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Prototyping Integrated and Ecological Arable Farming Systems (I/EAFS) within a EU-network

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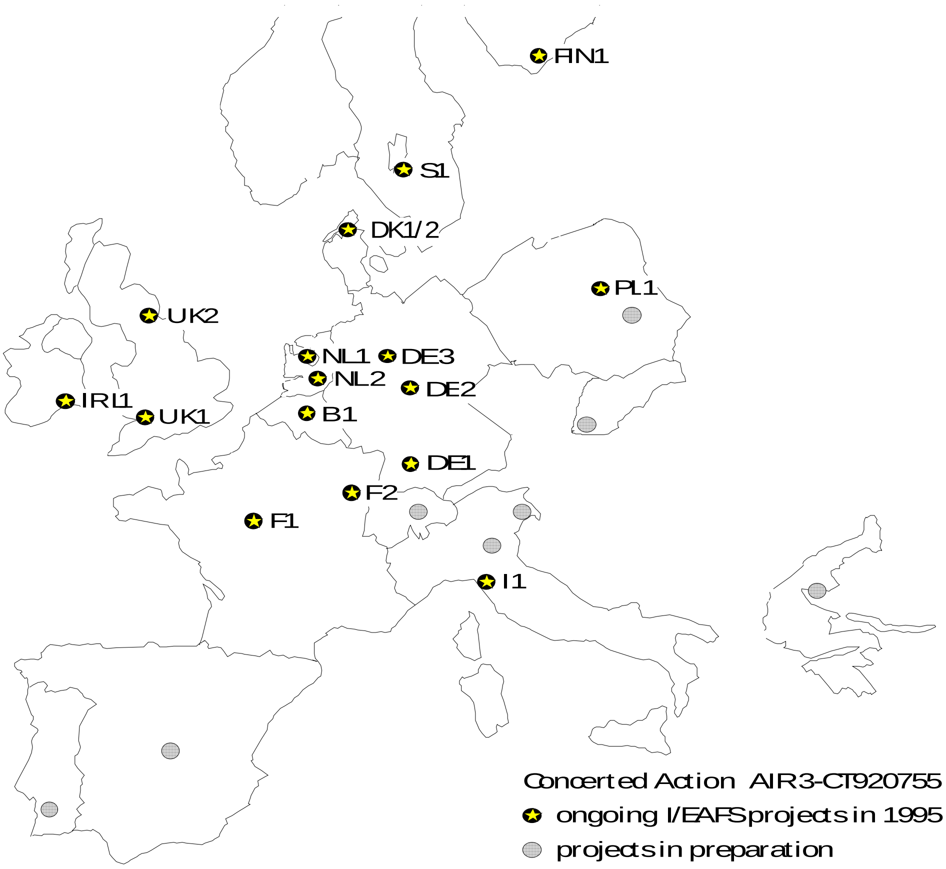
Introduction

The European Union (EU) is facing an agricultural crisis with two major symptoms: deterioration of rural income and employment and deterioration of environment, nature and landscape. The basic mechanism is a never ending intensification causing surplus production and price fall on the one hand and ecological deterioration on the other hand. Therefore, a crucial question for the Common Agricultural Policy (CAP) is to alleviate the symptoms of intensification on the short term and to find a sustainable solution on the long term. In the early nineties, various EU-countries started promoting Integrated Farming Systems to alleviate the agricultural crisis, when drastic reductions in inputs of pesticides and fertilisers were achieved with initial prototypes on experimental farms. Subsequently, in 1993 the EU-Commission invited the author to act as co-ordinator of a network of research teams on Integrated Arable Farming Systems (IAFS). The setting up of the network should be combined with development and standardisation of the methodology in a concerted action within the third EU framework programme for agricultural research called AIR.

Most research teams joining the network develop IAFS prototypes feasible for the main group of farms. This group must try to be competitive on the world market, based on high and efficient production, and this gives only limited scope for pursuing non-marketable objectives such as environment, nature/landscape and sustainability of food supply. Therefore, a more consistent integration of objectives is needed for a sustainable solution of the agricultural crisis. Consequently, many research teams also or exclusively develop an IAFS for the long term, albeit that this IAFS is as yet only feasible for pilot groups of farms. Contrary to short-term IAFS, these long-term IAFS place income/profit subordinate to environment, and rely on ecologically-aware consumers willing to pay premium prices for food products with high added value and a credible label. The latter implies the sharing of responsibility by producers and consumers for a multifunctional and sustainable management of the rural areas. Social conversion to this market model seems the only sustainable solution to end intensification and replace it by a socially controlled and ecologically responsible technology development, notwithstanding a free world market.

In the long-term IAFS, Chemical Crop Protection is fully replaced by a package of non-chemical measures, to achieve ambitious objectives in environment, nature/landscape and quality and sustainability of food supply. So, long-term IAFS are based more on ecological awareness and knowledge than short-term IAFS. Therefore, our prototypes of long-term IAFS are simply called EAFS (Ecological Arable Farming Systems), and short-term IAFS are referred to as IAFS. However, it should be explicitly stated that EAFS are not the same as the organic farming systems that currently feature under an official European label. Organic systems can be considered to be a forerunner of EAFS, but they have no quantified objectives in environment and nature/landscape and as a result, they need to be considerably improved to become acceptable to the majority of consumers. Nevertheless, organic farming has a strategic significance to Europe because it is the first example of the market model of shared responsibility of consumers and producers for the rural areas. Therefore, many research teams are collaborating with a pilot group of organic farms, which have primarily been selected for their willingness to achieve more than is required by current minimal guidelines of the EU organic label.



I/EAFS

Figure 1: Network of research teams prototyping

Selected on a set of general and specific criteria, 22 research teams from 14 EU and 3 associated countries have been brought together into the network, since the start in 1993 (Figure. 1). Together they invest more than 30 scientist years per annum in prototyping. This paper focuses on a methodical way of 5 steps we have developed within the network as a common frame of reference for prototyping I/EAFS. The consecutive steps will be presented and illustrated by the state-of-the-art of the author's own project on EAFS with a group of pilot farms (NL 2), started in 1991.

Methodical way of prototyping I/EAFS (5 steps)

Building on initial experience with an experimental farm at Nagele (Vereijken, 1992) and the input of the research leaders from the network, prototyping of I/EAFS has been elaborated in a methodical way of 5 formal steps (Vereijken, 1994, 1995). (Outline 1). The outcome of these 5 steps is expressed in parts of an identity card for the prototype to facilitate the co-operation within the team and the exchange with the other teams in the network. In the following sections the 5 steps will be explained in more detail and illustrated by the various parts of the identity card of our prototype EAFS for the central clay region in the Netherlands (NL 2).

