Need for system approach to increase nutrient use efficiency in horticulture

EIP Focus group Fertilization in Horticulture

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Introduction

Higher nutrient efficiency means that a larger share of the fertilizer input is utilized by the crop and is ending in the output, products harvested from the field. There is a large need to increase the nutrient efficiency of horticultural crops. Firstly, to reduce emissions of ammonia and nitrous oxides related to fertilizer use. Secondly to improve ground water and surface water quality as required by the EU Nitrates Directive (91/676/EEC) and the EU Water Framework Directive (2000/60/EC). An increase in nutrient use efficiency is needed because inputs for fertilizers are becoming scarce: e.g. phosphate rock but also energy to produce nitrogen fertilizers (IFAdata, 2014). Finally an increase in fertilizer efficiency is also important to reduce production costs and increase profits for farmers.

Various measures are available to improve nutrient efficiency. However, simple solutions are often lacking as different aspects have to be taken into account when starting to select the appropriate measure(s): the objectives for which nutrient use efficiency has to be increased, the effect of the different measures under local biophysical conditions, the feasibility and the costs and benefits for farmers. Very often, trade-offs between objectives need to be considered in selecting the measures. Besides, measures can have unwanted direct or indirect side effects outside the scope of the objectives. A direct side effect is pollution swapping, for instance the reduction of NH_3 emissions by injection of animal manures may increase N_2O losses and leaching. An example of an indirect side effect is the application of drip-irrigation, which makes mechanical weed control more difficult, eventually increasing the use and emission of herbicides. Finally, it is important to note that the main objectives of farmers are producing good quality crops and making a profit and not improving nutrient efficiency. The costs of fertilizers are yet not a major obstacle and the fulfilment of EU requirements is mainly administrative and not leading to change of behaviour. Therefore, farmers are not often motivated to reduce the use of fertilizers.

A system approach is thus needed to make a coherent integrated solution that reaches the objectives of both farmers and society as best as possible. This system approach should focus on the farm level as the farmer is responsible to select the measures that will be applied in the field. In this paper, we describe how the prototyping approach can be used to improve effectively nutrient use efficiency. The approach is extensive. Therefore, we discuss various examples that uses parts of the approach. To conclude we provide some recommendations on how system approaches can be used more extensively to improve overall sustainability of horticulture production.

Development of farming systems (prototyping)

For the development of farming systems for vegetable crops, a standardised methodology called "prototyping" has been developed. The methodology is a combined research and development effort beginning with a profile of agronomic, environmental and economic demands (objectives) for a more sustainable, future-oriented farming. This exercise ends with tested, ready-to-use prototypes, designed for widespread use. The prototyping methodology was examined for arable farming in a four-year European Union Concerted Action (Vereijken, 1999) and further developed for vegetable farming during the EU-VEGINECO-project (de Haan and Garcia Diaz, 2002; de Haan, 2002).

The methodology consists of four phases: 1) analysis and diagnosis, 2) design, 3) testing and improving and 4) dissemination (Figure 1). The first phase starts with a regionally based analysis of the prevailing agricultural systems resulting in a diagnosis of the situation in terms of sectorial statistics, farm structure, agro-ecological state-of-the-art, ecological–environmental impact, the socio-economic situation and trends in structural changes and political conditions. In this phase, challenges and opportunities need to be identified.

The design phase is based on objectives defined for sustainable farming systems (Figure 1, phase 2a). These objectives are translated into five major themes: "quality production", "clean environment", "attractive landscape and diversified nature", "sustainable management of resources", and "farm continuity" (in this theme is next to farm economics also attention to labour and management aspects).

For each theme, a limited number of relevant parameters are defined on farm-level to characterize the systems performance. Each parameter is given a target value (Figure 1, phase 2b). The targets are future oriented and are derived from legislation, scientific evidence or expert knowledge. The themes together with the parameters and target values represent the objectives for the farming systems to be developed.

The next step is to design a suitable set of farming methods (Figure 1, phase 2c). Methods are defined here as coherent strategies on the major aspects of farming. Methods are for example "multifunctional crop rotation", "integrated nutrient management" and "integrated crop protection". In most cases, these methods need further development if they have to reach the objectives set.

The final step in the design phase is the development of a "theoretical prototype" combining all the selected methods (Figure 1, phase 2d). When completed, the prototype is checked, by expert judgement, comparing whether it is able to meet the targets set for the different parameters The last part of this theoretical exercise shall provide detailed cropping programmes, allowing for adjustments that might be necessary for specific crops, weather and soil conditions.

