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MULTICRITERIA EVALUATION OF THE PATHOLOGICAL RESILIENCE OF IN-SOIL PROTECTED CROPPING SYSTEMS

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Abstract

Cropping systems in in-soil protected cultivation are often very intensive and are characterized by a very low number of crops in the rotation. They are therefore very fragile with respect to soil-borne pests and diseases, and depend on pesticides. These cropping systems must be redesigned to exploit pesticide free techniques to control these soil-borne pests and diseases. Because these techniques (soil solarisation, chosen intercrop or manure, biofumigation, tolerant cultivars…) are not totally effective, they must be combined to add their effects. Although these techniques are described in the R&D literature, few systems approaches are available to describe their combined effects. Part of this knowledge, though, is held by advisers and growers combining these techniques on farm. Building on the hypothesis that this local knowledge can be combined to the available scientific literature, we design a multicriteria tool to evaluate the properties of candidates cropping systems in in-soil protected cultivation. The properties that are qualified deal with the *resilience* of the cropping system with respect to the main occurring pests and diseases, and with the environmental impact of the cropping system, taking into account several pests at once. Because the knowledge of the growers and advisers is more qualitative than quantitative, we have chosen a qualitative multicriteria approach. We present here the knowledge and evaluation tree built in the specific case of in-soil protected cultivation cropping systems common in South-east France, cropping systems based on winter salad crops (from 1 to 3 successive crops) associated to a spring cash crop (melon, cucumber, eggplant…). The main pests addressed in this presentation are root-knot nematodes. We advocate then that such a tool can be used with growers and advisers to redesign cropping systems and select the promising ones that will be put into trial in R&D stations.

INTRODUCTION

Soil-based greenhouse vegetable production is often achieved in intensive cropping systems where several crops follow one another within the year. In these intensive systems, the main reasons for yield losses are soil-borne pests and diseases (Oda, 2007). Until recently, they were controlled by methyl bromide fumigation or by chemical pesticides and fungicides. However methyl bromide has been banned for environmental reasons and the increasingly strict regulations on residues in food product combined with stronger concern for public health result in a drastic decrease of the homologated molecules. Growers are therefore faced with the necessity to find new ways to control soil-borne pests and diseases. Alternative techniques like solarisation, use of nematicide oilcakes, biofumigation are promising candidates (Stapleton, 2000; Matthiessen and Kirkegaard, 2006), but if their efficacy seems good in experimental conditions, growers and local advisers often report partial efficiency. Moreover these techniques require time and therefore may conflict with the crop sequence of the grower (solarisation must be applied during the warmest period of the year and lasts about two months; biofumigation requires to grow the crop which will be used as green manure).

There is a strong need to redesign the soil-based greenhouse cropping system to incorporate alternative pest control techniques and to combine them in order to add their beneficial effects. Although little knowledge is available in the scientific literature about the effects of these combinations of techniques, advisers and growers do have some experimental knowledge about these combinations. They also know about the conflicts that may arise when combining given crops and techniques in a cropping system. Appraising the pest control qualities of a given cropping system is a difficult task not only because of the interactions between the elements of the cropping systems, but also because long-term effects must be taken into account. Being able to assess these control qualities before putting a given cropping system to test is therefore a good way to select the promising ones. The work presented here describes a multicriteria evaluation tool qualifying the pathological control abilities (the *pathological resilience*) of soil-based greenhouse vegetable cropping systems. Because part of the knowledge used to build this system is expert knowledge from growers and local advisers, a qualitative methodology has been chosen. The next section gives an overview of this methodology and describes how the techniques and their combinations contribute to the final evaluation of a cropping system. The result and discussion section describes some cropping systems and their evaluation, and discusses on how such tool can be used to improve the proposed cropping system.

METHODOLOGY

Qualitative multicriteria evaluation

The goal of the approach is to be able to assess the resistance or resilience of a given cropping system to soil-borne pests, namely root-knot nematodes. It is based on relations linking the different components of the cropping system with their results on resilience. However, while some practices will directly modify the size of the nematode population, others will only have an indirect effect. As will be described later, we have defined four types of contribution to the pathological resilience of cropping systems, contributions that are finally aggregated into one unique evaluation. This is one of the reasons for choosing a multicriteria method. The other reason is that our final goal is also to characterise the environmental and the economic properties of these cropping system.

Some effects of the techniques or of given modalities of the cropping techniques are not fully documented in the scientific literature, nor in reports from experimental stations. In such cases, surveys have been carried out with growers and advisers to assess these effects. Using qualitative representations allows tackling with the uncertainty but mainly with the impreciseness of such knowledge. The DEXi system (Bohanec, 2003) has been chosen to implement the qualitative evaluation model, because of its ability to implement such agriculture dedicated models (Bohanec *et al.*, 2004).