Outline 1: Methodical way of designing. testing, improving and disseminating prototypes of Integrated and Ecological (Arable) Farming Systems (I/EAFS).

1. *Hierarchy of objectives:*
   making a hierarchy in 6 general objectives, subdivided into 20 specific objectives as a base for a prototype in which the strategic shortcomings of current farming systems are replenished (Part 1 of the identity card of a prototype).
2. *Parameters and methods*:
   transforming the major (10) specific objectives into multi-objective parameters to quantify them,
   establishing the multi-objective methods needed to achieve the quantified objectives (Part 2 of the identity card).
3. *Design of theoretical prototype and methods:*
   designing a theoretical prototype by linking parameters to methods (Part 3 of the identity card),
   designing methods in this context until they are ready for initial testing (Multifunctional Crop Rotation as major method and Part 4 of the identity card).
4. *Layout of prototype to test and improve:*
   laying the prototype out on an experimental farm or on pilot farms in an agro-ecologically appropriate way (Part 5 of the identity card),
   testing and improving the prototype in general and the method in particular until (after repeated laying out) the objectives, as quantified in the set of parameters, have been achieved. (Part 6 of the identity card).
5. *Dissemination:*
   disseminating the prototype by pilot groups (< 15 farmers), regional networks (15 - 50 farmers) and eventually by national networks (regional networks inter-linked) with gradual shift in supervision from researchers to extensionists.

Hierarchy of objectives (step 1)

Table 1 presents 6 general values or interests involved in agriculture, subdivided into 3 or 5 specific values or interests. The first step you take as a designer of farming systems is to establish your hierarchy of objectives within this framework, taking into account the shortcomings of farming systems in your region and the targeted contribution your prototype should deliver to improve the situation in the short term (IAFS) or the long term (EAFS).

The procedure is simple: in the first round you rate your general objectives from 6 to 1 in descending order of importance. In the second round you rate your specific objectives within each general objective from 3 to 1 in descending order of importance (in food supply by 3, 2, 1, 0, 0 because there are 5 specific objectives, not 3). By this procedure we have drawn up the hierarchy of objectives as step 1 in pilot project NL 2 (Figure. 2). It clearly shows we want to prototype an EAFS, building forth on organic farming as a forerunner and improving it on 3 strategic shortcomings: nutrient management, care of nature and landscape and quality production.

This hierarchy of objectives should not be considered as just the vision of our prototyping team. Though we proposed it, the group of pilot farms has taken it over after ample discussions during several study meetings. To our experience, the hierarchy of objectives is a simple and effective instrument to achieve consensus between researchers and farmers. It could also be a good instrument to achieve consensus if more parties would be involved, such as consumers organisations or environmental groups. In that case a useful procedure would be to firstly let the various parties draw up their own hierarchy of objectives. Secondly, the various hierarchies should be highlighted and critically examined. Thirdly, a common hierarchy of objectives should be negotiated, based on a thorough weighting of the various arguments and sealed by a memorandum of mutual understanding or rather an agreement of co-operation and mutual support.

Table 1: General and specific social values and interests involved in agriculture*

Values and interests (not in order of importance)			
general	specific	general	specific
Food supply		Abiotic environment	
	quantity		soil
	quality		water
	stability		air
	sustainability		
	accessibility	Nature/Landscape	
Employment			flora
	farm level		fauna
	regional level		landscape
	national level	Health/Well-being	
Basic income/Profit			farm animals
	farm level		rural people
	regional level		urban people
	national level		

* Simplified from (Vereijken, 1992)

Parameters and methods (step 2)

Having put the objectives in a hierarchy you need to transform them into a suitable set of parameters to quantify them. Subsequently, the quantified objectives are used as the desired results at the evaluation of the prototypes. Prototypes are tested and improved until the results achieved match the desired results. Given the overwhelming number of parameters available, there are two major reasons for not using a large set. Firstly, using a large set is time-consuming and expensive. Secondly, doing so does not assure that the objectives are integrated which is crucial because the objectives may conflict in many ways. Consequently, you must first identify a limited set of key parameters, to ensure that the objectives are integrated sufficiently. Additionally, you must establish a set of specific parameters for those objectives that are not or only insufficiently covered by the integrating parameters.

To develop I/EAFS prototypes in which potentially conflicting objectives are sufficiently integrated, you need a suitable set of farming methods and techniques. Current methods and techniques mostly serve one or two of your set of objectives and harm the others. Chemical crop protection is a clear example. Therefore, you first look for integrating methods and techniques which bridge the gaps between conflicting objectives and are not harmful to the others. Additionally, you may establish specific methods aimed at major specific objectives that are insufficiently covered by the set of integrating methods.

In this way we have quantified the objectives and established the methods as step 2 in pilot project NL 2 (Table 2). In the first column of Table 2 the top 10 of specific objectives is listed, drawn up from the hierarchy of objectives (Figure. 2) by multiplying the ratings of the specific objectives by the ratings of the general objectives, which they belong to. In the second column of Table 2 the top 10 of specific objectives has been transformed into and quantified by a set of 16 parameters, of which 12 are on a shortlist of the I/EAFS network and 4 have a local status. In the third column of Table 2 it is listed the 4 methods needed to achieve the top 10 of specific objectives, as transformed into the set of 16 parameters. The 16 parameters and 4 methods are briefly defined in outline 2.

In Flevoland (central clay region) abiotic environment is the main objective, ahead of nature/ landscape and food supply. Although pesticides have been abandoned, abiotic environment remains of primary concern since soil fertility in EAFS is chiefly maintained by recycling organic waste, especially manure. Because organic fertilisers generally contain nutrients in ratios which do not correspond with the crop needs, accumulation and eventually leaching of certain nutrients can only be avoided by sophisticated nutrient management focusing on ergonomically desired and ecologically acceptable nutrient reserves in the soil. Nature/landscape is the second main objective, since current organic farming has no explicit guidelines and technology for this increasingly scarce commodity. An ecological infrastructure will overcome this shortcoming and stimulate ecologically-aware consumers to switch to ecological products. In Flevoland, development of an ecological infrastructure will focus on vegetation of the ditch sides, attractive to man and animals. Food supply is the third main objective, with the focus on an optimum balance of quantity and quality, as an indispensable basis for basic income/profit and health/well-being. This balance, called quality production, requires new and sophisticated technology, including a multifunctional crop rotation as a major substitute for external inputs, notably pesticides.

Design of theoretical prototype and methods (step 3)

Most of the methods of the European shortlist have to be designed or redesigned, because they are non-existent or not ready for use. However, you cannot design them independently from each other and in arbitrary order, because they should be multi-objective and should achieve the set of objectives quantified by the set of parameters within a consistent farming system and by mutual support. Consequently, in step (3) you start by linking the methods to the parameters they should help to achieve in a theoretical prototype before you proceed by designing the methods in their appropriate context.

