Potato Research 39 (1996) 371 – 378

Environmentally safe and consumer-friendly potato production in The Netherlands. 1. Development of ecologically sound production systems

J.H.J. SPIERTZ, A.J. HAVERKORT and P.H. VEREIJKEN

Research Institute for Agrobiology and Soil Fertility (AB-DLO), P.O. Box 14, 6700 AA Wageningen, The Netherlands

Additional keywords: environment, quality, cropping systems, prototyping

Summary

Methodology is presented for the development of integrated and ecologically based arable farming systems to achieve goals of ecological sustainability and food safety in potato production. The quest for change in potato growing procedures and the need for a quantitative system approach are discussed. Furthermore, the structure of a comprehensive experimental and modelling approach to develop ecologically sound production systems has been outlined. Examples of participatory research projects with farmers are highlighted.

Introduction

Agricultural production in the Netherlands has intensified over the past decades. The use of fertilisers, herbicides and pesticides strongly increased in order to attain maximum crop yields and reduce labour costs. Intensification has also led to short rotations of high yielding crops in arable farming, with a strong reduction in the acreage of cereals and increase in crops such as potatoes, sugar beet, field grown vegetables and flower bulbs. The intensification in growing high-value crops occurred predominantly on relatively small arable farms (<40 ha) in regions with light textured soils. The contribution of the potato in these cropping systems varies between one-fourth and one-third of the acreage. A special type of intensification was developed for the cultivation of starch potatoes on sandy and reclaimed peat soils: on specialised farms, using soil fumigation, up to 50% of the acreage is currently cultivated with potatoes (Van Loon, 1992).

Intensification in arable farming has contributed to maintaining farm incomes concurrently with increasing costs of labour, land and equipment. On average 50% of the net income of arable farming derives from potato growing. However, soil and crop health became a growing problem over the past decades, threatening yield levels and the quality of the produce (Vos, 1992). The latter is very important to meet phytosanitary standards of seed potatoes and quality standards of ware potatoes set by consumers and the processing industry. The health of a seed potato crop is monitored during the whole production chain: from inspection of soil health and seed quality to field inspection and laboratory testing of the crop and the harvested seed potatoes. The seed potato industry, with an acreage of almost 40,000 ha, depends on export markets and as a consequence on quality standards of the European Union and of countries outside the community.

The quest for change in farming

In responding to public concern for the hazards of pesticide residues in food and in the environment during the 1960s and early 1970s, the Ministry of Agriculture set up a Committee of Experts to study the prospects of organic farming systems. The political driving force for studying alternatives to conventional farming has been the association promoting biodynamic farming and organisations involved in the protection of nature and the environment. The report of this committee and other initiatives led to a long-term experiment on a farm scale to develop and test conventional, integrated and organic farming systems. The development of farming systems, the so-called DFS-experiment, was started in 1979 on an experimental farm in the province of Flevoland, a polder district, and has continued with some minor alterations. Within Europe it has been one of the first experimental farms to develop and test new farming strategies aimed at improving food safety and quality and at protecting the environment and nature. The set up and results from the first five year cycle have been reported by Zadoks (1989). After five years organic farming without the use of any external inputs, especially fertilisers and pesticides, was found to be promising for various crops except potatoes. Resistance to *Phytophthora infestans* and nitrogen supply appeared to be the factors most limiting yields and quality. Progress was made in developing ecological farming systems that matched crop demand and supply of nutrients better within the limitations of nutrient dynamics in the sequence of a crop rotation. As a consequence nutrient losses to the environment are minimised.

Public awareness among consumer organisations and environmental movements in The Netherlands, regarding the amount and frequency of pesticide use in agriculture and horticulture, has grown over the last decades and especially in potato and flower bulb production. Research on environmental side-effects of current farming practices focused on monitoring pesticide use per farm, crop and even per cultivar. Deviation of pesticide use in The Netherlands from average use in other European countries fuelled opposition against the production practices of cultivars with a low disease resistance and therefore a high dependency on crop protection with fungicides and insecticides. Some important commercial cultivars were blamed as 'poisonous potatoes'. This led to conflict with growers and traders. Ultimately, all parties involved agreed on criteria for environmentally safe and consumer-friendly potato growing procedures.

Two main approaches to achieve goals of ecological sustainability and food safety in potato production will be discussed:

a. the development of integrated and ecological potato-based arable farming systems,

b. the implementation of a 'green label' certification scheme for potato production systems based on mutually agreed criteria.

The latter will be presented by De Vries (1996) in this volume.

