to control Panama disease (*Fusarium* wilt) in banana. We identified several natural compounds from the leaves and roots of Chinese chive, which show strongly inhibitory effects on FOC. We have screened several other plant species which demonstrated a control effect on Panama disease. We also isolated an array of biocontrol bacteria for the control of Panama disease.

For the development of systemic approaches to pest management without pesticides it would be beneficial to address issues such as:

1. Breeding resistant cultivars. Cultivar resistances are very important to control diseases and pests in organic culture. The damaging effects of powdery mildew, grey mould and red spider mite are serious in South China, but it is beneficial to identify and select the highly resistant materials in breeding programs.
2. Study crop rotation and intercropping, specifically the variety of crops for rotation and methods for inter-planting will be studied.
3. Develop and evaluate methods for biological control
4. Develop a system for evaluation of economic aspects of pesticide-free pest management methods

[3] Green food: Under strict supervision, control and regulation in production, processing, packing, storage and transportation, Green Food adopts the whole-some quality control from field to table, while it requires reasonable applications of inputs, including pesticide, fertilizer, veterinary drug and additive etc. to prevent any pollution of toxic and harmful matters to produce and links in food processing so as to ensure environmental and product safety. (http://www.greenfood.org.cn/sites/GREENFOOD/List_3675_3812.html).
For production of Green Food, four environmental criteria, need to be met: 1. "Area should meet the highest grade of air standards in China"; 2. "Heavy metal residues are restricted in irrigation, water and soil (tests for mercury, cadmium, arsenic, lead, chrome, etc.)"; 3. "Processing water must meet the National Drinking Water Standard"; 4. "Chemical applications are restricted and regulated, and some of the most poisonous pesticides and herbicides are banned" (Giovannucci, 2005).

3.2 Denmark: State of the art and future perspectives

3.2.1 Present practice for non-chemical invertebrate pest and diseases management in vegetable production in Denmark

Invertebrate pests

Field vegetables

Host plant resistance: Varieties with at least partial host plant resistance are available for a number of the vegetable species grown in Denmark, e.g. lettuce varieties with partial resistance to lettuce aphids. The extent of use of resistant varieties depend on the actual crop and the severity of the pest problem that might be addressed through host plant resistance as well as the grower's possible preference for other variety characteristics such as yield, taste or appearance.

Cultural methods: Basic knowledge about pest biology are exploited by Danish growers in an attempt to reduce pest infestations for instance by avoiding placing lettuce fields close to poplar hedges to minimize problems with lettuce root aphids. Another example is changing of the time of planting or harvest in an attempt to break the synchronization between a pest and its host plant as is practiced in relation to root flies by some Danish carrot growers.

Most Danish growers are also fully aware of the importance of general sanitation, removal of infested crop residues, keeping distance to fields of previous year and using sound crop rotation programs according to present knowledge. A recent initiative employed by some Danish growers is to practice within-year shift in location of production (satellite production) for instance by relocating production of lettuce between 3 different and distantly remote locations within the same cropping year.

The use of undersowing, cover crops and intercropping is practiced to some extent in organically grown vegetables in Denmark but presumably not in conventional farming. These techniques may be employed for other reasons than pest control but may act to divert pests and increase presence of natural enemies. The use of conservation biocontrol through establishment of flower strips, beetle banks and similar microhabitats in or near fields is likewise employed to some extent in organically grown vegetables in Denmark. The use of trap crops in the production of Danish vegetables seems to be nil at the moment.

Physical methods: Some Danish vegetable growers cover their crops with floating row cover or nets to prevent access of pests. This method is, however, expensive and may have drawbacks in the form of altered microclimate and reduced access of natural enemies. For some pest species where monitoring tools or warning systems are available, the period of coverage may be reduced to counterbalance these drawbacks.

The use of watering as a curative measure is practiced by Danish growers of e.g. onions and carrots targeting small larvae of cutworms. The timing of the watering is ensured through monitoring with traps or is based on warnings issued by the Danish advisory system.

Plant extracts, natural compounds: Danish growers have the possibility to use non-chemical substances like plant extracts or natural compounds against pest infestations, for instance garlic extracts against cabbage root flies and iron phosphate (with attractants) against slugs. The substances are used in organic production and also in conventional production if no legal chemical pesticides are available.

Augmentative biocontrol: Augmentative biocontrol based on releases of microorganisms (mainly *Bacillus thuringiensis*) and nematodes is used in Danish vegetables by both conventional and organic growers. Augmentative biocontrol based on parasitoids or predators is in principle possible based on the commercial assortment of beneficials, but the extent of use is presumably low and is limited to organic production.

Greenhouse vegetables

The non-chemical methods employed in the Danish greenhouse production of vegetables include the use of general sanitation principles, insect excluding netting on greenhouse vents, mass trapping with stick rolls, plant extracts and insecticidal soaps and augmentative biocontrol. Biocontrol is used routinely by Danish vegetable growers and is based on the commercial assortment of parasitoids, predators, nematodes and microorganisms.

Diseases

Resistant varieties: There is in general a rather broad range of varieties available for Danish vegetable producers. Seed producers of some vegetables, e.g. lettuce, offer new and more disease tolerant varieties each year. However, in the majority of plant breeding programs, plants are bred against higher yield or/and quality of yield. For instance, 27% of fungicides used in Denmark are used to control late blight (*Phytophthora infestans*) in potato, which is only grown at 2% of the agricultural area, but new potato varieties are bred towards higher yield and higher starch content.

Crop rotation: In general, Danish vegetable producers have rather well-developed crop rotation systems according to present knowledge. Unfortunately, our knowledge within this area is rather limited, especially in relation to the control of soilborne pathogens that can survive in the soil for many years as e.g. *Rhizoctonia* sp. in many vegetables, *Plasmodiophora* in cabbage and *Aphanomyces* in pea. Both conventional and organic growers ask for more knowledge within this area as they have no tools to control these pathogens at present.

Biofumigation: The use of green manure crops or winter crops is still increasing in Denmark. Many of the green manure crops contain secondary metabolites that by incorporation in the field also can serve to biofumigate soilborne pathogens. However, information on which green manure crops that work most effectively against the different severe soilborne pathogens is still lacking, and more research is needed to identify and fully exploit the most multifunctional green manure crops, which both can serve by counteracting nutrient loss from the fields in the autumn, to biofumigate for soilborne pathogens and to fertilize the crop. Researchers, consultants and growers are aware of the high potential, but more knowledge is needed to exploit it.

Mechanical control of soilborne pathogens

Mechanical soil treatment can be an effective way to control soilborne pathogens. Research has e.g. shown that ploughing reduced incidence of potato stem canker and increased yield of potato 15% in Danish fields.

Thermal control of soilborne diseases

In Denmark, band-steaming has been developed and shown to be very effective to control weeds in rows of carrots in the field, and this method is implemented by some Danish organic producers. Band-steaming has also shown potential to control cavity spot in carrots in an experiment at one of these grower´s field, so this method may also have potential to control other soilborne pathogens in vegetables.

Change of sowing time
Changing sowing schedule can be a potential non-chemical method to control some soil borne pathogens, but this method is difficult to implement as it can reduce yield and also cause conflict regarding consumers' expectation of timing of the availability of vegetables on the market.

Biological control by inoculation with beneficial organisms or botanicals
Research has shown that inoculation of vegetables with beneficial microorganisms can be an effective non-chemical way to control diseases, also under Danish growth conditions, so there is a great potential to replace chemical control of several plant diseases with biological control. However, there are some severe bottlenecks to overcome to increase implementation of biological control of plant diseases in Danish vegetable production systems. Firstly, there are relatively few products registered and available for Danish growers; 'Contans WG' (based on *Coniothyrium minitans*) against *Sclerotinia sclerotium* in lettuce, 'Mycostop' (based on *Streptomyces* sp) against *Fusarium* sp in tomato (green house), five different products based on *Trichoderma* sp. to be used against soil borne diseases in several vegetables species and against *Botrytis cinerea* in tomato and finally, 'Prestop' (based on *Gliocladium* sp) is used against *Didymella bryoniae cucumbernulatum* in cucumber. The reason for the relative few products on the Danish market is probably the combination of very high cost to get a product registered and the rather small companies dealing with development and sale of these products. Secondly, the few biological control products on the Danish market have minor sale, probably because conventional growers choose to use fungicides and because organic growers either are unaware of the products or refrain from use due to the associated time consuming justification needed for the authorities.

3.2.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in vegetable production in Denmark

Invertebrate pests

Research related to the use of non-chemical methods against invertebrate pests in greenhouse vegetables is presently limited primarily due to the fact that biological control is well-established and well-functioning. Some research related to the use of non-chemical methods against invertebrate pests in outdoor vegetable crops is done including basic ecological and biological aspects of pests and natural enemies, aspects relating to development of biocontrol / IPM-strategies / pest management in organic farms, and aspects relating to the influence of agroecosystems / agricultural landscapes on pests, natural enemies and pest regulation.

For field crops the use of biocontrol (both conservation and augmentation) is still limited and development and implementation of additional methods and exploitation of combinations of methods is needed. This should ideally take place through development and implementation of holistic IPM-programs for control of diseases, pests and weeds, including development of non-biological methods where relevant, and including exploitation of agroecosystem services in plant protection. For greenhouse crops non-chemical pest management is already in place but appearance of 'new' pest species / increased production of 'new' greenhouse vegetables (e.g. herbs, leek) will require research for development of IPM- and biocontrol strategies.

Diseases

Ongoing applied research on biological management of plant diseases in Denmark is partly focused on implementation of the available microbiological products to control both air- and soilborne plant diseases, partly focused on the use of green manure crops to control soil borne diseases. On-going research projects also target a more integrated biological management of diseases, pests and weeds. However, more fundamental knowledge on the interactions between non-chemical management of plant diseases and the control of pests and weeds is needed.

