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Alternative cropping systems can have contrasting effects on various soil-borne diseases: Relevance of a systemic analysis in vegetable cropping systems

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ABSTRACT

Vegetable production makes an intensive use of pesticides, and a major challenge is to build alternative cropping systems that can control pests and diseases with fewer uses of chemical products. An on-farm analysis was conducted in Southeast France to assess the efficacy of several cropping systems in simultaneously controlling two major pests: root-knot nematodes (*Meloidogyne* spp.) and lettuce drop due to *Sclerotinia sclerotiorum*. Ten cropping systems resulting from the combinations of three crop sequences and two alternative techniques, solarization and green manure, were assessed during two years. The use of solarization once a year or once every two years limited the occurrence of *S. sclerotiorum*. Sorghum green manure tended to increase *S. sclerotiorum* incidence; the effect was positively correlated with green manure duration. Especially when no vegetable was cropped in summer, the green manure crop duration was lengthened and this probably created soil conditions favorable to the development of the fungus. The incidence of root-knot nematodes was largely dependent on crop rotation: a melon crop in summer increased its incidence on the subsequent lettuce crops whereas a summer sorghum cover crop had no effect. The cropping systems that limited *Sclerotinia* development in soil tended to support the root-knot nematode populations. These results should motivate farmers and advisers to adopt a systemic analysis and take into account the various interactions among inoculum level, soil characteristics, crop rotations, and technical management options for designing sustainable vegetable production systems.

1. Introduction

Vegetable cropping systems are intensive and based on crop rotations with a limited number of species. These systems are therefore vulnerable to pests and diseases. Several chemical products are now banned for environmental or public health reasons or are strictly controlled, and a major challenge for growers is to limit the use of those still available. This is especially true for market-gardening systems and even more so for protected cultivation (high tunnel) because vegetables are sold as fresh products and must not show any visible sign of disease symptoms or pest damage to meet marketing-firm requirements. Thus, designing sustainable cropping systems based on alternative cropping techniques is urgently needed (Klein et al., 2012).

In this context, soil-borne parasites are particularly difficult to control with alternative techniques because of the resistant forms surviving in soil for many years (e.g., sclerotia, resistant spores, eggs). In Mediterranean sheltered cropping systems, with warm and wet soils all year long, most problems come from root-knot nematodes (RKN) (*Meloidogyne* spp.) and fungi (*Sclerotinia* spp., *Rhizoctonia*, *Botrytis*). RKN cause considerable economic losses, and most nematicide products are now banned (17 out of the 26 listed in the 2013 EU database), which has resulted in increasing levels of colonization in soils (Wesemael et al., 2011). In the south of France, a recent survey estimates that about 40% of farms experience crop losses due to RKN (Djian-Caporalino, 2010); in Germany, Hallmann et al. (2009) found that 51% of the organic farms surveyed showed

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Meloidogyne presence. An average 10% of yield loss is frequently cited (Raaijmakers et al., 2009); for vegetables Koenning et al. (1999) report a lower figure (5.4%), but much higher percentages are observed under local conditions (Wesemael et al., 2011). Soil-borne fungi also cause severe diseases in vegetable production: according to Subbarao (1998), lettuce drop caused by *Sclerotinia* spp. regularly results in seasonal yield losses of about 15%.

Crop rotations that can control RKN or *Sclerotinia* are limited. Hardly any genetic resistance exists in vegetables, except the *Mi* gene on tomato and the *Me* gene on pepper, against RKN (Sikora and Fernandez, 2005), and these pests and diseases have a broad host range. According to Boland and Hall (1994) and Subbarao (1998), 408 plant species belonging to 78 families are hosts for *Sclerotinia* spp.; most vegetable species and weeds are hosts for *Meloidogyne* spp. (Bélair and Benoit, 1996; Sikora and Fernandez, 2005). Moreover, *Sclerotinia* survives saprophytically even if no host crop is present.

Several alternative techniques have been identified in the past few decades: sanitation, soil management, organic amendment, green manure, biological control, and heat-based methods (soil solarization, steam) (Zasada et al., 2010; Katan, 2000). Although these are promising in controlled conditions, results at the field level are partially inconsistent, with the same technique providing a satisfactory control in some cases but having no or insufficient effects in other cases (Collange et al., 2011, for RKN; Subbarao, 1998, for *Sclerotinia*). Such varied effects seem to be mainly the result of interactions within the soil and with crops and cropping practices. Moreover, little literature is available on the simultaneous effects of cropping systems on several pests and diseases. However, such information is crucial to elaborating operational knowledge for growers who have to assess cropping systems for their capacity to control several pests and diseases in the long term. Our research aimed at designing innovative market-gardening cropping systems using alternative techniques in combination, to simultaneously control RKN and *Sclerotinia*. We focused on the techniques applied during the intercropping season in summer, i.e. soil solarization and green manure, which are regularly used in commercial farms. As they occupy the land for 1–3 months and are in competition with commercial crops (Navarrete et al., 2006), they are implemented with various frequencies and orders of succession over years, depending on farm and crop organization, which probably explains their variable efficacies.