Table 2: Parameters and methods in EAFS prototyping in Flevoland (NL 2) as an example of Part 2 of a prototype's identity card in the I/EAFS-Network

Top 10 of objectives	Top 10 objectives quantified in multi-objective parameters (defined in outline 2)	Top 10 objectives achieved by multi-objective farming methods (defined in outline 2)
1. Abiotic environment-Soil	1.1 EEP-soil = 0 1.2 20 < PAR < 30 * PAB > 1 if PAR < 20 PAB < 1 if PAR > 30 ** 1.3 x < KAR < y * KAB > 1 if KAR < x KAB < 1 if KAR > y ** 1.4 NAR (0-100 cm) < 70 kg ha^{-1}	1.1 - 1.4 MCR 1.2 - 1.4 ENM
2. Nature/Landscape - Flora	2.1 EII > 5 % farm area 2.2PSD > 50 farm^{-1} 2.3 PSDN> 20 section^{-1} (100 m)	2. EIM (target species sowing) included)
3. Food supply - Quality	3.1 QPI > 0.9 crop^{-1}	see 1
4. Abiotic environment - Water	4.1 EEP-water = 0 4.2 NDW < 11.2 mg l^{-1} (EU-norm) see 1	see 1
5. Nature/Landscape - Landscape	5.1 SCI > 0.8 5.2 FDI > 10 flowers m^{-1} (Apr-Oct) see 2 5.3 BSD > ?	see 2 (bird habitats included)
6. Basic income/Profit - Farm level	6.1 NS > 0 6.2 HHW < 25 hours ha^{-1} see 3	6.1 FSO see 1 and 2
7. Food supply - Quantity	see 3	see 1 and 2
8. Health/Well-being - Urban people	see 1-6	see 1 and 2
9. Basic income/Profit - Reg. level	see 1-6	see 1, 2 and 6
10. Abiotic environment-Air	10.1 EEP-air = 0 see 1	see 1
	Total parameters: 12 EU, 4 local	Total methods: 4 EU, 0 local

* Pw and K counts are the usual parameters of Available Reserves of P and K in the Netherlands. For K the optimum range depends on clay and organic matter contents and varies from farm to farm.

** If actual PAR or KAR is in optimum range, PAB or KAB = 1.

Outline 2: Brief definitions of the 15 parameters and 4 methods used to quantify and achieve the top 10 of specific objectives for the prototype EAFS in NL 2 (as listed in Table 2).

A. Parameters

1.1. Environment Exposure to Pesticides-soil (EEP-soil) = active ingredients (kg ha^{-1}) * 50 % degradation time (days).

1.2. P Available Reserves (PAR) = Pw count in NL = mg l^{-1} P_2O_5 in the cultivated soil layer, 1:60 extracted with water.
P Annual Balance (PAB) = P input / P output.

1.3. K Available Reserves (KAR) = K-count in NL = mg K_2O in 100 gram air-dry soil from the cultivated layer, 1:10 extracted with 0.1 n HCl. K Annual Balance (KAB) = K input / K output.

1.4. N Available Reserves (NAR) = kg ha^{-1} M_{min} in the soil layer 0 - 100 cm at the start of the period of precipitation surplus e.g. N leaching.

2.1. Ecological Infrastructure Index (EII) = % of farm area managed as a network of linear and non-linear habitats and corridors for wild flora and fauna, including buffer strips.

2.2 Plant (target) Species Diversity (PSD) = number of species with conspicuous flowers by colour and/or shape, attractive for fauna and recreationists.

2.3. Plant (target) Species Distribution (PSDN) = mean number of target species/100 m of Ecological Infrastructure.

3.1. Quality Production Index (QPI) crop $product^{-1}$ = Quality Index (QI) * Production Index (PI) crop $product^{-1}$ = (achieved price kg^{-1}/top quality kg^{-1}) * (on market kg ha^{-1}/on field kg ha^{-1}) crop $product^{-1}$.

4.1. Environment Exposure to Pesticides-water (EEP-water) = EEP-soil * mobility. (Mobility = Kom-1 and Kom = partition coefficient of the pesticide to dry matter and water fractions of the soil/organic matter fraction of the soil).

4.2. N Drainage Water (NDW) = mg l^{-1} Nmin in drainage water, averaged on the period of precipitation surplus.

5.1. Soil Cover Index (SCI) = extend of soil cover by crops or crop residues during a crucial period (O<SCI<I).

5.2. Flower Density Index (FDI) = mean number of flowers $m^{-1}$of ecological infrastructure.

5.3. Bird Species Diversity (BSD) = number of migratory and sedentary bird species.

6.1. Net Surplus (NS) = total returns minus all costs, including an equal payment of all labour hours.

6.2 Hours Hand Weeding (HHW) = mean number of hours ha^{-1} in hand weeding.

10.1. Environment Exposure to Pesticides-air (EEP-air) = active ingredients (kg ha^{-1}) * vapour pressure (Pa at 20 - 25 ºC).

B. Methods

1.1. - 1.4. Multifunctional Crop Rotation (MCR) = a farming method with such alternation of crops (in time and space) that their vitality and quality production can be put safe with a minimum of remaining measures or inputs.

1.2. - 1.4. Ecological Nutrient Management (ENM) = a farming method with such tuning of input to output of nutrients, that soil reserves fit in ranges, which are agronomically desired and ecologically acceptable.

2. Ecological Infrastructure Management (EIM) = such layout and management of a network of landscape elements, that it is accessible and livable to wild flora and fauna and attractive to urban and rural recreationists.

6.1. Farm Structure Optimisation (FSO) = a mostly indispensable method to render an agro-ecologically optimal prototype also economically optimal, by establishing the amounts of land, labour and capital goods, which are minimally needed to achieve the desired Net Surplus.

In this way we have designed a theoretical prototype and the methods in this context as step 3 in pilot project NL 2 (Figure 3). This theoretical prototype shows the major and minor methods needed to achieve the desired results for each objective e.g. for each parameter. Vice versa, it also shows which parameters are supported by a method and thus indicates the overall impact of a method. Consequently, the theoretical prototype defines the context and the order of designing the methods.