Integrated potato production

Vereijken & Van Loon (1991) developed a set of measures to develop integrated low-input potato production:

1. *Healthy crop rotation.* To avoid severe pest and disease problems a maximum frequency of 1 in 4 years for potato growing is recommended in The Netherlands. Growing potatoes less frequently than in current potato production enables farmers to reduce and possibly abandon the use of nematicides and reduce the use of fungicides, subsequently reducing costs and environmental pollution. Currently it seems that the target of the Multi-Year Crop Protection Plan to reduce the use of soil fumigants by 70% will succeed; less progress has been made in reducing the use of fungicides.
2. *Resistant culti ars.* Cultivars with a broad spectrum of resistance to virus diseases, to pathotypes of the potato cyst nematodes and to *Phytophthora infestans* are needed but not yet available. Development of multi-gene transgenic plants may speed up the progress in breeding field resistance to *P. infestans*, both in the foliage and in tubers.
3. *Balanced nitrogen fertilisation.* Potatoes accumulate a high proportion of the nitrogen in leaves with only a small fraction allocated to the tubers. So, in senesced leaves there is a reservoir of nitrogen providing a considerable risk of leaching after harvest. Therefore there is much scope for site-specific and temporal fine-tuning of nitrogen fertilisation as has been shown by Neeteson (1989). New developments in organic matter dynamics yield tools to predict the mineralization and availability of nitrogen in relation to soil type and expected weather conditions.
4. *Weed control.* Chemical weed control can be reduced if the mechanisms of crop-weed interaction are better understood. Moreover in chemical weed control there is much scope for site-specific application within the framework of precision agriculture. Mechanical weed control can be successfully applied by the build up of ridges and harrowing.
5. *Mechanical haulm destruction.* New strategies are developed for mechanical rather than chemical destruction of haulm. The haulm of ware potatoes can be destroyed mechanically by chopping or by pulling. A new procedure, the so-called 'green crop-harvesting', combines haulm pulling with lifting the crop and covering it with soil. The aim is to allow for full skin set in the field during the few weeks before harvest and storage.
6. *Green and organic manuring.* There are two reasons to use organic manure; for improving soil structure and for replacing industrial fertiliser. Green manure is increasingly applied as a catch crop for nutrients after an early harvested crop.
7. *Soil culti ation.* The main purpose of soil tillage is to restore soil structure, to control weeds and to incorporate organic and green manure.
8. *Pest and disease control.* In a supervised system, chemical control of pests and diseases should be based on monitoring soil and crop parameters. This is also the base for methods used in precision agriculture. Because of the economic and environmental benefits of such systems, many initiatives aim at applying threshold values and economic criteria in the integrated control of pests and diseases in potatoes.

9. *Timing of har est.* In an integrated cropping system, early harvesting of potatoes is desirable because of beneficial effects on soil structure and the possibility of growing green manure crops.

Integrated low-input systems require special methodology to evaluate the agronomic, ecological and economic goals. On the DFS-farm at Nagele, average yields, kg active ingredient of pesticides and gross margins per ha are used as criteria to evaluate the performance of the system. Currently, research groups from the Research Institute for Agrobiology and Soil Fertility (AB-DLO) and the Department of Theoretical Production Ecology (TPE) of the Wageningen Agricultural University focus on theoretical and methodological aspects of ecological and integrated agricultural systems. This development will contribute to our understanding of the interaction of associated components and to development of approaches to quantify these systems and to understand their complexity.

Ecologically based cropping and farming systems

Vereijken & Kropff (1996) developed a combined approach for studying ecological and farming systems that consists of:

a. Analysing and prototyping cropping systems on an experimental farm,
b. Exploring options for cropping and farming systems with the aid of computer models,
c. Prototyping of cropping and farming systems on pilot farms varying in soil type and management skills.

The feed-back and interactions between the various components of this research programme are illustrated in Fig. 1. This approach in development and testing of new farming systems yields a rapid flow of information and the exchange of views between a pilot group of innovative farmers and the researchers. Data are collected at the plot, field and farm level on the experimental farm as well as on the pilot farms. This provides a data-base for evaluating and calibrating the models.

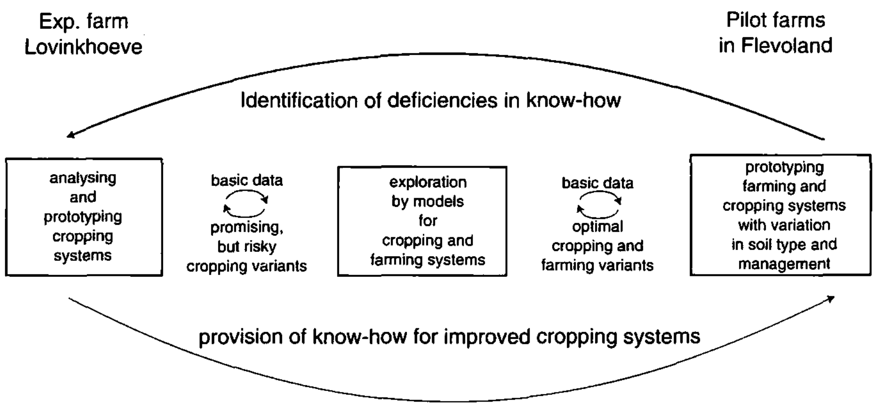

Fig. 1. Comprehensive and consistent research programme for Ecological Agriculture (after Vereijken & Kropff, 1996).