Moreover, ongoing fundamental research employs new biotechnology to explore the whole microbiological diversity, which so far has been quite a black box. Next step in this research area will be to investigate function and interactions among all these detected microorganisms, and to use this knowledge to develop new agroecological plant protection strategies against diseases.

Plant protection of vegetables should be based on a holistic agroecological strategy, so more interdisciplinary research is needed both by integrating research in agroecological control of diseases, pests and weeds, and also by combining more approaches to control diseases in an overall strategy (resistance, thermal/mechanical control, crop rotation/biofumigation, biocides). Furthermore, there is a need to focus on how application of biocides can be implemented and used by growers. More knowledge is needed on diversification of vegetable cropping systems to optimize exploitation of agroecological mechanisms in plant protection, and identification of multifunctional crops that can be used for plant protection, nutrient turnover and sale.

4. Fruit and berry cropping systems: towards collaborative research development of non-chemical systemic approaches to pest management

The area with organic fruit production in China is 143,400 ha with another 101,050 ha in conversion. This accounted for 2.12% of the total fruit production area in 2010.

The main production is located in Xinjiang (48,000 ha, 20%), Beijing (15,000 ha, 4%), Shandong (10,000ha, 4%), and Shanxi (12,000ha, 5%). The main organic fruits are date, apple, grapes, strawberry, and melons.

Apple and strawberry are two of the most important fruits in China. In the 2010, there were 2.1 million ha and 33 million tons of apples produced in China, accounting for 41% of the total cultivation area and 42% of and total production in the world respectively, and both ranking first in the world. Strawberry, which developed rapidly in recent years, was cultivated on 90,100 ha in 2009 with a total production of 2.2 million tons, accounting for 36% of the world production.

Apple and strawberry are also the major fruit and fresh berry crop in Denmark. The area with apple is 1,700 ha of which 18% was organic in 2011. Average yields are 14 tons per ha. In sprayed apple orchards the annual average number of sprays is 20, of which 1-3 are insecticides. Pesticide use in strawberries is also high making non-pesticide management methods much needed. The turnover of organic apples in Danish retail shops was app. 1,700 tons in 2010. The main part was imported organic apples from Europe, America and China. The area with strawberry is 1,300 ha of which 1.2% was organic in 2011. Strawberry yields 6-15 tons/ha. Organic fruit and berry production in Denmark has increased by five fold since 1991.

4.1 China: State of the art and future perspectives

4.1.1 Present practice for non-chemical invertebrate pest and diseases management in fruit and berry production in China

The most common pests in apple production are spiraea aphid (*Aphis spiraecola*), Woolly apple aphid (*Eriosoma lanigerum*), Hawhorn spider mite (*Tetranychus viennensis*), red spider mite (*Tetranychus urticae*, *Myzus malisutus*, and the most common disease of apple in China are apple canker (*Valsa mali*), apple ring rot (*Botryosphaeria berengeriana*), leaf spot (*Alternaria mali, Marssonina mali*). Variety, cultivation methods and diversity of natural enemies are key factors for the pest control in the apple plantation. Present non-chemical pest management methods in apple plantations include adaptation of resistance variety, multi-scale (field scale, between field scale and landscape scale) habitat manipulation, application of insect pheromones and pathogenic microorganisms. Various physical methods, including brushing trunks with lime and copper sulphate mixture to kill the overwintering pests under bark, bagging, manual treatment (scraping trunks or branches, pick out or clear out affected parts), deep ploughing, were also widely applied as non-chemical pest management measures. Furthermore, improving irrigation or/and fertilization measures were also important for non-chemical pest control in apple production.

Comparing with apples, strawberries are more susceptible to pests and diseases and more challenging for non-chemical management. The key pest for strawberry in China are greenhouse whitefly (*Trialeurodes vaporariorum*) , aphids (*Aphidoidea*), spider mite (*Tetranychus urticae*), and strawberry beetle (*Anomala corpulenta Motschulsky*) . As most strawberries are produced in greenhouses, disease problems are even more serious. More than 20 different diseases of strawberry were reported in China. The most common diseases are red stele (*Phytophthora fragariae*), anthracnose (*Colletotrichum fragariae*), Fusarium wilt (*Fusarium oxysporum* f. sp. Fragariae), powdery mildew (*Sphaerotheca aphanis*), leaf spot (*Ramularia tulasnei*; *Mycosphaerella fragariae*), gray mold (*Botrytis cinerea*), Verticillium wilt (*Verticillium dahliae*).
Unfortunately, non-chemical management measures for strawberry pest and disease control are limited. The key measures for non-chemical pests and disease control in strawberry production are selecting resistant varieties, manually picking out affected parts, clearing out weeds, applying sticky trap, optimizing fertilization and irrigation to avoid environment encouraging pest and diseases. Furthermore, although not commonly applied, habitat manipulation to attract beneficial insects is also a potential measure for strawberry pest control.

4.1.2 On-going research and future perspective for non-chemical invertebrate pest and disease management in fruit production in China

The philosophy that man is an integral part of nature, traditional agriculture production in China has resulted in the development of a series of elaborate cultivation methods, such as rotation, intercropping, fertilizer management for pest and disease control. Unfortunately, increasing demand for fruit products and industrialised modern production methods have encourage more and more intensive production. Manual treatments, which used to be widely applied as non-chemical pest and disease control measures, has become more and more infeasible due to the increasing labour costs. Traditional non-chemical pest and disease management has as a result been widely replaced by chemical treatments. In many cases, agricultural chemicals are overdosed and have become a major threat to food security. More environmental friendly pest and disease management measures/systems should be developed. Comparing with western countries, research in non-chemical pest and diseases management has had less focus in China. For example, publications from China on the two important international biological pest control related journals (*BioControl* and *Biological Control*) from 2005 to 2008 were 49 in total only, accounting for 16 per cent of that of USA (Chen et al., 2010).

For more sustainable and secure apple and strawberry production, future non-chemical pest management measures should be urgently developed and improved in a systemic approach from the following aspects:

- To breed resistant varieties. Although China has a huge cultivation area and production, few varieties of both fruits are planted. More than 70% of the planted apple is Fuji. Toynoka, Benihoppe Akihime, and Tochiotome are the most common varieties for strawberry. Breeding more varieties with good resistance in relation to pest and diseases is the first step for non-chemical production.
- To develop methods and techniques, such as fertilization, irrigation, mulching, and soil sterilization, to improve the soil health which is essential to control soil borne diseases or infected pests and diseases.
- To develop methods of intercropping and rotation to control pest and diseases.
- To design and establish diversified landscape and habitat, including spatial and temporal configuration of habitat/land use around the field to improve effectiveness of natural enemy on pests and disease by providing natural enemies with the necessary resources like such as

supplementary and complementary food, microclimate modification and existence of refuge habitats, or by mitigating the negative impact of agricultural practices.
- To develop more effective and new biological control agents

To achieve these aims, research in the following topics should be encouraged and strengthened in the nearby future:
- The behavioural mechanisms of pest, natural enemies and their interaction (Chen, 2010);
- The mechanism of plant-pest-natural enemy tritrophic interaction;
- The mechanism of landscape moderated biological control function and biodiversity conservation (Batáry et al., 2011; Tscharntke et al,2012);
- To investigate new efficient biological control agents and develop techniques to exploit them
- A better understanding on the interaction among different managements and developing more integrated management.

4.2 Denmark: State of the art and future perspectives

4.2.1 Present practice for non-chemical invertebrate pest and diseases management in fruit production in Denmark

In Danish apple production the trend goes towards closer planting and more intensified production with up to 2000-3000 trees per hectare. Pest and disease problems in apple are a major threat against organic production as growers strive to meet quality standards. Often only about 20% of apples from organic orchards meet the first class standards. Rejected apples are sold as apple juice, presently, however, at a fair price. The low yield in Danish organic apple production is mainly due to lack of control of apple sawfly (*Hoplocampa testudinea*), codling moth (*Cydia pomonella*), apple scab (*Venturia inaequalis*) and apple canker (*Nectria galligena).*

Strawberries are predominantly grown in the open field, cultivated as a 2-3 year crop. The main harvest of open field crops is from 20 June - 20 July. Fiber/plastic covering of open field crops allows up to two weeks earlier harvest. Tunnels can prolong the cultivation period both early and late season. The use of tunnels has increased in recent years, also with some uptake by organic growers, but is a minor fraction of the outdoor area. In tunnels yields reach 15-22 tons/ha. Topping of the strawberry after harvest is a common practice. This mechanical control is principally done to control difficult (perennial) weeds but can also reduce diseases and pests.

Invertebrate pests

Major pests in apple are aphids (*Aphis pomi*, *Dysaphis plantaginea* and *Rhopalosiphum incertum*), codling moth (*Cydia pomonella*), other tortricids (*Adoxophyes orana, Adoxophyes reticulana, Hedya nubiferana, Pandemis heparana, Archips rosana, A. podana, Spilonota ocellana*), geometrids, principally the winter moth (*Operophtera brumata*). Apple sawfly (*Hoplocampa testidunea*) is a pest in unsprayed orchards, where pesticides against other pests does not control it. Fruit tree red spider mite *Panonychus ulmi* is normally not a problem in unsprayed orchards. Present non-pesticide practices include the following: pruning and removal of infested fruit, pheromone disruption of codling moth and a few other species of tortricids (since 2011). The codling moth virus also became available in 2011. *Bacillus thuringiensis* is available against Lepidopterans in apples. Pheromone traps and sticky traps are used for monitoring.

Major pests of strawberries are the strawberry weevil (*Anthonomus rubi*), strawberry tortricids (*Acleris comariana*), spider mites and tarsonemid mites. Under certain conditions slugs and birds can be pests. Typical greenhouse pests such as whiteflies, thrips, mites and aphids are important in protected production. Protected conditions favour black vine weevil (*Otiorhynchus* sp). Mirids are a problem in late season berries. Non-chemical alternative are lacking for pyrethroids used against the strawberry tortricid and the strawberry weevil. Pyrethroids (and other insecticides) are harmful to many natural enemies, and may contribute to propagation of other pests such as mites. *Bacillus thuringiensis* can be applied against strawberry tortricid but the open field is considered too cold in spring for a good result. Predatory mites can be applied to control mites in strawberries. Commercial biocontrol agents are available against greenhouse pests and some are used against strawberry pests in greenhouses.