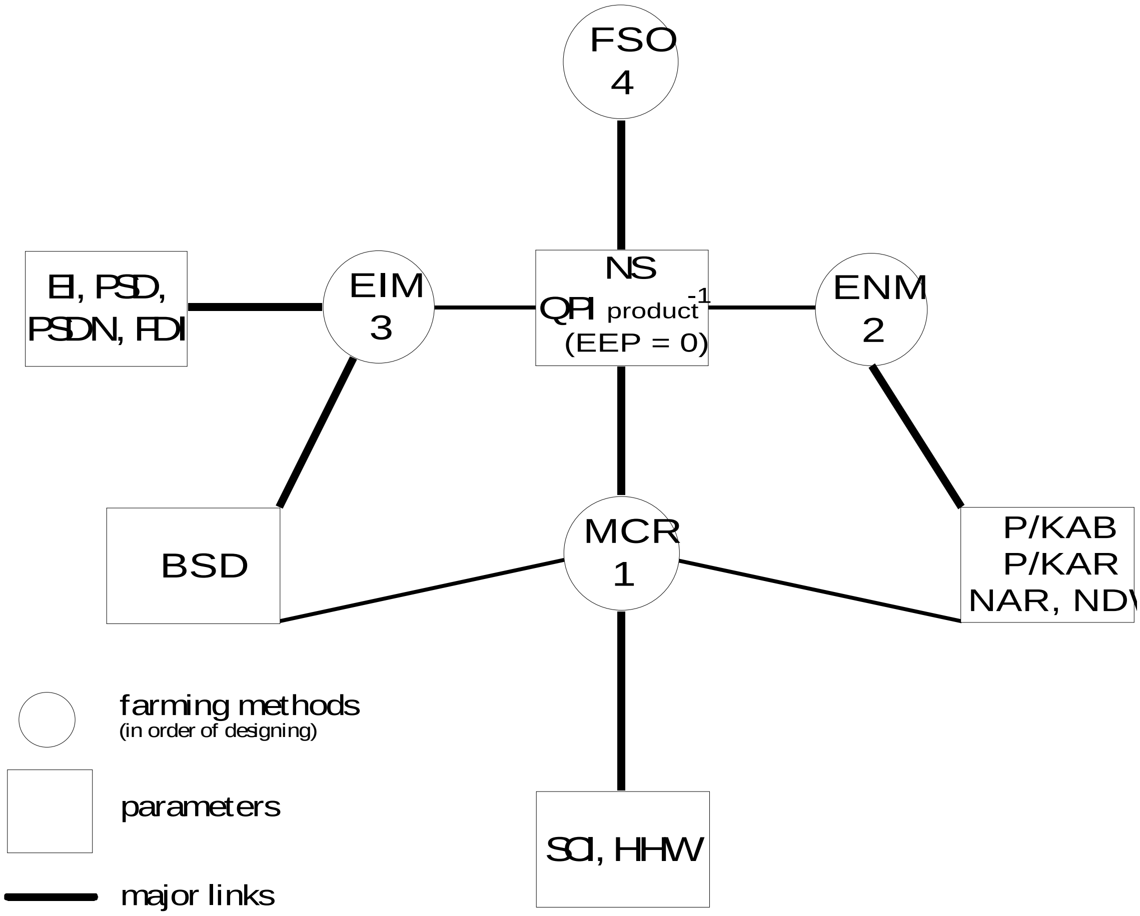


Figure 2: Theoretical prototype for EAFS in Flevoland (NL 2) as an example of Part 3 of a prototype's identity card in the I/EAFS-Network.

In Flevoland, the major 10 objectives as quantified in 16 parameters are achieved by 4 multi-objective methods and made ready for use in the order that follows.

1. Multifunctional Crop Rotation (MCR) is the major method to achieve desired results in Quality Production Indices (QPI product^{-1}) without using pesticides (EEP=0), Net Surplus (NS), Hours Hand Weeding (HHW) and Soil Cover Index (SCI). It is also a method supporting P and K Annual Balance (P/KAB), P and K Available Reserves (P/KAR), N Available Reserves (NAR), N Drainage Water (NDW) and Bird Species Diversity (BSD).

2. Ecological Nutrient Management (ENM) is the major method to achieve desired results in P and K Annual Balances, P and K Available Reserves, N Available Reserves and

N Drainage Water. It is also a method supporting Quality Production Indices (without using pesticides) and Net Surplus.

3. Ecological Infra-structure Management (EIM) is the major method to achieve desired results in Ecological Infrastructure (EI), Bird Species Diversity, Plant Species Diversity (PSD) and local parameters of flora: Plant Species Distribution (PSDN) and Flower Density Index (FDI). It is also a method supporting Quality Production Indices and Net Surplus.

4. Farm Structure Optimisation is the finalising method to achieve the desired result in Net Surplus, if the current amounts of land, labour or capital goods of a pilot farm fail to do so with the ergonomically and ecologically optimised prototype EAFS.

In all theoretical prototypes of the I/EAFS-Network, Multifunctional Crop Rotation (MCR) plays a central role as a major method to achieve desired results in the multi-objective parameters of soil fertility and environment (SCI, OMAB, EEP, P/KAR etc), as well as in the Quality Production Indices (QPIs product^{-1}) and the major parameters of economic and energy efficiency (NS, HHW and EE). Consequently, MCR should be designed primarily to provide for a well-balanced 'team' of crops requiring a minimum of inputs that are polluting and/or based on fossil-energy (nutrients, pesticides, machinery, fuel) to maintain soil fertility and crop vitality as a basis for quality production (Outline 3).

Outline 3 : Procedure of designing a Multifunctional Crop Rotation (MCR) for I/EAFS.

1. *Identifying and characterising potential crops for your region or farm (format A):*
   - making a list of crops (set-aside included) in diminishing order of marketability and profitability (≥ 6 crops for IAFS and ≥ 8 crops for EAFS);
   - characterising the crops in their potential role in the MCR in biological, physical and chemical terms, as listed in format 1 or adapted to your region.
2. *Drawing up an MCR based on (1) and simultaneously fulfilling a multi-functional set of demands (format B):*
   - filling the first rotation block with crop no. 1.;
   - filling subsequent blocks while preserving biological soil fertility by limiting the share per crop species to £ 0.25 in IAFS and £ 0.167 in EAFS and the share per crop group to £ 0.50 in IAFS and £ 0.33 in EAFS;
   - filling subsequent blocks, while preserving physical soil fertility by consistently scheduling a crop with a high rating of soil cover (erosion-susceptible soils) or effect on soil structure (compaction-susceptible soils) after a crop with a low rating, overall the MCR resulting in a soil cover ≥ -1 in IAFS and = 0 in EAFS and a soil structure ≥ -1 in IAFS ans ≥ 0 in EAFS;
   - filling subsequent blocks while conserving chemical soil fertility by consistently scheduling a crop with a high rating of N transfer before a crop with a high rating
   - of N need and a crop with a low N transfer before a crop with a low N need, overall the MCR resulting in an N need £ 2 in IAFS and £ 1 in EAFS;
   - filling single blocks by 2 or 3 crops with corresponding characteristics, if needed for reasons of limited labour capacity or market demand;
   - ensuring crop successions are feasible in terms of harvest time, crop residues and volunteers from preceding crops.

