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Efficacy of pest and pathogen control, yield and quality of winter lettuce crops managed with reduced pesticide applications

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ABSTRACT

In conventional agriculture, lettuce crops receive large amounts of pesticides to meet stringent industrial specifications and market requirements. Pesticides are used on lettuce to ensure high-yielding, attractive products free from foreign bodies and damage. Pesticide reduction is a major challenge for lettuce growers in this context. The objective of this study was to assess the risk arising from a reduction in pesticide applications by using a combination of alternative techniques for the management of pests and diseases in winter lettuce crops. Two alternative crop protection strategies (called low-input and intermediate) were designed by prototyping and then compared to a conventional lettuce protection strategy in independent trials carried out in three locations over two successive winters. The efficacy of each strategy for pest and pathogen control, as well as lettuce yield and quality, were assessed and compared. Pesticides were reduced by 32% in the intermediate crop protection strategy, and by 48% in the low-input crop protection strategy. At least 15% of lettuces were affected by pest and pathogen damage, whatever the strategy. Among possible pests or diseases, aphids were the only biotic stress which differed significantly between strategies (9.25% of lettuces infested and 2.7% of commercial losses under the low-input strategy, as compared to 0.83% of lettuces infested and 0% of commercial losses under the conventional strategy). Globally, biotic damage was less important than abiotic damage (frost and tip burn), and resulted in low commercial losses under all strategies. Similar yields and lettuce quality were recorded under the three systems. Therefore the performances of intermediate and low-input crop protection strategies were consistent with market expectations, and possible improvements are discussed. This work provides a methodology and landmarks for the design and dissemination of cropping systems targeted to leafy vegetables and less dependent on chemical control of pests and pathogens.

1. Introduction

Conventional farming systems use large amounts of pesticides to manage pest and pathogen populations. Pesticides are used to improve yield and visual quality of harvested products (Wilson and Tisdell, 2001). However, due to their harmful effects on the environment (Geiger et al., 2010; Goulson, 2013) and possibly on consumers' and applicators' health (Mostafalou and Abdollahi, 2013), the viability of conventional cropping systems is nowadays widely questioned. The European Union recently established a directive to reduce pesticide consumption and promote the use of non-chemical methods wherever possible (EU, 2009).

In the past decades innovative cropping systems have been designed, aimed at reducing pesticide use, mainly for arable crops. During the last 20 years, a range of low-input cereal-based cropping systems has been experimented and assessed (Debaeke et al., 2009; Loyce et al., 2012). These systems rely on reduced sowing rates and/or nitrogen inputs, sometimes reduced tillage, and on the use of suitable, multi-resistant varieties (in mixtures or in monocrop systems). Profit margins are maintained, since yield losses associated with reduced inputs are balanced by lower costs. In temperate and Mediterranean climates, winter lettuce is usually grown under shelter, typically in high tunnels, with two or three harvests between September and April. In these systems, inputs are relatively marginal as compared to labor costs, and chemical protection represents only 3–6% of the total production costs. Therefore the design of innovative lettuce-based cropping systems

Abbreviations: IBEB, International Bremia Evaluation Board; CPS, crop protection strategy; TFI, Treatment Frequency Index; L, location; PACA, Provence Alpes Côte d'Azur; W, winter.

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cannot rely on the same strategy as cereal-based systems, since yield losses cannot be offset by significantly reduced input costs. Thus, any pesticide reduction in lettuce crops has to be achieved without yield reductions. Furthermore, lettuce is usually eaten raw and the aerial parts of the plant are almost entirely consumed, so market specifications for visual quality and the absence of foreign bodies are very high (Palumbo and Castle, 2009). On average, the tolerance threshold of the industry for the presence of animal foreign bodies (including pests but also beneficial insects) is no more than 10% of products infested with no more than 5 individuals per item. Pesticides are therefore considered as a means to ensure high-yielding and high-quality products. In organic agriculture, the possible yield reduction (de Ponti et al., 2012) can be balanced by a higher sale price of organic products, but many consumers are unwilling to pay these prices. Therefore, the question is how and by how much is it possible to reduce the use of pesticides in conventional lettuce crops without affecting lettuce quality or yield.