Diseases

In apple production, the following diseases are problematic: apple scab (*Venturia inaequalis*), apple canker (*Nectria galligena*) apple powdery mildew (*Podosphaera leucotricha*), twig blight (*Monilia laxa)* and Brown rot (*Monilia fructicola),* flyspeck (*Zygophiala jamaicensis*) and soothy blotch (caused by a complex of fungus-species: *Gloeodes pomigena*, *Peltaster fructicola*, *Geastrumia polystigmatis*, *Leptodontium elatius*).
Black currants have the following problems: Powdery mildew (*Sphaerotheca mors-uvae*), currant leaf spot (Drepanopeziza ribis / *Gloeosporium ribis*) and white pine blister rust (*Cronartium ribicola).*
Red Currants are attacked mainly by currant leaf spot.
The main diseases in strawberry are grey mold (*Botrytis cinerea*), powdery mildew (*Sphaerotheca macularis*) and Verticillium wilt (*Verticillium dahliae*).

In present practise the fungal diseases in organic growing of fruits and berries are prevented before planting by:

- Choosing a fairly dry location.
- Choosing a well-drained soil, JB 2-6
- Choosing a “fresh” soil (not replanting)
- Irrigating only by drip irrigation
- Choosing varieties, which are robust to diseases.
- Avoiding varieties with a single-gene resistance, which is easy to break down.
- Choosing weak-growing rootstocks

After planting, the fungal diseases are also prevented by:

- Pruning the trees to be open and aerated
- Keeping nitrogen-level low (2-2,3% in apple-leaves)
- Removing or mulching old leaves, infected branches, mummies etc. during winter.
- Spraying with approved organic fungicides in apples. Only sulphur is registered in Denmark. Potassium-bicarbonate was used for trials in apples in 2012.

4.2.3 On-going research and future perspective for non-chemical invertebrate pest and disease management in fruit production in Denmark

Invertebrate pests

On-going research in strawberries includes studies of the effect of cropping practice on strawberry tortricid and its natural enemies (Sigsgaard et al *submitted*) and conservation, biological control of strawberry tortricids (Sigsgaard *et al. In press*) and selection of biocontrol agents against shallot aphid (Enkegaard *et al In press*). A strategic paper on biological control in strawberry was produced with the advisory service (Jensen et al, in “*Biological control of tortricids and aphids in strawberry*”. Report in prep.). The CORE ORGANIC II project Softpest Multitrap 2012-14 investigates mass-trapping for the strawberry weevil and the mirid *Lygus rugulipennis* against both of which no alternative pest management is available for organic growers (see organic eprints for publications). The EU FP7 Inbiosoil project aims to develop new formulations and technologies using microbiological control agents to control soil borne crop pests such as the vine weevil in strawberries (http://inbiosoil.uni-goettingen.de/). University of Copenhagen (UCPH) heads the WP of effects on environment, interaction/ side-effects with other biocontrol agents.

Biological control of spider mites and other sucking insects in strawberries and apples by entomopathogenic fungi and predators is studied in the project Imbicont –improved biological control for IPM in fruit and berries, a collaboration between UCPH and Univ. Sao Paulo, ESALQ, Brazil 2012-15. Finally, 'Fruitgrowth - Novel organic solutions securing future growth' focusing on organic apples has a work package on pest and disease management including research in ecological infrastructures for codling moth control and inundative releases of the parasitic wasps *Trichogramma* spp to reduce codling moth (UCPH), test of plant extracts to control apple sawfly (Aarhus University) and mechanical control of apple scab (UCPH) (Williams 2011; Korsgaard, 2012).

Future potentials for non-pesticide control require a better understanding of the cropping system in order to optimize it for conserving natural enemies and the use of ecological infrastructures and design for reduced pest and disease problems (Sigsgaard et al submitted). For several pests further knowledge about their biology and the biology of their natural enemies is needed. More research and development is needed in prevention including choice of variety and sanitation measures. In order to develop biological control programs identification of potential biocontrol agents (bioprospecting) is important in some cases. In others, testing further development of rearing, application and use of existing biocontrol agents is needed. For biological control in fruit and berries more knowledge is needed on how to use multiple beneficials in combinations, and how to use beneficials together with other strategies such as mechanical control, the use of plant extracts and mass trapping. Control strategies must be adapted to the degree of cropping intensity, in the case of strawberries from open field to glasshouse.

Diseases

The ongoing research in organic fruit production takes place in the 'Fruitgrowth' project. It is described at http://orgprints.org/20012/4/20012.pdf.

In the project 'Fruitgrowth', several trials are on the prevention of fungus diseases in apple:

- Robust apple cultivars suited for Danish organic production systems:
  Testing new planted varieties (29 varieties)
  Evaluation of a mature planting (2000-02) consisting of more than 30 varieties. From 2009 the trees have been left totally unsprayed. In 2011, as part of the present project, 18 varieties have been evaluated both in terms of disease occurrence and fruit quality. The remaining 12 varieties were identified as being unsuitable for organic production.
- Trial with mechanical protection towards apple scab, covering the row with a plastic roof.
- Strategic irrigation against apple scab. Trying to 'fool' the ascospores to be released to early and dry out before host tissue is present.

The access to approved organic control products such as plant extracts and microbiological control agents is very limited in Denmark. This is mainly due to the size of the country. The companies are not willing to pay high fees to get a product registered by the Danish environmental authorities, while the number of potential customers in Denmark is very limited, and even more so than at the EU level. With respect to macrobiological control native predators and parasitoids are allowed, and in greenhouses also exotics can be used if there is no risk of them becoming invasive.

The future potential for non-chemical pest and disease management in fruit production in Denmark is rather big. As previously mentioned, there are very few of the approved organic control products, which are registered in Denmark. This causes low yield in organic production of fruit and berries in Denmark. Thus the need for non-chemical solutions to prevent diseases is urgent. Non-chemical solutions are also more accepted by the consumers, and are the most environmentally safe solutions.

5. Research topics of mutual interest and priority between China and Denmark within the field of non-chemical systemic approaches to pest management

As also mentioned in Section 1 of this report it is important to highlight that when we in this report use the terminology 'pests', we refer both to invertebrate animals (such as insects and arachnids) as well as to diseases (or rather microorganism causing diseases) that are damaging to the crops.

The core group of researchers in the network have identified research topics within the field of pest management without pesticides of mutual interest and priority and beneficial to be undertaken in transnational collaboration between China and Denmark. As a natural part of the process at the second workshop, the researchers split into two groups based on individual interest and expertise – one group focused on vegetables and the other group on fruit and berries. The outcome of their discussions is described in the following two sections 5.1 and 5.2. Because the groups have worked individually, the outline and descriptions of topics are not identical. However, the results and suggestions are more or less following the same approach.

In the choice of joint research initiatives it is important to consider the differences in climate and production as well as the differences in the flora and fauna of the two countries leading to differences in the pest and disease complexes. The workshops provided us with insight and understanding of these different conditions as well as the on-going development in the sector of fruit and berry in the two countries. For example, more strawberries are produced in protected conditions in China than in Denmark, and Chinese growers often only have the crop for one harvest, as a winter crop, while in Denmark the crop is kept for 2-3 years. Likewise, also a higher share of the vegetables in China is produced in protected conditions than it is the case for Denmark. However, both countries have an interest in developing solutions both for non-pesticide outdoor production and for protected systems. The differences in experiences can provide a valuable asset in collaboration where exchange of students and scientists can facilitate mutual capacity building.

In a changing world of climate change, new invasive species, globalization, and increasing demands for food as well as new food items, we identified the high value crops of vegetables, fruit and berries as presenting good opportunities for research collaboration between China and Denmark with high environmental and health gains from reduced or no pesticide use, and potential much higher yields for the producers. Pests and diseases present major challenges when converting to a production without the use of pesticides.

Crop protection strategies consist of prevention and control measures. For production without chemical pesticides prevention is very important. Designing the agricultural system to minimize pest problems and conserve natural enemies through crop rotation, use of ecological infrastructures such as hedgerows, flower strips and through the use of cover cropping, crop or varietal mixtures and intercropping is the key to prevention. Pivotal is also use of healthy, disease and pest free varieties and seeds. At a larger scale sufficient distance in time and space between crops can help prevent the spread of pests and diseases between crops. For control, biological control measures should and can be explored much further, especially for high value crops there is a great potential. The use of pheromones and plant volatiles for behavioural control are already in use against Lepidopteran pests in orchards, but much more remains to be done also in other crop systems and other insect orders. Plant extracts, i.e., bioactive compounds extracted from plants, are reported to have antimicrobial activity against plant pathogens. Even though research in plant extracts is on-going at several countries, basic knowledge on the mechanisms of plant extracts, their effects on the microorganisms as well as on the host plants and application strategies is lacking.

Some of these control methods are best applied preventively, i.e., before it is known whether the pest or the disease will be a problem that season. For example pheromone disruption against insect pests, biofumigation using green manure crops against soil borne diseases and inoculative biological control against both pests and diseases, where the beneficials need time to establish and multiply before control is achieved. In cases where non-chemical control is used curatively monitoring and early warning methods are important to allow the timely application of biocontrol agents. Preventive measures and control combined constitute integrated management.

5.1 Vegetable cropping systems

The joint Chinese-Danish collaborative research to provide the foundation for development of pest management in organic and agro-ecological vegetable cropping systems is recommended to focus on three research topics. The first two topics are to be regarded as necessary tools to aid the realization of the third and final research topic:

1) Research to provide biological foundation for development of non-chemical solutions targeting severe pest problems in vegetable production
2) Research to increase the knowledge on how to best exploit multifunctional plants (including crops) in pest management tactics
3) Designing and managing eco-functional vegetable cropping systems at field and landscape level for management of pests

Research may address vegetable production both in greenhouses and in open field.