Table 3: Multifunctional Crop Rotation for EAFS in Flevoland (NL 2) as an example of Part 4 of a prototype's identity card in the I/EAFS-Network

A. Selection of crops by pilot farm 6 (crops in order of profitability)

crop	biological		physical (ratings)				chemical (N ratings	
no.	species	group[1]	cover[2]	rooting[3]	compaction[4]	structure[3+4]	offtake[5]	transfer[6]
1	carrot	umbel.	-2	1	-4	-3	3	1
2	potato	solan.	-2	1	-2	-1	3	2
3	onion	lil.	-4	1	-2	-1	2	1
4	celeriac	umbel.	-2	1	-4	-3	2	1
5	sugar beet	chen.	-2	1	-4	-3	2	1
6	pea, bean	leg.	-2	2	-1	1	0	2
7	wheat	cer.	-2	3	-1	2	3	1
8	oats	oats	-2	3	-1	2	2	1
9	barley	cer.	-2	3	-1	2	2	2
10	grassclover	leg.	0	3	-1	2	2	2
mean of crop selection			-2.0	1.9	-2.1	-0.2	2.1	1.4

B. Multifunctional Crop Rotation of pilot farm 6

block	crop	biological		physical (ratings)		chemical (N ratings)		
no.	no.	species	group[1]	cover[2]	structure[3+4]	Off take[5]	transfer[6]	need[7]
I	1/5	carrot/sugar beet	umbel./chen.	-2/-2	-3/-3	3/3	1/1	2 -1
II	6	pea, bean	leg.	-2	1	0	2	
III	2	potato	solan.	-2	-1	3	2	1
IV	10	grassclover	grass/leg.	0	2	2	2	0
V	3/4	onion/celeria	lil./umbel.	-4/-2	-1/-3	2/2	1/1	0
VI	7	wheat	cer.	-2	2	3	1	2
VII								
VIII								
mean of crop rotation		share species^{-1} ≤ 0.167	share group^{-1} ≤ 0.25	-1.8	-0.2	2.2	1.5	0.7

1) Genetically and phytopathologically related groups, such as cereals, legumes, crucifers and chenopodes, composites, umbellifers, liliaceae. All subsequent blocks of perennial crops are counted as 1 block.

2) No cover in autumn and winter = -4, no cover in autumn or winter = -2, all others = 0 (green manure crops included).

3) Cereals, grasses and lucerne = 3, root, bulb and tuber crops = 1, all others = 2 (green manure crops included).

4) Compaction by mowing in summer = -1 and autumn = -2, lifting in summer = -2 and in autumn = -4.

5) N offtake by harvested crop product from soil reserves: legumes = 0. All other crops: 25-50 kg ha^{-1} = 1, 50-100 kg ha^{-1} = 2, 100-150 kg ha^{-1} = 3, 150-200 kg ha^{-1} = 4, etc..

6) N transfer is the expected net contribution of N to subsequent crop, based on N residues in the soil after harvest, N mineralisation from crop residues and N losses by leaching and denitrification. In this rating, the effect of green manure crops should be included. N transfer < 50 kg ha^{-1} = 1, 50-100 kg ha^{-1} = 2, 100-150 kg ha^{-1} = 3.

7) N need (block x) = N offtake (block x) minus N transfer (block x-1). N need is net N input to be provided by manure or N fertiliser.

Being by far the most major method, and also the first to be designed, MCR is an appropriate Part 4 of your identity card, after your theoretical prototype as Part 3. Table 3 presents the MCR of one of the 10 pilot farms in NL 2 as an example of Part 4 of the identity card of an EAFS prototype. Format A first presents the selection of the most profitable crops eligible for the MCR of the pilot farm in question, with their major characteristics concerning biological, physical and chemical soil fertility. Subsequently, format B presents the MCR which optimally complies with the multifunctional set of demands.

Layout of prototype to test and improve (step 4)

Step (4) implies testing and improving the prototype until the objectives as quantified in the set of parameters have been achieved. Because it is the most laborious and expensive step, requiring at least a full rotation of the prototype on each field (4-6 years for IAFS-EAFS), it is crucial that you have followed all preceding steps with the greatest accuracy. Therefore, it is useful to take a critical retrospective view before you proceed to step (4):

- does your hierarchy of objectives really cover the shortcomings of conventional arable farming (IAFS) or organic farming (EAFS) in your region (not too low ratings for 'new' objectives such as nature and too high ratings for 'old' objectives such as basic income/profit to ensure that you are really innovating and not just slightly ahead of the main group of farmers) (step 1)?

- have you really transformed the objectives in the appropriate set of multi-objective parameters (not too few but certainly not too many parameters!) and have you quantified each objective appropriately (not more but certainly not less ambitious than needed) and have you established the appropriate set of methods needed (not too many single-objective and too few multi-objective methods) (step 2)?

- should your theoretical prototype be redesigned to link up with possible changes in the first two steps (step 3)?

Testing a prototype means laying it out on an experimental farm or on a group of pilot farms and ascertaining if the results achieved correspond with the desired results. If you have designed all the methods of your theoretical prototype, an initial layout is not very complicated in the case of an experimental farm, providing a possible supervising committee and the farm manager think it acceptable and manageable. However, much more time is generally needed to come to a first layout for pilot farms. (Outline 4).

The basic task of I/EAFS designers, to replace physic-chemical methods by biological methods and techniques, requires an appropriate concept:

I/EAFS is an agro-ecological whole consisting of a 'team' of steadily interacting and rotating crops, plus their accompanying (beneficial or harmful) flora and fauna.

Outline 4: Preparations to come to a first layout of a theoretical prototype on pilot farms.

1. *Forming a pilot group*:
   - generating interest by articles in agricultural periodicals or by public meetings;
   - inviting potential pilot farmers to attend study meetings;
   - selecting pilot farmers according to general criteria such as being full-timers on farms of sufficient size, having appropriate production activities, being located in the region, having a particular soil type etc. but also according to agro-ecological criteria such as field adjacency and field size.
2. *Making a variant of the prototype for each pilot farm, in interaction with the farmer*:
   - variant of Multifunctional Crop Rotation (in time and space);
   - variant of Integrated or Ecological Nutrient Management;
   - variant of Ecological Infrastructure Management;
   - etc.

Outline 5: Criteria for an agro-ecological layout of I/EAFS.