The testing and improving phases are performed to verify the farming system in practice for at least a couple of years. Every year the actual value of the parameters has to be determined and compared to the target values. Shortfalls to the target values have to be analysed. Agronomic information and observations during the growing season are indispensable for this evaluation. The method(s) causing the shortfalls have to be identified and improved.

When, after testing and improving the system, the results are fulfilling (almost) all objectives, the results can be disseminated to all stakeholders involved in the production process (farmers, advisors, etc.) (Figure 1, phase 4). However, it is not the exact prototype to be disseminated, but the objectives with parameters and target values, the underlying integral approaches to farming, the farm methods and the toolbox with a practical guide to adjust the strategies to the local conditions.

Strong points of the prototyping method are the clear identification of shortfalls of the developed systems compared to the objectives set and identification of knowledge gaps. Weak points are the amount of data need and the time consuming process of testing and improving to reach a prototype that fits the objectives best.

Examples

1. *Redesign of farming systems because of insufficient solutions within current farming system. Example of the Netherlands*

In 2009 was concluded that in the Southeast of the Netherlands it is impossible to reach the EU-Nitrates Directive and maintain yield and income of arable and vegetable farmers within the current farming systems (de Haan et al., 2009; Meijer et al., 2011). A redesign of systems has leaded to two new research pathways (de Haan et al., 2010). The first is an agro-ecological pathway focused on improved soil management. This pathway shows that increased organic matter input can lead to increased yields and low nitrate leaching (de Haan & Verstegen, 2014). The second is a technical pathway, focused on soilless cropping. This pathway shows that soilless cropping of open field vegetables is possible and has perspectives for profitable production and large reduction in emissions (de Haan & van Dijk, 2013; Breukers et al., 2014; de Haan et al., 2014). This example shows that a shift of system perspective gives new opportunities, which are impossible within the current production system. However, still a lot of research and dissemination is necessary for a broad application of these new systems and strategies in practice.

2. *Two opposite approach of farming system are being carried out to solve fertilizer efficiency for leafy crops in open field conditions in Almeria*

The same shift in development of new farming systems is visible in Almeria (south-eastern Spain). Next to the conventional horticulture organic horticulture and hydroponic cultivation is in development (Rohner-Thielen, 2010). Research is done on both alternative farming systems. The hydroponic systems are developed in Pulpi town (figure 2, left side) are based on exhaustive knowledge of mineral elements supply. The organic farming research is executed in Nijar region (figure 2, right side) is based on organic matter management and its relationship with physical, chemical and biological soil conditions.

There are large differences in nutrient budgeting between the systems in terms of fertilizers (inputs), yield (outputs) and losses to the environment. There are some loss factors that do not exist in one of the extreme types of farming (organic and hydroponic), e.g. crop waste which is usually applied to the soil in organic horticulture or leaching which is limited in hydroponic because of the recycling of the nutrient solution. The efficiency of fertilizers in both organic and hydroponic system is higher compared to conventional farming, mainly because in organic farming no synthetic mineral fertilizer is used and nutrients are recycled continuously in closed hydroponics systems.

There is a large difference in control on nutrient uptake as well. In organic farming organic fertilizers are used and farmers trust on the release of nutrients for plant uptake through complex ecological interactions and biological processes (microorganism) during the growing season. In hydroponic systems there is more control possible on the composition of the nutrient solution. In conventional systems control is highly desirable, but difficult to realise with all complex soil processes. However various tools are in development to develop useful fertilizer programs.

3. *Introduction of conservation agriculture in Hungary*

The conservation agriculture medium-term programme started from 2014 with the participation of research units, seed and fertilizer companies and over 30 farms. The programme offers sustainable and intensive crop production solutions to increase the profitability of farmers. Sustainability and profitability requires crop cultivation techniques and economic management systems, to which the programme provides a solution with regard to all aspects, customized to the specific farm, by utilizing the knowledge base of high tech companies. Preconditions in using the conservation agriculture practices (mostly natural and economic) are:

1. extreme weather conditions (drought or extremely wet year),
2. deteriorated soil conditions (soil structure and organic matter content),
3. increased production costs (cost of labour, fuel, input materials, etc.),
4. higher financing requirement for the more efficient and intensive cultivation techniques,
5. volatile commodity prices,
6. increased administrative tasks,
7. new criteria to participate in the single area subsidy payment scheme,
8. stricter environmental protection regulations.