With this methodology, the cropping system is described by its elements (cropping techniques, crop sequence...) and their modalities (dose, date...). These elements, inputs, are aggregated according to a chosen logic into evaluations of the effects of these elements and finally in an overall evaluation of the cropping system.

Evaluation of the effects of the cropping systems on nematode control

Cropping systems are defined as the combination of the successive crops and their associated cropping techniques, including the intercrops and intercropping techniques. To understand and clarify the effects of these techniques and crops on the evolution of the populations of pathogenic nematodes, we have chosen to refer to the way they modify the cycle of these pests. Four main actions can be identified: 1) directly reducing the population by killing nematodes, 2) creating a break in the life cycle, especially by limiting the possibilities for reproduction, 3) enhancing competitions in the soil between the different organisms, so as to reduce the populations of pathogenic nematodes, 4) confining the nematodes to the already infested fields by prophylactic actions. The final step is then to combine these elementary evaluations together.

1. **Reducing populations.** Several pesticide free cropping techniques may have a nematicide action. The solarisation results in an increase of the upper soil layer temperature which can reach up to 60°C (Scopa *et al.*, 2008). It results in a decrease of the population of nematodes in these layers, although deeper layers are seldom enough heated to provide a full eradication. Therefore, the protecting effect of the solarisation depends on the frequency with which it is applied. Candido *et* al. (2008) showed that repeated yearly application of solarisation can control the nematode infestation while a single application has an effect limited in time. From these results, the contribution of solarisation to the eradication of nematodes has been weighted by its frequency, as well as by the solar radiation available during the solarisation, approximated by the period of solarisation application. Soil steaming also provides disinfection by the action of heat, thus being rather similar to solarisation in its action mechanism. Soil steaming effect is also limited to the upper layers of the soil and to a short-term time span. The contribution of soil steaming to the resilience of the cropping system has been defined as that of the solarisation. A nematicide action can also be obtained by using specific green manure (*Sorghum sudanense*, *Brassicacea juncea e.g.*), but sudangrass is less efficient than mustard (Collins *et al.* 2006; Lazzeri *et al.* 2003). The frequency of these crops within the cropping system also influences their long-term effects and yearly crops are more efficient than a lower frequency. According to advisers, sudangrass effect on nematode is limited to two to three years, so lower frequency will be considered as ineffective for the cropping system, although they provide a protection for the crops planted during the year following the green manure. Finally soil amendment with nematicide oilcakes (neem, mata-raton) may also provide a reduction of the nematode populations, which depends on the dose. The Fig. 1 summarizes how the effects of these different techniques are accounted for in appraising the nematode population reduction achieved.

2. **Introducing a break in the biological cycle.** The main goal here is to limit the reproduction potential of the nematodes by modifying a key element essential to complete their life cycle. The most effective break is provided by the absence of host plants at periods where the soil temperature is high enough to allow nematode activity. The main tools in such a cropping system are the choice of crops and varieties and the choice of plantation dates. For example, delaying the salad plantation from September to a colder period (end of October, November) will achieve this break because, although the salads are host plants, they are grown in soil temperature preventing or at least severely decreasing the activity of nematodes. Unfortunately, most common vegetable crops

(tomato, pepper, cucumber, egg-plant, melon) are host plants and very few resistant cultivars exist (some do for tomato, but the resistance is broken for high soil temperatures, Tzortzakakis, 2005). A gradation in the effectiveness of a cropping system to achieve the creation of a break in the life cycle of the pest can be defined as a function of the number of host crops planted during the year. The use of grafted plants deserves a special attention. Although some rootstocks are resistant to nematodes, many are not and only provide an increased vigour to the scion. This increase in vigour may mask the depletive effects of the nematodes, but examination of the roots generally shows, in infested soils, high infestation levels. Such rootstocks, although they allow a good production level and look tolerant to nematodes, have to be considered, as host plants allowing the multiplication of the pest. Finally, weeds in the greenhouse (generally on the sides along the plastic cover, close to the extremities or along the central path when it is not covered by a plastic mulch), or weeds outside the greenhouse but close to it may play the role of a reservoir so far as many common weeds are host plants too. Weed control therefore also contributes to providing a break in the life cycle of the nematodes (Fig. 2.).