Many pests and pathogens can threaten lettuce crops, such as biotrophic or necrotrophic, soil- or air-borne fungi, viruses, bacteria as well as aphids, moths, slugs, thrips, etc. The incidence and severity of each pest and pathogen depends on growing conditions (crop type, cultivation under shelter or in open fields, season) and changes over the year. In winter lettuce crops under shelter, pathogens are predominant. The most important is probably *Bremia lactucae* (Regel), the causal agent of lettuce downy mildew, because of its rapid and devastating spread in the field. The pathogen may attack the plant throughout its life. The primary inoculum typically consists of airborne sporangia from diseased plants of the genus *Lactuca* located close to the crop, or of mycelia present on plant debris in the soil (Crute, 1992). *Sclerotinia sclerotiorum* (de Bary), *Sclerotinia minor* (Jagger), *Botrytis cinerea* (Pers.), *Rhizoctonia solani* (Kühn), and *Pythium tracheiphilum* (Matta) are other important fungal pathogens of winter lettuce crops. Collectively, these pathogens cause symptoms of basal rot, i.e. rotting of the leaves in contact with the soil surface (Van Beneden et al., 2009). *S. minor* and *S. sclerotiorum* are of major concern for the cultivation of lettuce because they may affect a wide range of plant species and their sclerotia may remain latent in the soil for more than 8 years (Bolton et al., 2006; Melzer et al., 1997). Moreover, sclerotia are often buried and dispersed by tillage (Subbarao et al., 1996). Therefore, basal rot causes long-term problems in conventional lettuce crops since sclerotia are taken back up to the soil surface at each tillage. *B. cinerea* and *R. solani* can also cause significant damage depending on the growing season. *B. cinerea* injury to lettuce leaves is enhanced by cool and moist conditions, while *R. solani* sclerotia and mycelia are most frequently found in the soil in summer (Van Beneden et al., 2009). The fungus *Olpidium virulentus* is not a direct threat to lettuce, but a vector of two lettuce viruses that can cause significant damage, especially in winter: 'Mirafiori lettuce virus', responsible for big vein disease; and 'Lettuce big-vein associated virus', suspected to be the agent of ring necrosis (Lot et al., 2002; Maccarone, 2013; Verbeek et al., 2013). The resting spores of *O. virulentus* can persist in the soil for many years, and viruliferous zoospores that infect lettuces are very mobile, so management of the disease is complex (Campbell, 1985; Maccarone, 2013). Several aphid species can proliferate in winter lettuce crops such as *Nasonovia ribisnigri* (Mosley), *Myzus persicae* (Sulzer), *Aulacorthum solani* (Kaltenbach), *Macrosiphum euphorbiae* (Thomas), and *Hyperomyzus lactucae* (L.). *N. ribisnigri* is the most damaging one because it develops preferentially in the lettuce heart (Liu, 2004). In addition to feeding damage and the loss of product quality due to their presence when the lettuce is marketed, aphids are also vectors of viruses, such as the lettuce mosaic virus. Finally, slugs (*Deroceras* sp. and *Arion* sp.) and snails can also cause feeding damage to lettuce in winter.

In conventional lettuce crops in the Mediterranean region, eight to ten pesticides are applied on average to manage pests and pathogens during the 60- to 90-day-long crop cycle. In winter, these are mainly fungicides. Due to the long time required before harvest for the elimination of active ingredients by lettuce and the lack of curative efficacy of pesticides for some pathogens such as *B. lactucae*, pesticides are almost exclusively applied preventively. Several alternative techniques with a partial effect on diseases and pests are currently available and might be combined to design innovative lettuce cropping systems less dependent on pesticides (Barriere et al., 2014). These alternative techniques are generally preventive and have only a partial effect on pests and diseases. They can act at different times in the pest and pathogen cycle: they can (i) limit and reduce primary inoculum sources, (ii) limit the development of pests and pathogens through the modification of the abiotic environment or (iii) increase plant defenses, and (iv) have a curative action. Techniques that reduce primary inoculum in lettuce crops are sanitation methods such as the removal of infected plants, solarization, or some biological control agents such as *Coniothyrium minitans* and *Trichoderma harzianum*. *C. minitans* is an efficient biocontrol agent against *S. sclerotiorum* (Chitrampalam et al., 2008). This fungus preferentially parasitizes overwintering structures by synthesizing chitinases, glucanases, and antifungal metabolites (Zeng et al., 2012). *T. harzianum* also disturbs populations of *B. cinerea*, *Pythium* spp., *R. solani*, and *Sclerotinia* spp. in the soil by acting either as a competitor or as a parasite (Elad, 2000; Harman, 2006; Howell, 2003; Vinale et al., 2008). Another way to protect lettuce crops is to limit the development of pests and pathogens through the modification of the abiotic environment. Indeed, the germination of infectious forms (spores or sclerotia) of numerous pathogenic fungi depends on climatic factors such as humidity and temperature. Drip irrigation, as opposed to sprinkler irrigation which is widespread in southern France, may reduce leaf wetness duration, which is an important factor for the germination of *B. lactucae* sporangia (Scherm and Bruggen, 1994) and *B. cinerea* spores (Elad and Shtienberg, 1995). Lower plant density can also reduce foliage wetness due to better aeration, and limit soil-borne disease development by affecting the microclimate under lettuces. Alternative techniques can also modify plant susceptibility to pests and pathogens. Genetic resistance, resistance inducers and nitrogen fertilization have shown a partial effect on lettuce diseases and pests. Lettuce varieties with major resistance genes against *B. lactucae* are available and widely used. However, information about resistance is only provided by seed companies for the most common and widespread isolates (identified and denominated by the 'International Bremia Evaluation Board' – IBEB). *B. lactucae* can rapidly develop new virulent isolates. Therefore resistance breakdown is common and leads to a rapid turnover of lettuce varieties (Michelmore and Wong, 2008). Thirty-two races of *B. lactucae* are currently registered by the IBEB. Complete resistance to the aphid *N. ribisnigri*, and partial resistance to *M. persicae*, are conferred by a dominant gene called Nr, which has been introduced in many European cultivars (Cid et al., 2012; Liu and McCreight, 2006). However, this resistance was recently bypassed by a new *N. ribisnigri* biotype named Nr:1 (ten Broeke et al., 2013). Apart from genes conferring complete resistance, different susceptibility levels of lettuce accessions to *S. sclerotiorum* have been reported (Elia and Piglionica, 1964; Grube and Ryder, 2004; Hayes et al., 2010). In addition to genetic resistance, some techniques can strengthen plant defense. Several compounds, such as β-amino butyric acid or potassium phosphite (K_2HPO_3), have been identified as resistance inducers of lettuce against *B. lactucae* (Pajot et al., 2001). Some of them, such as potassium phosphite, also have a direct biocide effect on oomycetes (Massoud et al., 2012). Fertilization can affect plant–pathogen and plant–pest interactions. The nitrogen content of lettuce leaves is positively correlated to damage by