The main elements of the integrated system are:

1. conservation tillage practices which are reducing climatic damage and improve soil physical structure, biological condition and water holding capacity, increase the nutrient supply capacity, better adapt the crop to the extreme weather conditions and reduce the cultivation cost,
2. optimizing the nutrient supply which offers soil and crop specific nutrients, the doses are calculated according to the crop needs with different intensity levels,

3. use of specific varieties and hybrids adapted to field conditions, emphasizing early vigour and resistance to major diseases, adapted to specific nutrient management levels and to the changed tillage practices,
4. crop protection solutions adapted to the changed soil management practices (related to crop residues, weed control and moisture conditions) and nutrient management solutions which take into account the impacts of the previous crop, forecast-based applications, targeted use of pesticides (precision crop protection),
5. farm management software as and administrative basis for the efficient and transparent operation of the farm and supports the decision-making process based on local characteristics.

4. Integrated production in Emilia-Romagna region in Italy

In the last twenty years a system approach has been developed for several crops, including horticultural ones (fruits and vegetables), in the Emilia-Romagna region, in North Italy. The approach was established by the end of the '90s using the financial support of the Rural Development Plan, thus as a strategic tool in an effort of qualifying and increasing the quality of the agricultural production but respecting the environment. The system was developed by carrying on a detailed mapping of the soil chemical-physical properties of all land area of the Region, linking these data with the land use, soil capacity and water resources and producing zone maps (based on soil and weather characteristics, to identify suitable areas for different crops/cultivars). An extensive program of research about the crops nutrients needs, the test of varieties adapted to the different environments, and pest/diseases management based on Integrated Pest Management (IPM) was launched. The program was deeply linked with the activity of advisors and other professionals (e.g. the phytosanitary service of the Region) in order to promote the adoption of the different practices/measures that were aimed at reducing the overall environmental impact of the agricultural sector. The results of this strategic program can be assessed by considering that about 65% of the horticultural production of the region (more than 150.000 ha) is obtained by applying this integrated approach, which has lead to the establishment of a quality system (QC – Certified Quality) by the Regional administration.

The farmers and advisors are supported in their decisions about the soil management (e.g. fertilization, irrigation) by online applications that allow to calculate the amount of nutrients to be applied (e.g. https://agri.regione.emilia-romagna.it/Suoli/; http://www.irriframe.it/; Mannini et al 2013) on the basis of the crop history of the field, of the field physical-chemical characteristics, the precipitation history and weather forecasts, the expected yield of the crop, and the major pest/diseases of the specific crop (using for several of them also forecast models). The use of agronomical practices such as rotation, organic fertilization (using also composts), fertigation, limited tillage, use of catch crops and alternative fertilization strategies that are known to limit emissions and leaching of nutrients (e.g. mycorrhizal inocula, foliar fertilization with organic fertilizers) are all recommended to be used within the different farming systems. The continuous search for new practices/products that can improve the production systems is provided to the farmers with new decision supporting tools which are also allowing for their economical evaluation.

Discussion

The inventories of measures in NUTRIHORT (Amery et al., 2013) and Quemada et al. (2013) and Schoumans et al. (2014) provide a wide array of information about possible measures to increase nutrient use efficiency. Together with nutrient management measures, measures connected to other farming practices are summarized as well, e.g. measures on crop rotation, soil cultivation and water management. However, an inventory of measures aimed at one objective lacks by definition a systems approach. A system approach is by nature multi-objective and comprises multiple measures. Therefore, after the inventory, an evaluation of the feasibility of the different measures to a system needs to be made. To do this, elements from the prototyping approach may be used. Important aspects are the assessment of the current situation and the quantification of objectives of the farming systems.

The assessment of the current situation at farm and regional level should be based on: the main constraints, challenges and opportunities for the system, including biophysical (e.g. soil type and climate), socio-economic (e.g. farm structure and costs) and institutional (e.g. legislation and organization of sales) aspects. From an agronomic point of view, an important aspect is related to the main growth limiting factors, which may have a larger effect on nutrient use efficiency than the application of a nutrient management measure (i.e. soil-borne diseases).

For a thorough evaluation of the effects of the measures on the farming system as a whole, it is needed to quantify the objectives of the farming system. This should include parameters and target values for all major themes within the farming system, not only those connected to the objective of nutrient efficiency to quantify side effects as well. If effects cannot be measured or estimated, research is needed to provide such data.

In the last few years, the attention to integrated soil management has increased strongly. It is expected that an integrated approach of soil chemical, physical and biological aspects will lead to a better performance of the farming system. In the farming systems development approach, integral soil management has still limited attention and methods connected to this subject have to be developed further, paying more attention to e.g. organic matter management and soil tillage.

For practical reasons of e.g. time and money, the choice can be made to not apply the whole prototyping method. This is visible in the examples presented. When using parts of the method large steps can be made efficiently. However, the risk is presentment that important aspects are overlooked. Most important is to think and act from a systems perspective.