3. **Enhancing the competitions in the soil.** We consider here the practices that favour the microfauna and microbial activities. Brussaard *et al.* (2007) have listed the different agricultural management practices that affect the soil and their effects on the soil microbial and fauna activities. The most beneficial practices encompass organic amendments, green manure, fertilisation, tillage and crop rotation and sequences. At the opposite (negative effects), they list pesticides, soil contaminants, but also monoculture. Organic amendments can be realised either through fresh animal manure, composts or dehydrated products. The content in microorganisms and the positive influence of these different amendments is related to their characteristics. Fresh manure is more effective than a dehydrated product. The dose at which they are applied also influences their effect on the soil biodiversity. Green manure also provides a beneficial effect on the total soil microbial and fauna population and on its diversity. There are some evidences that biocidal green manures have a positive effect on the total populations on the soil, the suppression of some species being probably compensated for (Scholte *et al.*, 1998). Therefore no differences are made between standard green manures and biocidal ones so far as the effect on soil biodiversity is concerned. Finally, the effect of the diversity of crops during the year is accounted for (Fig. 3.). Monoculture brings no beneficial effect (Brussaard *et al.*, 2007) while a higher diversification of crop species will (up to three different crops in a year, or up to four over a two years period).

4. **Prophylaxis.** Although prophylaxis is not really a biological process acting on the cycle of the pest, it has consequences at the population and spatial distribution level. It can be used to avoid the contamination of new spots. The main way to achieve this goal is to avoid transporting crop residues and soil with the mechanical tools. Washing the tools between two greenhouses and planning the operations so as to start working on infection-less greenhouses and finishing with the infected ones are simple to put into practice. Weed management inside and outside the greenhouse also contributes to prophylaxis in so far that their removal will not offer refuge areas to the nematodes (Fig. 4.).

5. **Combining these effects.** To characterise the overall pathological resilience of a given cropping system requires that we combine the evaluation of the previous effects. The contribution of some of these processes depends on the infestation level. Indeed, population reduction and cycle breaking at low intensities cannot be successful in highly infested situations, while they can in low infestation level. Therefore, the evaluated efficiency of the population reduction and of the cycle breaking is combined to the

infestation level, to determine how effective the cropping system is in this respect. This result is then combined to the efficiency with which soil competition is sustained by the cropping system. The combination of these three processes (population reduction, life cycle breaking and soil competition enhancement) results in the evaluation of the *intrinsic* resilience of the cropping system, intrinsic because these characterisations concern the very greenhouse on which the cropping system is applied. Finally, this evaluation is combined with the evaluation of the prophylactic practices to obtain the overall resilience of the cropping system, including its capacity to resist to external infestations (Fig. 5.). The final evaluation grade ranks from *none* (no resilience at all) to *high* (eradication of high infestation levels on the long-term and good resistance to the development of new infestations), with two intermediate levels. *Fair* corresponds to a low resilience where the return to a clean situation from an infested one is not possible and where a new infestation has a high probability to develop. *Good* corresponds to a case where a low infestation level can be contained and eradicated, while high infestation levels will not, associated to a low probability for the development of a new infestation.

RESULTS AND DISCUSSION

Several soil-based greenhouse cropping systems have been described by surveys with the growers. They have been analysed through the multicriteria model described above. These analyses allow identifying four types of cropping systems (Fig. 6). The most successful (type 2) are balanced systems mostly obtaining good to high grades in each of the four components of the resilience. These systems rely on the combination of techniques such as solarisation and green manure to obtain at the same time a reduction of the populations and a break in the life cycle of the nematodes. Green manure also supports the competitions in the soil. These techniques are applied regularly, once every two years, in turn and are associated to prophylactic measures. Some cropping systems are also balanced (type 3), but combine these techniques at lower frequencies and do not adopt prophylaxis. Although balanced, they obtain a low rank in terms of resilience. Two other types of cropping systems were identified. Type 1 mainly relies on soil competitions to control the pest populations, which is not enough to obtain a good grade. Finally, one farmer mainly relies on prophylaxis to contain the infestations, and the corresponding cropping systems rank low in terms of resilience.

The infestation level of greenhouses corresponding to these cropping systems have been observed by unearthing melon roots and ranking the knots on the roots according to the scale designed by Zeck (1971), to analyse the correspondence between the qualification of the resilience of the cropping systems and their infestation level. The unbalanced cropping systems (types 1 and 4) were systematically highly infested with nematodes. The balanced types (2 and 3) correspond to variable levels of infestations, ranging from low (a few knots on some scattered plants in the greenhouse) to high (several knots per plant, affecting the functions of the roots, for most of the plants sampled in the greenhouse). The balanced cropping systems that obtained a good ranking of their pathological resilience (type 2) correspond to low infestation levels, while those that obtained a low rank (type 3) correspond to variable levels, from low to high. These observations show that the only cropping systems that are consistently associated with low infestation levels are the *effective* balanced ones (type 2), while the others can be associated with high infestation levels, either because they are not balanced or because they do not use the appropriate techniques intensively enough.