Identification of problem areas, development of management strategies and design of cropping systems should be carried out in close dialogue with farmers. Dissemination and demonstration of research results should involve on-farm activities where relevant and cooperation with social scientists on models for farmer learning and knowledge dissemination processes should be initiated to further strengthen uptake of non-chemical pest management practices.

Research topic 5.1.1: Research to provide biological foundation for development of non-chemical solutions targeting severe pest problems in vegetable production

Research under this priority topic will address several tasks crucial for optimal designing of cropping systems without chemical pest management. Initially, an analysis should be made to identify which crops are most difficult to grow without the input of chemical pesticides in China and in Denmark. The shortlist of such crops with their associated severe pest problems will allow researchers to select the most relevant problems and research questions to be addressed in collaboration. It is thus envisioned that cases demonstrating similar types of pest problems rather than similar and specific crops will be targeted in collaborative projects. For some pest, disease and weed species there is likely to be a gap in basic knowledge of their biology and ecology, and for several species there will be a need for research to provide an increased ecological understanding of mechanisms and interactions between organisms and trophic levels (multi-trophic interactions). There will also be a need for development of new preventative and curative methods for non-chemical management of different pests, diseases and weeds. Biological control using different strategies to conserve and augment natural enemies is one such method, and other methods include among others thermal treatment or application of organic amendments to soil against diseases. There will also be a need for developing efficacious mass production systems for some natural enemies, for research in application methods and for developing forecasting systems to optimize the timing of management. Securing soil health is considered a focus area and research should include studies on how different prevention and control methods may interact to suppress disease.

Research topic 5.1.2: Research to increase the knowledge on how to best exploit multifunctional plants (including crops) in pest management tactics

Plants, including crops, may have several functions crucial for non-chemical pest management. Examples of functions are plants containing bioactive compounds, which can be herbs used for soil sanitation against plant diseases, allellopathic interactions among plants that can be exploited for weed suppression in the crop rotation, flower strips and beetle banks that provide food and shelter for natural enemies and pollinating insects, trap crops and banker plants that aid in trapping pests/aid in maintaining populations of beneficial insects in crops, and plants that maintain beneficial mycorrhizal fungi when used in rotation. The main task under this priority topic is to identify multifunctional plant species that can provide substantial pest prevention or control when incorporated into a vegetable crop rotation and/or grown in mixture or adjacent to crops selected in Research theme 1. This will be done by literature reviews of existing knowledge and by screening promising candidates in greenhouse and field experiments.

Research topic 5.1.3: Designing and managing eco-functional vegetable cropping systems at field and landscape level for management of pests

The knowledge obtained in Research topics 5.1.1 (Biological foundation) and 5.1.2 (Multifunctional plants) will be included as background information this research priority. The objective is to design vegetable cropping systems where pests can be managed without the input of chemical pesticides, preferably by exploiting the inherent ecosystem services provided by the cropping system. A central task of this research priority is to develop improved methods to identify, understand and quantify the pest management potential of different management practices. This is a highly complex task, which will include the documentation of the ecological function of different pest prevention and control practises and will need to use traditional and modern research tools. The systems design will aim at developing optimal cropping systems through integration of the specific methods developed and evaluated in 5.1.1 and 5.1.2, e.g. to develop crop sequences to establish natural enemy assemblages for late season crops, timing of planting dates to minimize pest problems, to assess the effect of diversification of cropping systems using multifunctional plants to suppress diseases, weeds and pests, and to include biocontrol measures and biorationals when appropriate. The designed systems will be made operational by critically evaluating the designed systems through field or on farm trials in dialogue with farmers and where relevant, supported by simulation modelling.

5.2 Fruit and berry cropping systems

Based on the known challenges for the two countries, we have identified three topics of shared priority/ interest using a systemic approach. These topics all represent areas with common problems but also with problems that are special for the two countries.

Research questions of the three topics represent achievable goals for short term (2-3 years), mid-term (5 years) and the long term (10 years or more), which may be more basic research. The aim is to use state-of the art science (like molecular biology, communication science etc.) to solve challenges and develop innovative solutions.

Research topic 5.2.1: Could diversification help us to create a more healthy and productive system?

Conservation

Conservation biological control refers to the use of indigenous predators and parasitoids, usually against native pests. In conservation biological control, various measures are implemented to enhance the abundance or activity of the natural enemies, including manipulation of the crop microclimate, creation of overwintering refuges, increasing the availability of alternative hosts and prey, and providing essential food resources such as flowers for adult parasitoids and predators (Barbosa 1998, Wratten et al., 2003, Sigsgaard et al. *in press*) as well as for pollinators. Establishment and protection of ecological infrastructures such as hedgerows and flower strips will increase plant diversity, and this diversity can in turn be a source of natural enemies which can provide biological pest control. With respect to plants for hedges and flower strips, research is needed to identify selective plants or plant mixtures which favour the beneficials over the pests for the selected crops. For apple, conservation biological control is a high priority as a first barrier against the diversity of pests attacking this crop. Further studies of the use of flower strips in conservation biological control in apple orchards and in open field strawberry are needed.

Cover cropping, intercropping
Cover cropping and intercropping can provide diversification while at the same time provide an extra crop for production or green manure. Flower strips may be fodder crops such as lucerne or ornamental flowering plants.

Design -developing ecosystem methods for sustainable agriculture
There is still little knowledge about how agro-ecosystems should be designed to minimize pest and disease problems. According to the International Organisation for Biological Control at least 5% of farm land should be ecological infrastructures to conserve natural enemies of pests and diseases. However, research into the necessary area and spacing and composition of these elements –such as hedgerows and flower strips or intercrops require further study. Once the plants for a hedgerow or flower strip are selected, the next question is how they should be placed in the field to obtain the best pest control.

Cultivar resistance and mixtures
Growing disease resistance cultivars is the most environmentally friendly means to control diseases. Resistance is obtained by introducing one or a few major genes or many resistance genes with additive effects into a cultivar. The most devastating disease in apples is apple scab (*Venturia inaequalis*). Resistant cultivars are available at the market but the resistance is becoming more and more ineffective due to new pathotypes of the pathogen. This trend is well-known from other host-pathogen systems. Apple breeding programs are in progress in Europe with the aim of incorporating new resistance, but the same 'resistance break down' might be seen again. It may be possible to avoid the directional selection for new pathotypes by introducing management strategies based on diversification for instance cultivar mixtures such as a row-by-row mixture of three different scab susceptible cultivars (Elstar, Pinova, Golden Delicious) significantly reduced scab epidemics on Golden Delicious compared to the pure stand (Kellerhals et al., 2002). Another mix including both row-by-row and within-row mixtures of a susceptible cultivar and a resistant cultivar in equal proportions (Didelot et al., 2007) significantly reduced disease incidence over two years (7.3 to 21.3%). The best results (75% reduction on leaves) were obtained when the within-row mixture was associated with moderate fungicide treatment. Further studies on mixing cultivars either in row-by-row or within row mixtures are needed. And especially strategies using mixtures in combination with other non-chemical means should have high priority in future research programs.
Strawberry cultivars with resistance to powdery mildew (*Sphaerotheca macularis*) are available. No cultivars are highly resistant to *Botrytis* fruit rot (*Botrytis cinerea*) and it has been shown that the morphology of the strawberry plants and the microclimate influence the susceptibility to *Botrytis cinerea*. The microclimate is different in different production systems, such as plastic tunnel systems, field or green houses. Information on powdery mildew and grey mould development on strawberry fruit in protected culture systems is lacking.

To our knowledge variety mixtures have not been tested in berry system. Since several of the important diseases of berries like powdery mildew in gooseberry, rust of black currant or grey mould in strawberry are airborne, it is expected that mixing varieties may reduce these diseases. Further studies are necessary especially concerning the influence of different cultural practices on the disease reduction in variety mixtures of berries.

Intensified soil ecosystem - rotation
One of the big challenges in strawberry production is soil-borne diseases and pests, which generally build-up over time if nothing is done. Important diseases include Anthracnose, Verticillium wilt, Rhizoctonia root rot, Pythium root rot and Phytophthora crown rot. Nematodes can be serious soil-borne pests. In non-chemical strawberry productions crop rotation is considered the best tool against these harmful agents and at least 5-8 years between strawberries is recommended. Cover crops and sanitation crops which maintain soil health and fertility should be included in the rotation. Only little information can be found on sanitation and cover crops. Broccoli has been mentioned as a possible sanitation crop but studies on this crop as well as other sanitation crop candidates should be initiated. More and more strawberries are grown in plastic tunnels or in protected indoor environments. It is expected that in protected strawberry productions systems, intensified soil ecosystem management can aid in keeping the crop healthy. However more research is needed.

Research topic 5.2.2: How to improve efficiency of new and existing control methods through understanding mechanisms and interactions

Know mechanisms / interactions
In order to improve the efficiency of new and existing control methods an understanding of the interactions between plants, pests and beneficials and the mechanisms driving them is needed. Ecology, behavioural studies, chemical ecology and molecular ecology can be used to contribute to this. For example closely related predators in orchards may still be adapted to different plants (apple, pear) and prey (aphid, psyllid), with important implications for their use in biological control (Sigsgaard 2010). Further studies are needed for key pests in apple, in China spider mite, aphids, and *Carposina* spp. and *Grapholitha* spp., in Denmark the codling moth and apple aphids. In protected strawberries aphids, thrips and mites are problematic in both countries and studies of the biological control agents available can provide new knowledge on how to control these pests and diseases.

Develop agents/ methods
A serious hindrance for developing pesticide free pest and disease management is the lack of alternative pest and disease control agents and methods. In apple, control of various pests is needed, and agent and methods appropriate for their control need to be identified or improved. For example, even though against codling moth in apple pheromone disruption and virus are already in use, further additional control is needed to bring down infestation to an acceptable level. To reach sufficient control of mites in strawberries further studies are required, in particular for protected crops. The potential use of more than one control agent to achieve the desired damage threshold should be investigated for example against mites in strawberries. Promising plant extracts for disease control are under development and further studies could reveal their potential use in fruit and berry production.