1. Field adjacency = 1
   All fields of a farming system should be adjacent to each other, to obtain an agro-ecological whole as a prerequisite for an agro-ecological identity.
2. Field size ³ 1 ha
   To obtain a prototype farming system with sufficient agro-ecological identity, the fields as sub-units have to be of a minimum size.
3. Field length/width £ 4
   Round or square fields contribute optimally to the agro-ecological identity of a farming-system. Therefore, a maximum is to be set to the length/width ratio of fields, to limit the loss in identity.
4. Crop rotation blocks ³ 4 (IAFS) or ³ 6 (EAFS)
   The shorter the crop rotation, the greater the biotic stress on the crops and the need for external inputs to control that stress. Therefore, crop rotation is required based on 4 (IAFS) or 6 (EAFS) rotation blocks, at least (temporal dimension of crop rotation).
5. *Adjacency of subsequent blocks = 0*
   Harmful semi-soilborne species are to be prevented from following their host crop by a crop rotation without any adjacency of subsequent blocks to ensure crops are not just moved to an adjacent field from year to year.
6. *Share of cereals £ 0.5 (IAFS) or £ 0.3 (EAFS)*
   The larger the share of cereals in rotation, the greater the biotic stress and the need for external inputs for this crop group, the largest in European arable farming. Therefore, the crop rotation should have a maximum of 0.5 (IAFS) or 0.3 (EAFS) of cereals.
7. *Ecological Infrastructure ³ 5 % of I/EAFS area*
   To bridge the gap between 2 growing seasons, airborne and semi-soilborne beneficials need an appropriate ecological infrastructure of at least 5 % of the farm area.

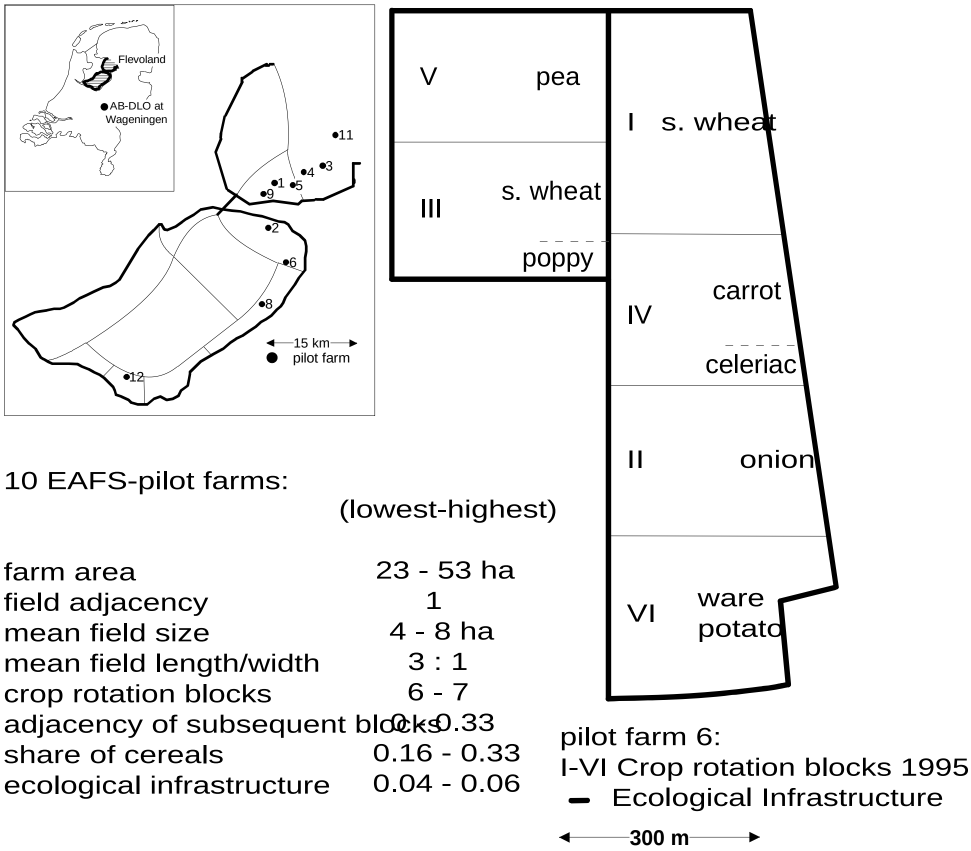
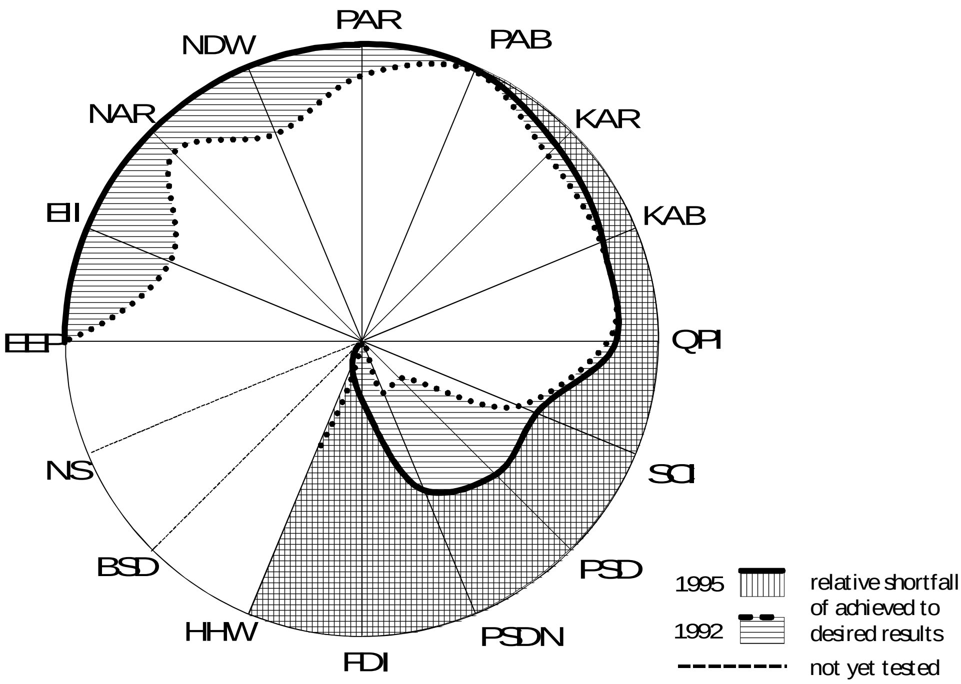


Figure 3: Layout of EAFS pilot farms in Flevoland (NL 2) as an example of Part 5 of a prototype's identity card in the I/EAFS-Network.