A systematic methodology to design, test, improve and disseminate prototypes of farming systems has been developed by Vereijken (1995). Components are:
- Hierarchy of objectives,
- Quantifying of parameters (multi-objective),
- Design of theoretical prototypes,
- Testing and improving prototypes,
- Dissemination by pilot groups, and by regional, national and international networks.

This methodology was tested from 1992 onwards on a group of nine pilot farms and was found to be effective for developing and testing prototypes of ecological farming systems. Multifunctional crop rotation is the most effective measure for achieving quality standards; other important measures are 'ecological nutrient management' and 'ecological infrastructure management'. Improvements are made in a close co-operation with a pilot group of farmers and an European network of research workers.

The need for a quantitative system approach

Considerable progress has been made during the last three decades in developing efficient and highly productive arable farming systems in the developed countries. An improved understanding of yield defining, limiting and reducing factors through a combined experimental and modelling approach in crop research has been gained for many temperate crops, especially cereals, sugar beets and potatoes (Haverkort & Kooman, 1997). The opportunities and prospects of using models in research and education have been presented by Penning de Vries & Rabbinge (1995). Models are tools in which knowledge of agricultural systems is integrated. They are used for the analysis of agricultural, biological and ecological systems to predict future developments and to explore the behaviour of such systems. In practice, crop growth can be limited by several factors during the growing season, whereas pests may occur any time.

For assessing yield three levels are distinguished (Fig. 2):

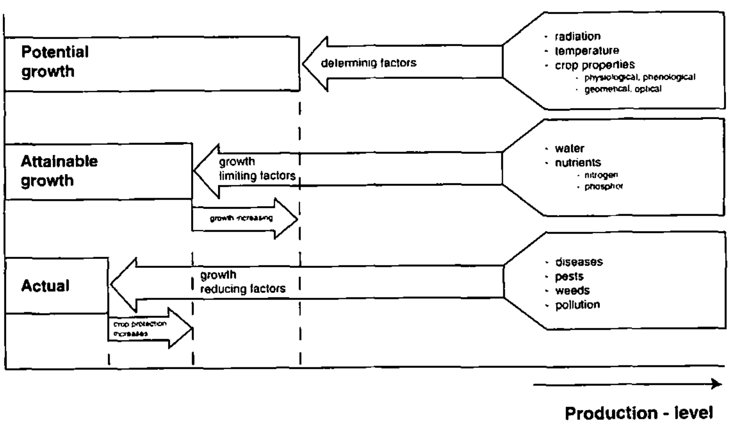

Fig. 2. Relationships among potential, attainable and actual yield and growth defining, growth limiting and growth reducing factors (Penning de Vries & Rabbinge, 1995).

a. potential yield; as determined by yield-defining factors, such as temperature, solar radiation, ambient CO_2-content and genetic traits,
b. attainable yield; roughly 20–50% below the potential yield. This reduction is caused by limiting factors such as water, nitrogen or phosphorus. Such limitations can largely be eliminated by yield-increasing measures.
c. actual yield; roughly 0–50% below the attainable yield due to reducing factors, such as weeds, pests and diseases. Yield reduction can be avoided by crop protection measures such as integrated pest management.

Most disciplinary fundamental research and applied research on improved crop productivity has taken place on the plant level (breeding), the plot level (irrigation and fertilisation) and the field level (crop protection). This knowledge contributed in reducing the yield gaps and in improving the efficiency of inputs in potato growing systems. Extending the leaf area duration and as consequence increasing the interception of the photosynthetic active radiation has resulted in a major yield increase (Kooman & Haverkort, 1995).

To study the environmental impact of potato production systems research has to be carried out on the field, farm and regional level. Then the side effects of the production system can be measured or assessed at the farm gate or at the boundaries of the environmental compartments, e.g. soil, groundwater, surface water and air. A framework to study sustainable farming systems has been developed by Vereijken (1995). He distinguishes different pathways for the definition, elaboration, evaluation and introduction of new farming systems. It is most important that the objectives and parameters of the various goals are defined clearly. These objectives differ according to the vision of policy makers on agricultural development, be they world-market oriented, integrated or ecosystem-oriented.