Evaluate efficiency
It is a common view that the efficiency of non-chemical management of pests and diseases is less than chemical pesticides. However, biological control, physical control, and cultural control can all be used as preventive control methods, which must be applied when a pest or disease population is at a lower density level. To properly use non-chemical control measures, much more knowledge

about pest population dynamics, natural enemy population dynamics and other components in the ecosystems is needed.
As for the evaluation of efficiency, we must put emphasis on long-term efficiency, which is the outstanding feature of non-chemical control. Biological control and cultural control have given reasonable evidences for long-term efficiency. Many natural enemies have established their population in released habitats, and as long term control factor. Besides, most biological control is not harmful to non-target organisms and, thus, favourable for reconstruction of a stable ecosystem and as result of lower outbreak frequency of pests and diseases. Therefore, we should evaluate non-chemical control methods both in relation to immediate efficiency as well as long term efficiency. Besides, we must investigate and develop recommendation for proper application time and dosage through thorough studies of pests and diseases biology and ecology.

Non-chemical controls as components in a cultivation program as well as their compatibility must be evaluated before distributed widely. This compatibility also includes local farmers' willingness to include the practice in their production. These two points should not be neglected.

Research topic 5.2.3: How to integrate management for organic production

A third question highly prioritized by the group was how to integrate management for organic production. It is proposed to a) evaluate different integration strategies/ scenarios to choose what is most relevant to study regarding pests, b) evaluate different integration strategies/ scenarios to choose what is most relevant to study regarding diseases, c) propose scenarios to combine pest and disease management, d) evaluate efficiency and risk and e) create input for decision support system for organic production (GIS, GPS, remote sensing).

6. Recommendations for strengthening future research collaboration between China and Denmark in the field of systemic approaches to agro-ecological pest management without pesticides.

The network was initiated based on the hypothesis that it would be possible to identify research areas of mutual interest and priority of research in China and in Denmark for development of integrated systemic approaches to pest management in specific crops of joint interest and for development of research methodologies and concepts for integrated systemic pest management. It was assumed that the differences between China and Denmark – e.g., in country size, organization and structure of agricultural sector, degree in variation in landscape and climate, tradition and the roles of governments, respectively – would be a challenge, but not sufficiently critical to be a hindrance for the development of a joint framework for research in systemic approaches to pest management without pesticides. We find that the discussions, engagement and collaboration that have taken place in relation to the network activities have proven that research interests and priorities can be matched between the two countries and that collaborative research can be beneficial for both countries when the different contexts are taken into consideration in the development of specific systemic approaches.

The recommendations for a joint research agenda that should form part of an overall framework for collaboration are detailed below.

i. **Collaboration should be initiated within the field of 'High value crops' such as vegetable, fruit and berries.** The initial work of the network to identify common research interests and priorities as well as to point to overall research problems to address jointly should be followed by a more in-depth analysis to identify crops that are the most difficult to grow without the use of chemical pesticides in China and in Denmark. This will allow researchers to detail the most relevant problems and research questions to be addressed in collaboration. It is thus envisioned that cases demonstrating similar types of pest problems rather than similar and specific crops will be targeted in collaborative projects.

ii. **Systemic approaches should include both well-known and new practices.** Many practices have been used traditionally in both China and Denmark and are known to be beneficial in the management of pests. However the knowledge of the specific functions and interrelations of the known practices may be too limited for using it systematically and intentionally in systemic approaches to pest management based on eco-functional intensification. Therefore, it is important to further investigate some of the well-known pest management practices and their functionality and role in a systemic approach.

iii. **Research should focus on approaches for farming systems with no pesticide input, but considerations should be given to application and applicability in conventional systems**. The need to reduce the use of pesticides for food safety and for environmental protection (as well as for economic reasons) is general and therefore new approaches and knowledge on how to manage pests without the use of pesticides is relevant across farming systems. There are several examples where methodologies developed for organic systems have been adopted broadly also in conventional systems either directly or in modified versions. Therefore, new systemic approaches to pest management without pesticides may apply to the agricultural sector in general and help to reduce the use of pesticides at a large scale.

iv. **Research for development of systemic approaches to pest management should include three main themes (detailed in recommendations 4-6).** Although the group that focused on vegetables and the group that focused on fruit and berries worked in parallel, they both in the end came up with three similar main research themes. This confirms that it is possible to collaborate to develop joint methodologies for systemic approaches that can be used across a broader range of high value crops although pest problems and cultivation methods may differ between the two countries. The three main research themes are:

1) *'Research to provide the biological foundation and understanding of mechanisms and interactions for development of non-chemical solutions and to improve the efficiency of new and existing control methods for severe pest problems'*. Basic knowledge of the biology and ecology of crops and pests and their interactions is crucial to provide an increased ecological understanding for optimal design of cropping systems without pesticides. In spite of the previous and existing research there are major gaps in basic biological and ecological knowledge necessary for non-chemical system approaches to pest management. Knowledge on pest population dynamics, natural enemy population dynamics and other components in the ecosystem are also essential. With a better biological foundation it will be possible to improve efficiency of known biological control methods, develop new systemic control methods as well as evaluate the efficiency of non-chemical management in a long-term perspective.

2) *Research in 'How best to integrate multifunctional plants (and crops) and use diversification to create a more healthy and productive farming system which is resilient to pests?'* There is a need for research into functionality of diversification and integration of plants with bioactive compounds or allelopathic interactions for pest management based on intercropping, cultivar mixtures, crop rotations, flower strips, conservation biological control, etc. Many practices that have been used traditionally in both China and Denmark are known to be beneficial in the prevention or control of pests, however, the knowledge of the specific functions and interrelations is too limited for using such eco-functional intensification systematically and focused in systemic approaches to pest management.

More knowledge on the multi-functions and interactions between plants-plants and plants-pests-natural enemies will enable the development of systemic approaches to pest management.

3) Research in '*How to design and integrate pest management in eco-functional cropping systems at field and farm/landscape level?*' Integration of knowledge on pests and crops and their interactions and various non-chemical pest management methods into systemic approaches at field level is complex. The degree of complexity increases even more when moving from field to farm and/or landscape level. How to integrate and design systemic approaches for a larger area or a production unit (which may consist of one or more farm units) and its boundaries and how to do research that applies to larger areas or landscape level is new. It can build on knowledge and methods as described in the above research themes. It is important to make the knowledge and methods operational, for example, in some form of decision support tool, by critically evaluating the designed systems in dialogue with farmers and where relevant, supported by simulation modelling.

7. Concluding remarks on the framework for future collaboration from the Network

Funding of Chinese-Danish collaborative research projects?
While the network with this report underlines the potential of collaboration between China and Denmark, it is the hope that funding will be made available from the Chinese and Danish governments for establishing collaborative research projects in the field of systemic approaches to pest management. The network hopes that this report will help pave the way forward for such collaboration and that the first step in the right direction has been taken.

Danish research funding opportunities
The Danish Ministry of Science, Innovation and Higher Education will as funders of the Network receive the present report together with the final report and accounts through the Agency for Science, Technology and Innovation. The Agency administers the funding that is earmarked for independent research and for thematically defined and politically prioritized research areas, such as the research funding allocated via the Danish Council for Independent Research (DFF). DFF funds specific research activities, within all scientific areas, that are based on the researchers' own initiatives and that improve the quality and internationalization of Danish research.
Collaboration with China already exists within the Ministry under the Danish Council for Strategic Research, namely the Sino-Danish Strategic Research Cooperation where the Chinese partner is MOST. The network hopes that the topics recommended for research in the present report would be included in the future collaboration between China and Denmark, for example, by inclusion in the existing Sino-Danish cooperation.

Chinese research funding opportunities
This report will also be translated into Chinese and submitted to relevant research funding authorities in China, such as:
The National Natural Science Foundation of China (NSFC) through the National Program on Key Basic Research Project (973 Program) from Ministry of Science and Technology supports projects for basic research such as biological research suggested above under Research Theme 1 (recommendation v.). There is also international cooperation and exchanges with the Danish National Research Foundation (DNRF) in relation to this programme.
Traditional renovated ways integrated with new technology may get support by National High-tech R&D Program of China (863 Program) as well as the international cooperation programme from Ministry of Science and Technology (MOST) and also the programme of 948 funded by Ministry of

Agriculture (MOA). The latter two programmes focus on new technology development and introduction from developed countries, thus specific projects could be proposed to these two programmes.
Furthermore funding in the Chinese research system is provided by the five-year plan programme, Chinese National Programs for Science and Technology Development from Ministry of Science and Technology (MOST), and also by the Agro-scientific Research in the Public Interest programme by Ministry of Agriculture (MOA).

Collaboration with Europe
Collaboration between Denmark and China could also provide an opening for closer collaboration between research in China and Europe though the above mentioned network Core Organic. The network activities are supported by EU as Core Organic is one of the so called EU ERAnets. Establishing closer research collaboration between two big players in the global food production would be beneficial and highly relevant for the development of sustainable future food production.

The Network will make the report available to relevant authorities in Denmark responsible for providing inputs to the Directorate General for Research and Innovation, as well as to relevant EU authorities.

The network – a platform for future collaboration
While the authors of this report (a total of 16 people) have formed a core group of the Chinese-Danish Network for Systemic Approaches to Pest Management without Pesticides, the network includes a large group of other researchers from both China and Denmark (please see Annex 4 for names, contact details and specialization) who has participated in either the workshop in China or the workshop in Denmark. With this network of researchers with different background, however, involved in the same field of work, there is already a platform for further collaboration.

Form of future collaboration
Research collaboration could take place at various level (undergraduate, graduate, postgraduate) and with various collaborative activities such as individual exchange between the two countries (mobility, guest professor, visiting scientist, scholarships), conferences, and collaborative projects.