CONCLUSION

Based on the combination of scientific and expert knowledge, the contributions of the different elements of soil-based greenhouse vegetable cropping systems have been combined to provide an overall evaluation of the resilience of cropping systems to root-knot nematode infestations. The evaluations of existing cropping systems have been shown to be consistent with observed infestation levels in these cropping systems. The computer tool used to implement this qualitative evaluation model also allows identifying the weak points of the evaluated cropping system. It is therefore a valuable tool to analyse with the growers their cropping systems and enhance them. It is also a valuable tool to assist advisers and growers in the task of designing new cropping systems that will be resistant to nematode infestations. This tool will be extended to include other soil-borne pests and diseases and to also provide an assessment of the environmental and economic performance of these cropping systems.

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Figures

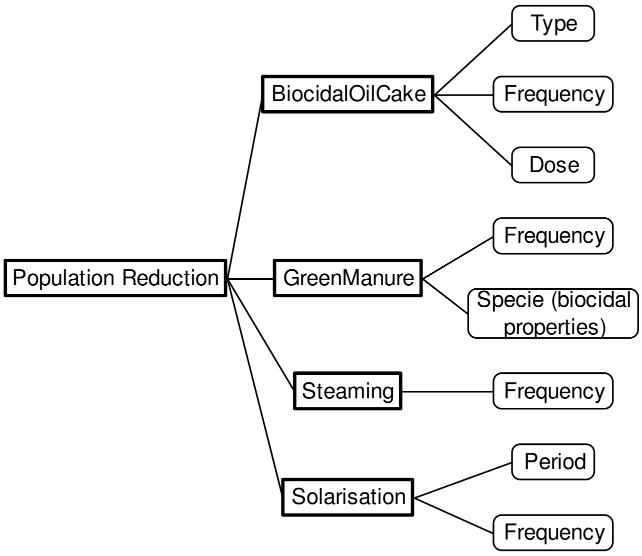

Fig. 1. Evaluation tree for the practices contributing to the reduction of the nematode population by a lethal action (rounded boxes denote a basic node describing a modality of a cropping technique; square boxes denote an aggregated evaluation obtained by combining the levels of the boxes immediately below).

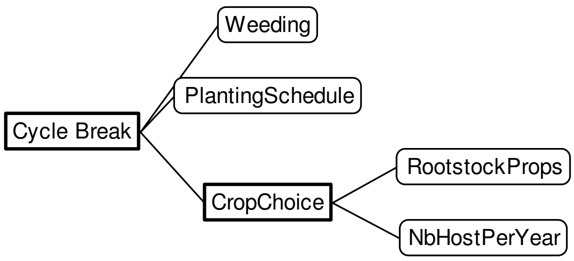

Fig. 2. Evaluation tree for the practices introducing a break in the life cycle of the nematodes.

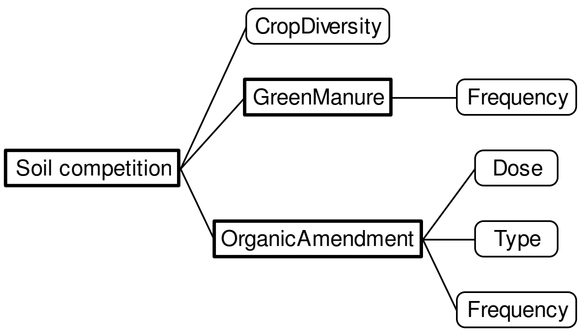

Fig. 3. Evaluation tree for the practices contributing to sustain the competitions in the soil and the diversity of the microorganisms.

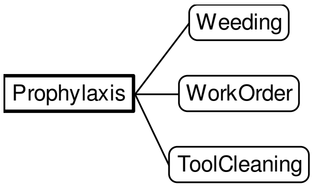

Fig. 4. Evaluation tree for the prophylactic practices.