Recommendations

From the prototyping methodology and the examples described above, the following recommendations can be made to increase nutrient use efficiency from a systems perspective:

- Evaluate constraints, challenges and opportunities on biophysical, socio-economic and institutional aspects in the region of interest to assess the applicability of different measures.
- Estimate the most important growth limiting factors in the systems other than those related to fertilization and when present improve these together with improving the fertilizer efficiency.
- Integrate measures in a farming system from a system perspective to assess all wanted and unwanted effects
- Define a parameter set with target values on all themes connected to the farming system and monitor the indicators.
- Develop integrated soil management within the context of farming systems development.

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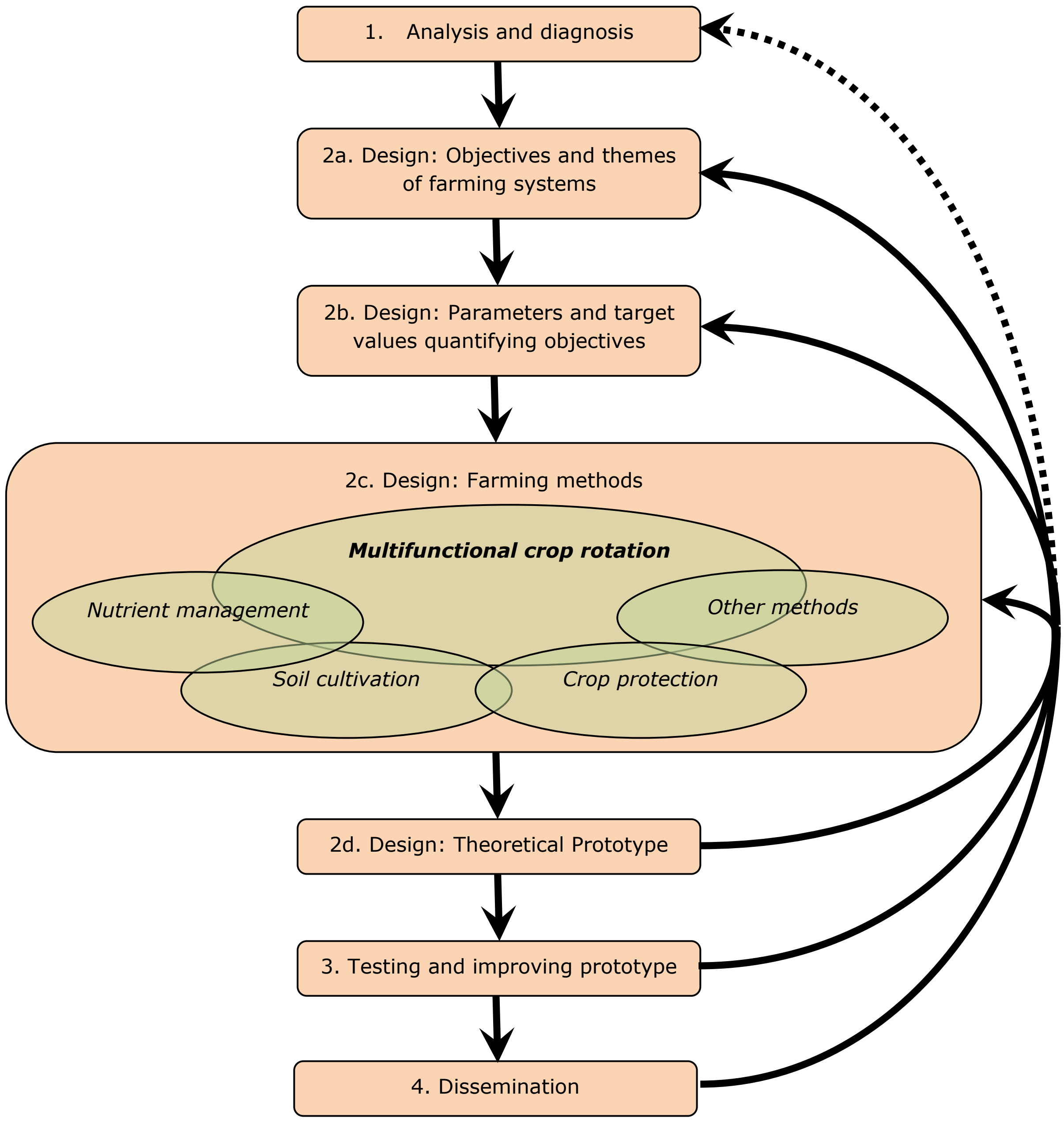

Figure 1. Methodology of farming systems development in four phases. Phase 2 is divided in four sub-phases. After de Haan & Garcia Diaz, 2002.

Figure 2. Left side: Closed hydroponic system (NGS – New Growing System) in Pulpi (Almeria). Right side: organic horticulture in Níjar (Almeria).