Solarization consists of trapping solar radiation with plastic films laid on the soil, which allows soil temperature increases of up to 50 °C (Katan et al., 1976) near the surface. Its efficacy against fungi under shelters has been shown by Patricio et al. (2006) and Bonanomi et al. (2008), but it is questioned for RKN (Anastasiadis et al., 2008). The heating intensity, thus the control efficacy, depends on two main factors. First of all, a rapid increase of temperature must be achieved during the first days of the treatment, and then maintained during several weeks (Chellemi et al., 1997). As a consequence, in the Mediterranean area, it is recommended to start solarization between mid-June and mid-July and make it last for at least 5–6 weeks. Second, the heating effect decreases in deeper soil layers, with hardly any effect at 30–40 cm (Stapleton, 1997). This fact probably explains the low efficacy against RKN: not only are the eggs quite tolerant to heat (Wang and McSorley, 2008), but juveniles can also survive in deeper soil layers and migrate upward later (Klein et al., 2012). Thus, long-term efficacy may depend on the frequency with which the technique is applied, in order to maintain low populations from one year to the other.

A few species can be cropped as green manure under shelters; Sudangrass (*Sorghum sudanense*) and Sudangrass hybrids (*Sorghum bicolor* × *S. sudanense*) are the most frequent because they grow rapidly and produce high dry matter yields. First of all, they are considered as a non-host of *Meloidogyne* (Dillard and Grogan, 1985; Viaene and Abawi, 1998) and *Sclerotinia* spp. (Heffer Link and Johnson, 2007). But many other biophysical processes are involved in pest control and the overall effect is quite controversial (Collange et al., 2011). Little scientific literature is available on sorghum effects on *Sclerotinia*; nevertheless, some extension services encourage its use to limit disease (Heffer Link and Johnson, 2007). As regards RKN, a negative relationship was observed between hydrogen cyanide concentration in soil (potentially released by some sorghum cultivars) and root galling induced by *Meloidogyne* spp. (Widmer and Abawi, 2002). Viaene and Abawi (1998) observed that a Sudangrass cover crop decreased the number of *Meloidogyne hapla* eggs in the soil and root galling under a subsequent lettuce crop. Kratochvil et al. (2004), comparing several crop rotations with several green manures, also found that Sudangrass could decrease RKN population densities.

As stated above, it appears that both soil solarization and green manure are potential techniques to control a fungal pathogen (*Sclerotinia* spp.) and root-knot nematodes (*Meloidogyne* spp.), but that their in-field efficacy is not always in agreement with their potential as demonstrated in controlled experiments. Besides, the in-field use of these techniques, alone or in combination, is constrained by the cropping system structure, because the recommended time slots for both solarization and green manure may conflict with commercial crop cycles. The aim of this study was therefore to assess, on commercial fields, the efficacy of different cropping systems to simultaneously control these pests and diseases, using various combinations of these techniques. To assess the value of innovative cropping systems, studies on experimental stations suffer from several drawbacks: the long time necessary to create stable cropping systems and exhibit their effects, the large area required to test numerous cropping systems. For example, a very heterogeneous pest such as RKN requires a minimum area per cropping system to obtain a representative picture of the disease reality. The alternative approach of in-field assessment on commercial farms was chosen, in order to exploit the largest available variability in cropping systems (Casanova et al., 1999). As pointed out by Clermont-Dauphin et al. (2005) and Doré et al. (2008), a purposeful choice of the farmers' fields is required to disentangle the complex relationships between environment and agronomic variables and cropping systems structure. In our case, the cropping systems were chosen to test the frequency of use of a given technique and the combination or not of two techniques, interacting with the frequency of melon cropping. We tested the hypotheses that (1) some cropping systems effective for controlling one pest may favor the development of the other; (2) the efficacy of the two techniques depends on crop and practice pattern over time.

The following part details the rationale of the on-farm design and the variables (environmental and agronomic) that were used, along with the statistical design. Results are then presented and analyzed from a systems point of view. Finally, we conclude on both the potential of these alternative control techniques and on the potential of such a systems study.

2. Materials and methods

2.1. General framework

The study was performed under high tunnels from 2007 to 2009 in Southeast France on traditional cropping systems involving lettuce (*Lactuca sativa* L.) and melon cantaloupe (*Cucumis melo*). We focused on the two year rotations based on two consecutive lettuce crops in autumn and winter, associated to a variable frequency of melon cropping in spring: once a year, once every two years, or never (Fig. 1a). These crop sequences allow for varying lengths of