Quantitative evaluation of potato production systems

A method for the quantitative evaluation of arable farming systems with respect to conflicting goals, using a production systems generator and interactive multiple goal linear programming techniques, was developed by Schans (1991). A number of potato production systems were defined, each characterised by specific inputs and outputs. A series of potato production systems ranging from low-input to high-input were generated with a computer model: the Potato Cropping Systems Generator (PCSG). In this model a potato production system is formulated as a specific combination of crop management practices with a defined environment. Data from long term fertiliser and crop rotation experiments in the Flevopolders were used to formulate the basic input-output relations. Potato crop management consists of various components, e.g. cultivar, number of cycles in a crop rotation, planting distance, fertilisation schemes, pesticide use levels and soil health conditions. For each component various options were defined. The total number of defined production systems amounted to 5000. The cultivar options included Bintje (susceptible to most pests and diseases, but appreciated for high cooking and processing quality), and Santé (the highest available level of resistance to pests and diseases, excluding *Globodera pallida*, and suitable for cooking).

Tuber yield is computed in two steps:

- in the first run, yield in the absence of pests and diseases is calculated as a function of crop rotation, cultivar, planting distance, P- and K-fertilisation methods and levels,
- in the second round, this yield level is modified for damage by pests and diseases, e.g. late blight (*Phytophthora infestans*), stem canker (*Rhizoctonia solani*) and top-roll aphids (*Macrosyphum euphorbiae*).

Tuber quality is defined as a combination of size and internal quality (dry matter, reducing sugars and nitrate content). A more comprehensive review of environmental factors influencing the quality of ware potatoes is presented by Hughes (1974). However, in modelling and quantitative evaluation it is difficult to involve a wide variety of quality parameters.

The first ecological goal of potato production is minimisation of the use of pesticides. Soil fumigation with dichloropropene to control nematodes was reduced as a consequence of the actions taken to meet the goals of the Multi-Year Crop Protection Plan. Soil fumigants contaminate the soil and threaten the quality of drinking water. Control of potato late blight with Maneb and Fentinacetate accounts for more than 50% of all fungicides used in The Netherlands. These chemicals contain 'heavy' metals that accumulate in the soil and after becoming mobile contaminate plants and water. Chemical control can be substituted by other management practices, e.g. the use of resistant cultivars.

The second ecological goal is minimisation of the loss of nitrate to the environment. Increasing concentrations of nitrate in soil and surface water threaten drinking water quality and biological diversity. Potato has a high demand and low recovery of nitrogen, but nitrate losses can be reduced by appropriate management. Neeteson (1989) calculated, that the recommended fertiliser nitrogen application rates can be lowered by about 25% with an average yield reduction of only 1.5%.

Schans (1991) computed that none of the potato production systems will give optimal levels of all goals simultaneously. Nitrate loss from potato fields can be reduced by 80% of its original values with little reduction in gross margin. The EC-norm of 11.3 mg N per litre was reached at a nitrate loss of 60% of the original values, hence potato production within this limit is possible under average conditions. Above 92% restriction of nitrate loss there is no scope for further reductions except a reduction in the cultivated area.

Stepwise restriction of the use of pesticides on potatoes, other than nematicides, caused a gradual reduction in average gross margin to a maximum loss of 23%. At 100% restriction, only 7% of the acreage had to be converted into a 1:6 crop rotation. At average market prices, the restriction in pesticide use reduced gross margin by 8% or 300 Dfl. per ha. This outcome of the optimisation study is reflected in the evaluation of the results of 38 practical farmers aiming to achieve ecological standards on their farms.

The IMGLP methodology is a useful tool for developing and evaluating integrated farming systems, aiming at ecological and economic sustainability. This theoretical exploration of farming systems serves as a basis for experimental research on integrated farming systems and introduction of prototypes in practice.

Concluding remarks

The outlook for environmentally safe potato production systems is promising. The market pull from a growing demand for ware potatoes under a green label, combined with the knowledge push of strategic and applied research on ecologically based cropping systems, will accelerate the change from a yield-oriented potato production to a more balanced approach of economic and ecological sustainability. The interactive methodology of developing ecologically sound potato production system requires the active participation of research workers and farmers to solve strategic as well as applied problems. Recently, the DLO - Research Institute for Agrobiology and Soil Fertility (AB-DLO) initiated a large co-operative project on ecological farming with the participation of the C.T. de Wit Graduate School of Production Ecology, the DLO - Institute for Plant Protection (IPO-DLO) and a pilot group of farmers. The results will be made available to farmers in The Netherlands as well as in Europe through research networks sponsored by the European Community.

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