How to organize future collaboration has not been specifically discussed in the core group, but from the discussions that have taken place formally and informally during the workshops, it is clear that there is interest in a wide range of project set-ups from collaboration of a more limited character on a person-to-person basis such as visiting scientists or PhD students (Chinese students partly or fully enrolled in Denmark and Danish students partly or fully enrolled in China), to fully integrated projects with joint funding and implementation. Models for projects with various degrees of integration are illustrated in the below figure.

The model in the table named 'the Core Organic model' refers to a system used in the European research network on organic foods systems 'Core Organic' that has now existed for more than 6 years. In this network the research projects are undertaken in collaboration between research institutions in several of the network member countries, but funds that are pooled into a common-pot are earmarked to fund the activities of institutions from the same country as the funding body.

ICROFS is, as the coordinator of Core Organic, very experienced with the implementation, management and administration of this type of project, as well as with the other 'models' outlined below.

At present the Chinese government (China Scholarship Council) provides scholarships for visiting researchers as well as for PhDs from half year to two years and Chinese students may be partly or fully enrolled in the Danish education system. Research collaboration can therefore build on the existing exchange of PhD students and visiting researchers in the up-scaling to more integrated projects with joint funding and implementation.

Models for collaboration:

Formalized Network Collaboration	**Expanded Formalized Network Collaboration**	**The 'Core Organic model'**	**Fully integrated projects**
• Joint Research Agenda • Individual projects applied for nationally and funded by national sources • Regular scientific workshops for exchange of knowledge and new results	• Joint Research Agenda • Regular scientific workshops for exchange of knowledge and new results • Individual projects applied for nationally and funded by national sources • Exchange of visiting scientists	• Joint Research Agenda • Regular scientific workshops for exchange of knowledge and new results • Joint Research Programme with joint calls, but separate funding for Chinese and Danish researchers in joint projects by the two governments • Joint Programme implementation and monitoring • Joint project implementation	• Joint Research Agenda • Regular scientific workshops for exchange of knowledge and new results • Joint Research Programme with joint calls • Joint Programme implementation and monitoring • Joint project implementation • Exchange of visiting scientists from China to Denmark and from Denmark to China • Exchange of PhD students from China to Denmark and from Denmark to China (either part-time exchange or full time exchange)

Increasing degree of integration

Annex 1: References

Akol AM, Njagi PG N, Sithanantham S, et al. 2003. Effects of two neem insecticide formulations on the attractiveness, acceptability and suitability of diamondback moth larvae to the parasitoid, *Diadegma mollipla* (Holmgren) (Hym: Ichneumonidae). J Applied Entomol, 2003, 127(6): 325-331.

Barbosa, P. (ed.). 1998. Conservation biological control. Academic Press, NY.

Batáry P, Báldi A, Kleijn D, Tscharntke T. 2011.Landscape-moderated biodiversity effects of Agri-environmental management: a meta-analysis. Proceedings of the Royal Society B. 278:1894–1902

Bianchi, F.J.J.A , Booij, C.J.H, Tscharntke ,T., 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceddings of the Royal Society B: 273, 1715-1727.

China MOA statistics.

Chen X. 2010. Recent progress existing problems and prospects in biological control of insect pests in China. Chinese Bulletin of Entomology 2010, 47(4): 615 – 625.

Chen XJ, Yang YZ, Zhang ZX, Xu HH. 2010. Progress on safety evaluation of azadirachtin and neem insecticide. Ecol Environ Sci 19(6): 1478-1484.

Clough Y, Crist TO, Dormann CF, Ewers RW, Fründ J, Holt RD, Holzschuh A, Klein AM, Kleijn D, Kremen C, Landis DA, Laurance W, Lindenmayer D, Scherber C, Sodhi N, Steffan-Dewenter I, Thies C, van der Putten, WH, Westphal C. 2012 .Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biological Reviews. DOI: 10.1111/j.1469-185X.2011.00216.x.

Cui X.W. and Wu B.Z. 2009. Advances in research oil vegetable intercropping. Journal of Yunnan Agricultural University. 24: 128-132

Duan MC, Liu YH, Zhang X, Zeng WG, Yu ZR.2012.Agricultural disease and insect-pest control via agro-ecological landscape construction. Chinese Journal of Eco-Agriculture, 20(7): 825−831. (In Chinese with English abstract)

Didelot, F., Brun, L. and Parisi, L. (2007), Effects of cultivar mixtures on scab control in apple orchards. Plant Pathology, 56: 1014–1022. doi: 10.1111/j.1365-3059.2007.01695.x

Eilenberg, J.; Hajek, A.E.; Lomer, C. (2001): Suggestions for unifying the terminology in biological control. BioControl, 46: 387-400.

Enkegaard A., Sigsgaard, L., Kristensen, K. Shallot aphids, *Myzus ascalonicus*, in strawberry – biocontrol potential of three predators and three parasitoids. J. Insect Science. *In press*

Giovannucci, D., 2005, Organic Agriculture and Poverty Reduction in Asia: China and India Focus, International Fund for Agricultural Development (IFAD), Rome, Report No. 1664, July.

GIZ. 2011. Eco-functional intensification and agricultural production. Seeds and fertilizer – contribution to food security. Documentation of the Workshop, 6th October 2010, GTZ (/GIZ) 1, Eschborn.

Jianzhong Bao, Dexiang Gu (Edt.) 1998 Biological Control in China. Shanxi Science and Technology Press .

Jönsson, M., Wratten, S.D., Landis, D.A, Gurr, G.M 2008. Recent advances in conservation biological control of arthropods by arthropods. Biological Control 45, 172-175

Kellerhals, M.; Kesper, C.; Koller, B. and Gessler, C. 2002. Breeding apples with durable disease resistance. In: Boos, Markus (Ed.) *10th International Conference on Cultivation Technique and Phytopathological Problems in Organic Fruit-Growing and Viticulture. Proceedings to the Conference from 4th to 7th Feb. 2002 at Weinsberg/Germany*, pp. 5-10.

Korsgaard, M. 2012. Strategic irrigation against apple scab (*Venturia inaequalis*) s. 245-248. Proceedings to the 15th International Conference on Organic Fruit-Growing. February, 20 to February, 22, 2012 at Hohenheim/Germany Editor: Foerdergemeinschaft Oekologischer Obstbau e.V. (FOEKO). Weinsberg 2012. ISBN 978-3-98 04883-6, http://www.ecofruit.net/2012/proceedings-2012.pdf.

Rou Sun, 2012 A survey report on biological control in China. Master Degree Thesis of China Agricultural University, Beijing

Ouyang, F., Ge, F. 2011. Effects of agricultural landscape patterns on insects. Chinese Journal of Applied Entomology 48(5), 1177-1183 (In Chinese with English abstract) .

Purtauf, T., Roschewitz, I., Dauber, J., Thies, C., Tscharntke, T., Wolters, V., 2005. Landscape context of organic and conventional farms: Influences on carabid beetle diversity. Agriculture, Ecosystems and Environment 108, 165-174.

Shen JF, Wang ZK, Zhang JW, Yin YP. 2012. Identification of two Metarhizium species and bioassay of their virulence against the white grubs of peanut. Chn J Bio Control 28(3): 334-340.

Sigsgaard, L., Betzer, C, Naulin, C., Eilenberg, J., Enkegaard, A., Kristensen, K. Floral resources affect parasitoid and host longevity – prospects for conservation biological control in strawberries. Journal of Insect Science. *In press*

Sigsgaard, L 2010. Habitat and prey preferences of the two predatory bugs *Anthocoris nemorum* (L.) and *A. nemoralis* (Fabricius) (Anthocoridae: Hemiptera-Heteroptera) Biological Control , vol 53, no. 1, pp. 46-54.

Sigsgaard, L, Haukeland, S., Naulin, C., Kristensen, K., Enkegaard, A., Jensen, N.L., Eilenberg, J. Strawberry cropping practice effects on pests and their natural enemies. *Submitted*

Sun XL, HY Peng. 2007. Recent advances in biological control of pest insects by using viruses in China. Virologica Sinica 22 (2): 158-162.

Tscharntke T, Tylianakis JM, Rand TA, Didham RK, Fahrig L, Batáry P, Bengtsson J, Clough Y, Crist TO, Dormann CF, Ewers RW, Fründ J, Holt RD, Holzschuh A, Klein AM, Kleijn D, Kremen C, Landis DA, Laurance W, Lindenmayer D, Scherber C, Sodhi N, Steffan-Dewenter I, Thies C, van der Putten WH, Westphal C. 2012: Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biological Reviews 87: 661-685.

Turner M.G., Gardner R.H. and O'Neill R.V. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springerverlag, New York, New York, USA.

Veres, A., Petit, S., Conord, C., Lavigne, C., 2011. Does landscape composition affect pest abundance and their control by natural enemies? A review. Agriculture, Ecosystems & Environment, doi:10.1016/j.agee.2011.05.027

Wang YL, Guan ZG, Jia XS, Wu SY, Wei HG. 2007. Study progress of matrine application in farming pest control. J Shanxi Agri Sci 40(4): 424-428.

Williams, M.; Bertelsen, M.; Sigsgaard, L.; Andersen, L.; Pedersen, H.L.; Paaske, K; Jørgensen, R.N.; Bertelsen, K; Korsgaard, M. (2011). Nye løsninger sikrer fremtidig vækst i økologisk æbledyrkning. *ICROFSnyt*, June 2011, pp. 8-9. (Engl: http://www.icrofs.org/Pages/Research/organicrdd_fruitgrowth.html)

Xiu-lian SUN and Hui-yin PENG. 2007. Recent Advances in Biological Control of Pest Insects by Using Viruses in China. State Key Laboratory of Virology, Wuhan Institute of Virology, Chinese Academy of Sciences, Wuhan 430071, China

Ye X-Z, Zhao Y-S, Wang Q, Jiang Y-G. 2012. Present status of pesticide residue in vegetables and its potential risk analysis. China Vegetable (14): 76-80.