The designer's task can thus be specified as to design a rotation with a maximum of positive interactions and a minimum of negative interactions between the crops. These interactions strongly influence physical, chemical and biological fertility of the soil and consequently vitality and quality production of the crops. However, a Multifunctional Crop Rotation (MCR) cannot cope with semi-soilborne and airborne harmful species. Therefore, an agro-ecologically optimum layout of I/EAFS should meet additional criteria (Outline 5). In line with these criteria, we have designed an appropriate agro-ecological layout for any EAFS variant on the 10 pilot farms in NL 2 (Figure. 4).By laying out a prototype it can be tested. By testing it will appear to what extent the desired results for any parameter have been achieved. If it will appear a shortfall between achieved and desired results the prototype should be improved in the parameter in case, by adjusting the major or minor methods involved according to the theoretical prototype. The state-of-the-art in step 4 for EAFS in NL 2 clearly shows, which of the 16 parameters still have to improved before the prototype is 'all round' (Figure. 5).



Parameters		Desired results	Main causes of shortfalls 1995	Methods to be improved in: Read.	Accept.	Manag.	Effect.
EEP	= Exposure Environment to Pesticides	0 (air, water, soil)					
EII	= Ecological Infrastructure Index	> 0.05					
NAR	= N Available Reserves	< 70 kg/ha (0-100cm)					
NDW	= N Drain Water	< 11.2 NO3-N mg/l					
PAR	= P Available Reserves	20<Pw-count<30					
PAB	= P Annual Balance	1					
KAR	= K Available Reserves	14<K-count<20	ENM		x		
KAB	= K Annual Balance	0.95	ENM		x		
QPI	= Quality Production Index	> 0.95 (mean/crop)	MCR				x
SCI	= Soil Cover Index	> 0.6 (year)	MCR	x			
PSD	= Plant Species Diversity	> 50 species/EI	slow response				
PSDN	= Plant Species Distribution	> 20 species/EI-section (100 m)	slow response				
FDI	= Flower Density Index	> 10 flowers/m/month EI	slow response				
HHW	= Hours Hand Weeding	<15 hours/ha	MCR			x	
BSD	= Bird Species Diversity	?					
NS	= Net Surplus	> 0 guilders/ha					

Figure 4: State-of-the-art for EAFS in Flevoland (NL 2) 1992 - 1995, as an example of Part 6 of a prototype's identity card in the I/EAFS-Network

Improving a prototype is a matter of relating the shortfalls between achieved and desired results to the methods and improving them in a targeted way. Such shortfalls between achieved and desired results may arise from one or more of the following 4 causes: the method(s) in question is not ready for use, or not manageable by the farmer, or not acceptable to the farmer or not effective. In positive terms, step 4 (testing and improving) has been finalised if the prototype in general and the methods in particular fulfil these 4 consecutive criteria. Consequently, improving the prototype implies the following procedure (Outline 6).

Outline 6: Improving the prototypes

1. *Establishing which parameters have shortfalls between achieved and desired results*
2. *Establishing from the theoretical prototype which methods are involved*
3. *Establishing which criteria are not yet fulfilled by these methods:*
   - ready for use;
   - manageable by the farmers;
   - acceptable to the farmers;
   - effective.
4. *Establishing targeted improvements to meet the successive criteria*
5. *Laying out and retesting*

The 4 criteria will have already received much attention before the prototype is laid out for the first time, especially in the case of testing and improving a prototype on pilot farms. Commercial farmers want to be sure a prototype is feasible and all its methods are safe! Nevertheless, on-farm testing will certainly bring to light various shortcomings of individual methods, which should be improved based on the set of 4 criteria.

One major reason why a method may not appear ready for use, is unexpected occurrence of factors which interfere to such an extent that the method needs to be revised to include these factors and their effects. As a result, methods will gradually evolve from simple and subjective to comprehensive and objective.

Examples:

– management factors such as choice of crops and varieties, machines, fertilisers, pesticides;

– agro-ecological factors such as pests, diseases, weeds, and physical and chemical soil status.

Even if ready for use, a method may still not appear to be manageable to the farmers, for several reasons.

Examples:

- planning or operations too complicated;
- too laborious to fit into the labour film;
- too specific to be carried out with the usual machinery.

Even if ready for use and manageable, a method may still not appear to be acceptable to the farmers, for several reasons.

Examples:

- too high costs and/ or too few benefits, at least in the short term;
- too little confidence in utility and/or effectiveness.

Even if ready for use, manageable and acceptable, a method may still not appear to be effective to achieve the desired result in a certain parameter. This conclusion may be premature, in case of parameters with a slow response. Apart from this, the major reason why a method indeed may not be effective is that the theoretical prototype is too simple or distorted considering the method and the parameter in case.

Examples:

- the method needs support by another method;
- the method has only a minor influence, another method should be established as the major method.

Because most parameters are under control of more than one methods, and many parameters have a slow response, effectiveness is the most difficult and also the most time-consuming of all 4 criteria to establish. Testing and improving a prototype will take at least 4 years for I/EAFS and 6 years for EAFS, corresponding with one run of the prototype as a complete crop rotation on each field, before reliable responses of abiota (soil, groundwater) and biota (crops, flora and fauna) are obtained. The effectiveness of the methods and the overall prototype can only be established on the basis of these reliable responses in terms of the multi-objective parameters.

Theoretically, the number of years needed for step 4 would be the sum of the years needed to fulfil the first 3 criteria and the years, needed to fulfil the fourth criterion. In practice however, biota and abiota start developing a response from the first year the prototype is laid out, provided the prototype is well designed and will not change dramatically in subsequent years. As a result, the adaptation of abiota and biota will mostly occur simultaneously with the testing and improving by farmers and researchers, so step 4 could be done in minimally 4-6 years. However, this does not imply that all parameters will have achieved a steady state. For example, it may take decades before possible excessive reserves of soil P have been diminished or depleted organic matter reserves have been replenished to desired ranges. Nevertheless, if the shortfalls between achieved and desired results are incontrovertibly decreasing from year to year, you may speak about reliable responses proving the effectiveness of the prototype. As a result, the final step of dissemination can be envisaged with confidence.

Dissemination (step 5)

If the first 4 steps of prototyping have been made on a single experimental farm, the prototype cannot just be handed over to the extension service for wide-scale dissemination! It is because such a prototype does not cover region-specific ranges in soil, climate and management conditions, which are crucial for its manageability, acceptability and effectiveness.

Therefore, prototyping on an experimental farm always needs a follow-up with pilot farms to elaborate a range of variants of the prototype. Consequently, prototyping in interaction with pilot farms saves a lot of time and money and is always to prefer. Besides, a group of capable and motivated farmers provides for an indispensable technological and social base to an innovation project, which should include dissemination throughout the region. To this purpose we have developed a model of interactive prototyping with pilot farms (Figure. 6). Since it has appeared to work quite satisfactory in our EAFS project, we have proposed it as a standard to the teams in the I/EAFS-Network. In case of interactive prototyping with 10 - 15 pilot farms, step 4 can be finalised with 10 - 15 variants of the prototype covering the regional ranges of soil, climate and management. This provides for an excellent base for wider dissemination throughout the region.