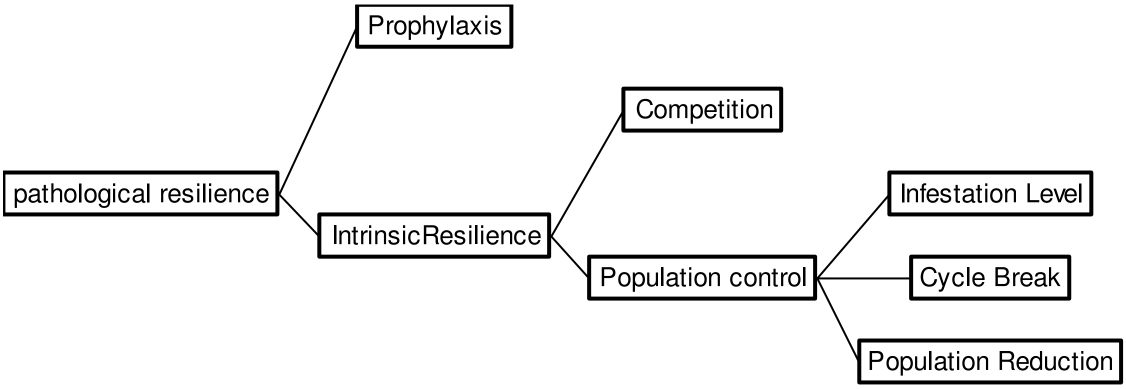

Fig. 5. Evaluation tree combining the evaluation of the practices made along the four elementary processes contributing to conferring pathological resilience (against nematodes) to a soil-based greenhouse vegetable cropping system.

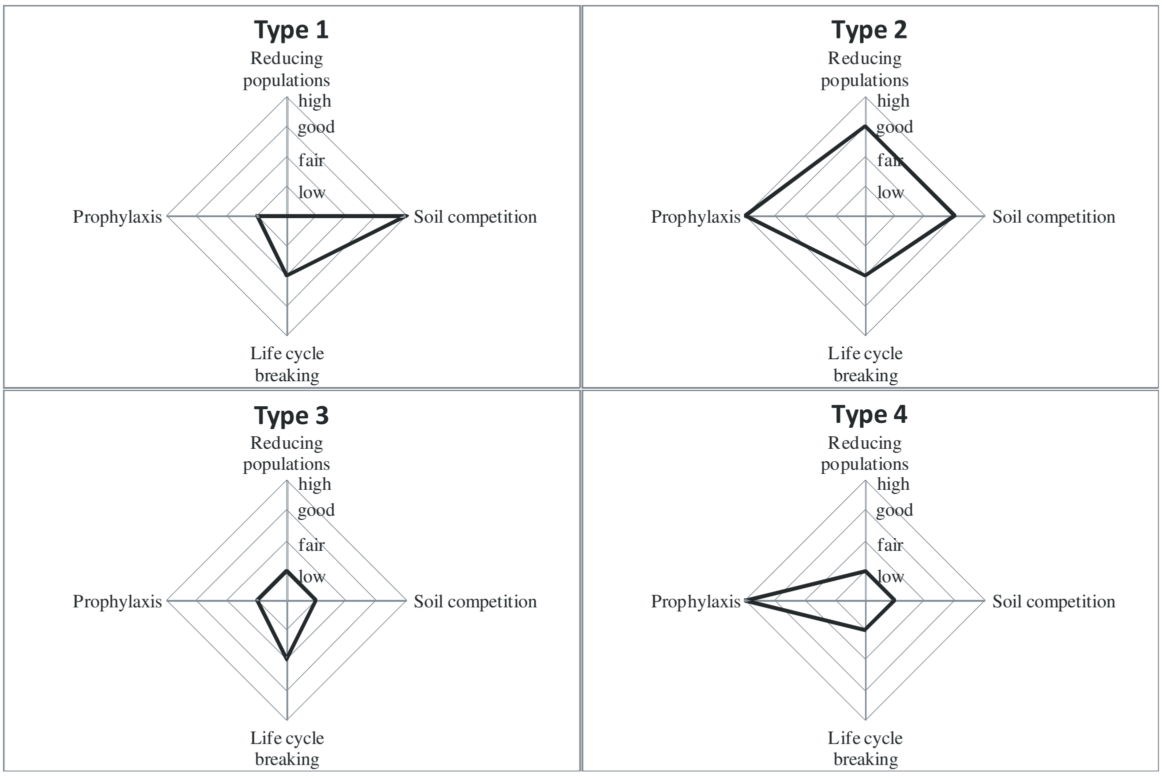

Fig. 6. Qualitative evaluation of the four types of cropping systems. Type 1 is based on soil competitions and achieves a fair resilience. Type 2 and type 3 are balanced cropping systems, type 2 being more successful than type 3. Type 4 is mainly based on prophylaxis which confers little (low) resilience to the system.