Yu G.B.. 2009. Effects of different rotation and intercroping modes on cucumber yield and rhizosphere soil microbial environment. Master Thesis. Northeast Agricultural University.

Yu JQ. 2011. Progress in protected vegetable production and research during 'The Eleventh Five-year Plan' in China. China vegetables. 1: 11-23

Zhang ZH, Chen QY, Gao LH, Wang JJ, Shen J, Li ZM, and Zhang XY. 2010. Development of vegetable production in China. Vegetables. 5: 1-3

Annex 2: 1st Workshop on Systemic Approaches to Pest Management without Pesticides, 15-17 April, Boshan, China – Programme

15 April: Fieldtrip – Visits to:

- North China Intensive Agro-ecosystem Experiment Station in Huantai
- Organic Agriculture Developing Centre of Boshan, China
- Organic kiwi production base of Yuanquan town of Boshan
- Organic honeysuckle flower production base of Chishang town of Boshan
- Organic strawberry and vegetable production base of Shangwaquan town of Boshan

16 April: Symposium – Organic Agriculture Developing Centre of Boshan, China

- Welcome address (*Mr. Zong Zhijian,* Boshan Leader)
- Welcome address (*Ms. Lise Andreasen.* International Coordinator, ICROFS)
- Welcome address (*Mr. Wu Wenliang,* Professor, CAU)
- Introduction of the development of organic farming in Boshan city (*Mr. Wang Bo.* Agriculture Comprehensive Development Office of Boshan)
- Green and organic products, production, processing and quality control at Yili in Sinkiang Province (*Mr. Wu Wenliang,* Professor, CAU)
- Insect pathogens (fungi): ecology, co-evolution and application (*Mr. Jørgen Eilenberg,* Professor, University of Copenhagen)
- Systemic Approaches to pest management without pesticides - Biological control of insect pests with predators and parasitoids (*Ms. Lene Sigsgaard,* Associate Professor, University of Copenhagen)
- Insect biological control in China: Progress and perspective (*Mr. Zhang Guife,* Professor, Environment and Development Institute of Chinese Academy of Agricultural Sciences)
- Environmental friendly pest and disease control technology in greenhouse (*Ms. Cao Aocheng,* Professor, Protection Institute of Chinese Academy of Agricultural Sciences)
- Systemic approaches to non-chemical pest management at Aarhus University (*Ms. Tove Steenberg,* Associate Professor, Aarhus University)
- Examples of non-chemical pest management projects at Aarhus University (*Ms. Sabine Ravnskov,* Associate Professor, Aarhus University)
- Efficient natural control of insect pests by increasing biodiversity in apple orchards (*Mr. Zhang Long,* Professor, CAU)
- Natural biological control of insect pests in rice without insecticide for 10 years: a case study in the subtropical rice ecosystem in Sanmen, Zhejiang Province, China (*Mr. Zhu Zeng-Rong,* Professor, Zhejiang University)
- Organic farming: An effective approach to conserve FIAHS (*Ms. Sun Yehong,* Dr.,Geography Institute of Chinese Academy of Science)
- Eco-functional intensification as an approach to developing sustainable pest management (*Ms. Vibeke Langer,* Associate Professor, University of Copenhagen)
- Plant Disease Management with focus on crop diversification and disease forecasting (*Ms. Lisa Munk,* Associate Professor, University of Copenhagen)
- Reducing pesticides and fungicides inputs in Lichi and Banana Production (*Mr. Wang Jianwu,* Professor, Southern China Agricultural University)
- Organic vegetable production (*Mr. Li Ji,* Professor, CAU)
- Utilisation of biodiversity in agroecosystems: Models and their mechanism in case of rice-fish co-culture systems (*Mr. Tang Jianjun,* Professor, Zhejiang University)
- Eco-functional intensification of below ground biodiversity to control soil borne disease (*Ms. Qiao Yuhui,* Associate Professor, CAU)

17 April – Workshop

- Group Discussions aimed at answering the following questions:

    - What are the similarities (and differences?) in Chinese and Danish approaches?
    - Identify 3 priority research areas that the group would like to suggest for joint Sino-DK research in development of systemic approaches to pest management without pesticides.
- Report back and Conclusions
- Summing up and way forward

Annex 3: 2nd Workshop on Systemic Approaches to Pest Management without Pesticides, 22-24 August, Flakkebjerg/Copenhagen, Denmark – Programme

Tuesday 21 August – visit to ICROFS, Research Centre Foulum

- Welcome session (*Mr. Niels Halberg*, Director, ICROFS)
- Presentation of the national organic research strategy and research priorities, the present and the previous national research programmes (*Niels Halberg*)
- Introduction to Organic Eprints (*Ms. Ilse A. Rasmussen*, OrganicEprints Coordinator)
- Field visit to organic long-term crop trials at Foulumgaard (*Ilse A. Rasmussen*)
- Presentation of the organic platform at AU, relevant research results and trials combined with visits to trials in the field (*Mr. John Hermansen*, Head of Research Unit, & colleagues)

Wednesday 22 August –Aarhus Universitet, Flakkebjerg – Workshop Day 1

Welcome

- Welcome and introduction to Research Centre Flakkebjerg (*Mr. Steen Lykke Nielsen*, Head of Research Unit, Department of Integrated Pest Management, Aarhus University)

Welcome to the workshop (*Ms. Lise Andreasen*, International Coordinator, ICROFS)

Organic farming systems in Denmark and China

Output: ll workshop participants have a good understanding of the organic farming systems in Denmark and China and a better foundation for the discussions in Theme 1 and Theme 2

- Introduction to organic production in Denmark – what are the typical organic farming systems in Danish farms and what production factors are the main drivers for the development of the organic farming system (*Ms. Vibeke Langer*, Associate Professor, University of Copenhagen)
- Introduction to organic production in China – what are the typical organic farming systems in Chinese farms and what production factors are the main drivers for the development of the organic farming system (*Ms. Qiao Yuhui*, Associate Professor, China Agricultural University)
- Discussion of similarities and differences in the organic farming systems that have to be considered when implementing joint research projects on systemic approaches to pest management without pesticides.
- Plan of action for this Chinese-Danish 'network development' of a strategy and recommendations for Chinese-Danish collaboration on the development of Systemic Approaches to pest management without pesticides (*Lise Andreasen & Qiao Yuhui*)

Theme 1: Vegetable cropping systems- research for integrated-systemic non-chemical pest management

- *Output: Agreements on draft strategy and recommendations for research collaboration between China and Denmark for theme 1*
- Introduction to theme 1 discussions (*Ms. Sabine Ravnskov*, Associate Professor, Aarhus University)
- From identification to implementation of a biocontrol agent in Denmark (*Mr. Bent J. Nielsen*, Senior Scientist, Aarhus University)
- From identification to implementation of a biocontrol agent in China (*Mr. Zhang Long*, Professor, China Agricultural University)
- Introduction to field experiments with integrated pest management in field grown vegetables (*Ms. Annie Enkegaard*, Senior Scientist, Aarhus University)
- Demonstration of field experiments t Flakkebjerg
- Present practice, on-going research and future potential for non-chemical pest management in vegetable production in Denmark (*Ms. Annie Enkegaard*, Senior Scientist, Aarhus University)
- Present practice, on-going research and future potential for non-chemical pest management in vegetable production in China (*Mr. Zhu Zengrong*, Professor, Zhejiang University)
- Group discussions 1

- Present practice, on-going research and future potential for non-chemical disease management in vegetable production in China (*Mr. Guo Yanbin*, Associate Professor, China Agricultural University)
- Present practice, on-going research and future potential for non-chemical disease management in vegetable production in Denmark (*Ms. Sabine Ravnskov*, Associate Professor, Aarhus University)
- Group discussions 2
- Present practice, on-going research and future potential for non-chemical weed management in vegetable production in Denmark (*Mr. Bo Melander*, Associate Professor, Aarhus University)
- Field excursion to the organic farm 'Krogagergaard'
- Summary and outputs of theme 1 (*Agreements on draft strategy and recommendations for research collaboration between China and Denmark)*

Thursday 23 August – KU-Science (PLEN), Copenhagen University, Frederiksberg Campus, Copenhagen – Workshop Day 2

Farm visits to two farms including demonstration of on-going experiments at the two organic farms 'Bakkegården' and 'Ventegodtgård'

Welcome and introduction to KU and Department of Plant and Environmental Sciences

Welcome and introduction to PLEN and new Centre on Sustainable Agriculture and Forestry Systems – SAFor (*Mr. Svend Christensen*, Professor, Head of Department of Plant and Environmental Sciences, University of Copenhagen)

Theme 2: Fruit and berry cropping systems –research for integrated-systemic non-chemical pest management

Output: Agreements on draft strategy and recommendations for research collaboration between China and Denmark for theme 2

- Introduction to theme 2 discussions (*Ms. Lene Sigsgaard*, Associate Professor, University of Copenhagen)
- Present practice, on-going research and future potential for non-chemical pest management in fruit and berry production in China (*Mr. Zhang Long*, Professor, China Agricultural University)
- Present practice, on-going research and future potential for non-chemical pest management in fruit and berry production in Denmark (*Ms. Lene Sigsgaard*, Associate Professor, University of Copenhagen)
- Group discussions 1
- Present practice, on-going research and future potential for non-chemical disease management in fruit and berry production in Denmark (*Ms. Maren Korsgaard*, Scientific secretary at University of Copenhagen)
- Present practice, on-going research and future potential for non-chemical disease management in fruit and berry production in China (*Mr. Wang Jianwu*, Professor, Southern China Agricultural University)
- Group discussions 2
- *A walk around University of Copenhagen facilities campus Frederiksberg -optional*

Friday 24 August – KU-Science (PLEN), Copenhagen University, Frederiksberg Campus, Copenhagen – Workshop Day 3