The initial group of pilot farms can act as demonstration farms and the farmers can be involved in training and guiding farmers willing to convert. To disseminate the prototype in wider circles regional extension services should be trained to participate and gradually take over the innovation project. The interaction model (Figure. 6) can be maintained to convert groups of farms in a programme of at least 4 years.

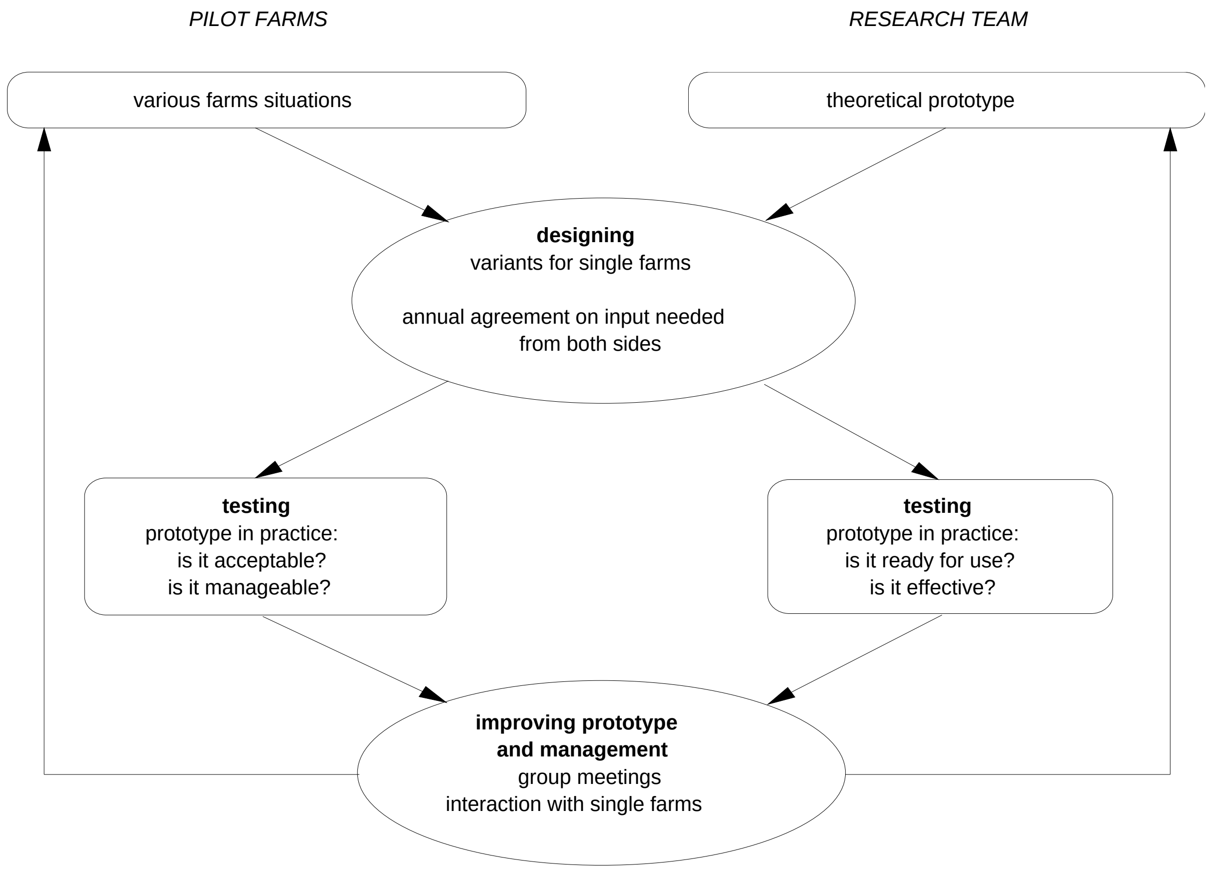


Figure 5: Interactive prototyping: designing, testing and improving a prototype by interaction of pilot farms and research team

Discussion

The methodical way of prototyping I/EAFS presented here has its roots in two global organisations. The concept of IAFS is based on the work of the crop protectionists, assembled in the International Organisation for Biological and Integrated Control (IOBC). Initially , most working groups of IOBC aimed at the control of single pest species. However, this brought by various problems, such as insufficient cost effectiveness and the arise of new pests. Therefore, they developed a wider scope and aimed at integrated protection of crops.

During the last decade, the scope has further been widened to IAFS, comprising the entire crop rotation and also considering soil cultivation and fertilisation (Anonymous, 1977, Vereijken *et al*. 1986, El Titi *et al*. 1993). The concept of EAFS has been developed by the teams in the I/EAFS-network, searching for a more consistent and sustainable elaboration of IAFS. They have been inspired by the concept of organic farming, as defined by the standards and guidelines of the International Federation of Organic Agriculture Movements (IFOAM) (Geier, 1991). The great advantage of the organic concept is its offering a market model of shared responsibility by producers and consumers for a sustainable and multifunctional management of the rural areas as agro-ecosystems. It is expressed by the principle of premium prices for the added ecological value of the products under label. This provides for the needed economic base for the consistent and sustainable elaboration of IAFS, to be called EAFS. However, EAFS should go further than is demanded by the IFOAM guidelines for organic farming in sustainable and multifunctional management of the environment, nature/landscape and health/well-being of people and farm animals.

The methodical way of prototyping I/EAFS presented here starts at the stage where most farming systems research stops, and that is the stage of analysis and diagnosis (Gibbon, 1994). From this point of view, the prototyping teams from the I/EAFS-Network may be considered as complementary to the teams from the AFSRE-Network. Vice versa, the I/EAFS teams, strong in agronomy and ecology may improve their start by building on a more comprehensive and profound rural and farming systems analysis from the AFSRE teams, strong in sociology and economy. Therefore, teams from both networks with corresponding target regions should seriously consider the mutual benefits of collaboration. The methodical way of prototyping I/EAFS presented here is still provisionally elaborated considering the interaction with pilot farmers in general and the last step (5) of dissemination in particular. In this respect, the I/EAFS teams could also benefit from the expertise developed by various AFSRE teams, such as those led by Röhling (1994) and Sevilla Guzman (1994).

With this enlargement and reinforcement of their capacity, the teams of the I/EAFS-Network have excellent chances to succeed where up till now most farming systems researchers failed (Gibbon, 1994). It is to come further than the step of diagnosis and analysis, and to make also the subsequent steps of design, layout for testing and improving, and eventually dissemination. The entire methodical way of prototyping I/EAFS will be available in a manual at the end of the current EU concerted action (Vereijken, in press).

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