- Summary and outputs of theme 2 (*Agreements on draft strategy and recommendations for research collaboration between China and Denmark)*
- *Concluding session – final discussions and writing up*
- Finalizations of draft strategies and recommendation for individual themes
- Finalizations of draft strategies and recommendation for individual themes - continued
- Conclusions and agreements on way forward - from draft to final version and submission to funding bodies)

Annex 4: Systemic Approaches to Pest Management without Pesticides - Chinese-Danish network members

Chinese-Danish Network on Systemic Approaches to Pest Management without Pesticides - Address Book

中丹“无农药病虫害系统控制方法”交流研讨会 - 通讯录

姓名/Name; 联系电话/ Phone, 邮箱/Email	单位/Organization	Specialisation	Report Co-author	WS 1	WS 2
Niels Halberg, Director E-mail: niels.halberg@icrofs.org Phone: +45 87158037	International Centre for Research in Organic Food Systems (ICROFS)	Organic and conventional farming systems including agronomy, economics and resource use and environmental impact. Life cycle analysis and sustainability indicators.	X		X
Jørgen Eilenberg, Professor E-mail: jei@life.ku.dk Phone: +45 353-32692	Department of Plant and Environmental Sciences, University of Copenhagen	Biological control, insect pathogens, host-pathogen co-evolution, population interactions, molecular characterization	X	X	X
Lene Sigsgaard, Associate Professor E-mail: les@life.ku.dk Phone: +45 353-32674	Department of Plant and Environmental Sciences, University of Copenhagen	Insect predators and parasitoids, applied ecology, non-chemical management strategies in relation to insect pests	X	x	x
Vibeke Langer, Associate Professor E-mail: vl@life.ku.dk Phone: +45 353-32383	Department of Plant and Environmental Sciences, University of Copenhagen	Ecology and design of production systems, pest management in organic farming, farmer practices and decision making in pest management	X	X	X
Lisa Munk, Associate Professor E-mail: lm@life.ku.dk Phone: +45 53-32178	Department of Plant and Environmental Sciences, University of Copenhagen	Non-chemical management strategies in relation to plant diseases of agricultural crops	X	X	X
Sabine Ravnskov, Associate Professor E-mail: sabine.ravnskov@agrsci.dk Phone: +45 87158136	Department of Agroecology, Aarhus University	Biological management of plant diseases. Microbial interactions in soil and plants with special emphasis on interactions between plant growth promoting microorganisms and pathogens, and their influence on plant health.	X	X	X
Tove Steenberg, Associate Professor E-mail: tove.steenberg@agrsci.dk Phone: +45 87158123	Department of Agroecology, Aarhus University	Insect pathology and microbial pest control	X	X	X
Annie Enkegaard, Associate Professor E-mail: Annie.enkegaard@agrsci.dk Phone: +45 87158223	Department of, Aarhus University	Biological and integrated control of arthropod pests in greenhouses and outdoor crops; beneficial arthropods;biology; population dynamics; IGP and other interactions in multi-species systems ; host-plant	X	X	X

		interactions; HIPVs; rearing methods; quality control.			
Lise Andreasen, International Coordinator E-mail: Lise.Andreasen@icrofs.org Phone: +45 87157704 / 51591003	International Centre for Research in Organic Food Systems (ICROFS)	Research management and coordination. Farming systems development for food security and adaptation to climate change. Ecological economics and sustainable development.	X	X	X
吴文良/ Wu Wenliang, Professor E-mail: wuwenl@cau.edu.cn Phone: +86 13701128101	中国农业大学/China Agricultural University	Agro-ecology and ecological planning.	X	X	
张龙/Zhang Long, Professor E-mail: locust@cau.edu.cn Phone: +86 13521781080	中国农业大学/ China Agricultural University	Biological control of vegetable pests and fruit tree pests, grasshoppers and locusts with entomophagous fungi, protozoa and prdators, and incresing biodiversity of ecosystems.	X	X	X
王建武/Wang Jianwu, Professor E-mail: wangjw@scau.edu.cn Phone: +86 13602863467	华南农业大学/Southern China Agricultural University	Agro-ecology and ecological agriculture development, risk assessment of GMOs.	X	X	X
祝增荣/Zhu Zengrong, Professor E-mail: zrzhu@zju.edu.cn Phone: +86 13958023763	浙江大学昆虫研究所/Zhejiang University	Natural biocontrol (predators and parasitoids, ecol-engineering, non-chemical strategies for insect pest management.	X	X	X
Guo Yanbin, Associate Professor E-mail: Yanbin_guo@163.com guoyb@cau.edu.cn Phone: +86 1062732000	中国农业大学/China Agricultural University, presently Visiting Scholar at University of California Riverside, US	Biological management of plant diseases and application of plant growth promoting rhizobacteria in organic farming.	X		X
Liu Yunhui, Associate Professor E-mail: liuyh@cau.edu.cn Phone: +86 1062734819	中国农业大学/China Agricultural University, presently at Göttingen University	Research on the effects of faring management,landscape pattern on the biodiversity of natural enemy in agricultural landcape and develope measures for natural enemy conservation and pest control through landscape planning and habitat re-construction.	X		X
乔玉辉/Qiao Yuhui, Associate Professor E-mail: qiaoyh@cau.edu.cn Phone: +86 13693029649	中国农业大学/China Agricultural University	Soil ecosystem health and earthworm ecology.	X	X	X
李季/Li Ji, Professor E-mail: liji@cau.edu.cn Phone: +86 13601055373	中国农业大学/China Agricultural University	Biofertilizer and agricultural waste treatments.		X	
曹坳程/Cao Aocheng, Professor E-mail: caoac@vip.sin.com Phone: +86 13911826293	中国农科院植保所/Plant Protection Institute of Chinese Academy of Agricultural Science	IPM technology and pesticide application. Soil-borne disease control with chemical and non-chemical technologies.		X	

唐建军/Tang Jianjun, Professor E-mail: chandt@zju.edu.cn Phone: +86 571-87997840	浙江大学生态研究所/Zhejiang University ecology institute	Integrative management of agroecosystem based on the well-understanding to their ecological processes, aimed to low-agrochemicals input and high quality production and low environmental impacts through interspecific and intraspecific interactions of biota, especially in southeastern China.		x	
张桂芬/Zhang Guifen, Professor E-mail: Guifenzhang3@163.com Phone:+86 1082109572 / 13511039463	中国农科院植保所/Institute of Plant Protection, South Campus, Chinese Academy of Agricultural Sciences	Insect predators and parasitoids (including intraguild predation), biological and integrated control of arthropod pests in greenhouses and outdoor crops, population interactions, molecular characterization.		X	
郑长英/Zheng Changying E-mail: yaaslxl@sina.com Phone: +86 13515327357	青岛农业大学/Qingdao Agricultural University	Biological and integrated control of insect in greenhouses and outdoor crops, insect pathogens,		X	
孙业红/Sun Yehong E-mail: sunyh.07b@igsnrr.ac.cn Phone: +86 13581929113	中科院地理所/Geography Institute of Chinese Academy of Science	Tradition agro-ecosystem ; engaging in Globally Important Agricultural Heritage Systems		X	
刘月仙/Liu Yuexian E-mail: yxliu76@hotmail.com Phone: +86 13621352233	北京市农林科学院/Beijing Academy of Agriculture and Forestry Science	LCA of organic and conventional farming systems. Integrated pest management and development of agricultural expert systems to predict/control pests		X	
Changxing Wu, Vice-Director E-mail: wu_cx@yahoo.com.cn Phone:	Zhejiang Academy of Agricultural Sciences (visiting scientist at Aarhus University)	Weed Control			X
陈春/Chen Chun, Associate Professor E-mail: aspring@cjlu.edu.cn Phone:+86 13093765395	中国计量学院/China Jiliang University (Visiting Scientist, University of Copenhagen)	Microbial pest control; insect pathogens, mass production and formulation of Entomopathogenic Fungi; application and risk evaluation on mycopesticide, host-pathogen interactions, molecular characterization and epizootiological mechanism.			X
Bo Melander, Associate Professor E-mail: bo.melander@agrsci.dk Phone: +45 87158198	Department of Agroecology, Aarhus University	Non-chemical weed control in conventional and organic agricultural and horticultural crops including investigations of the mechanisms and effects of a wide range of mechanical and thermal control methods; and ways to combine direct physical methods with preventive and cultural weed control tactics.			X
Bent J. Nielsen, Senior Scientist E-mail: bent.nielsen@agrsci.dk	Department of Agroecology, Aarhus University	Disease control in cereals, potatoes, peas and oil seed rape. Control of seed borne diseases in cereals including investigations			X

Phone: +45 87158125		on efficacy of fungicides, microbiological products and alternative methods (hot water/air, alternative chemicals)			
Per Rydahl, Academic employee E-mail: per.rydahl@agrsci.dk Phone: +45 87158197	Department of, Aarhus University	Development, maintenance and system export of the weeds module of the decision support system Crop Protection Online (CPO-weeds), which on a field level can: provide directions that ensure 'punctual care' in relation to crop weed control throughout a growing season; assist identification of weed species; quantify needs for weed control; suggest herbicide treatment options, which match the need; provide overviews of the efficacy of herbicides and herbicide mixtures under different conditions			**X**
Gabor Lövei, Associate Professor, E-mail: gabor.lovei@agrsci.dk Phone: +45 87158224	Department of Agroecology, Aarhus University	Environment, climate and energy – earth, nature and plot use – utilization and protection, biodiversity, population ecology.			**X**
Maren Korsgaard, Scientific Secretary E-mail: mkor@life.ku.dk Phone:+ 45 3533 3401	Department of Plant and Environmental Sciences, University of Copenhagen	Fruit and berries. Plant genetic resources. Organic horticultural production. Non-chemical prevention of diseases.			**X**
Annette Bruun Jensen, Associate Professor E-mail: abj@life.ku.dk Phone: +45 353-32662	University of Copenhagen	Population ecology and evolution of insect pathogenic microorganisms and economically important insects (honeybees and aphids). Conservation biology of the Black European honey bee *Apis mellifera mellifera*.			**X**