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Powdery mildew development is positively influenced by grapevine vegetative growth induced by different soil management strategies

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ABSTRACT

In various crop species, high levels of powdery mildew infection and severity have been associated with high vegetative vigour. In grapevine this relationship has also been observed by vine growers, though it has not been quantified. This study was undertaken to investigate the relationship between the development of powdery mildew on leaves and berries and canopy growth, and thus to quantify the relationship between the pathogen and its host. Over a two-year period (2005 and 2006), an experiment was carried out in a vineyard (cv. Aranel) near Montpellier, southern France. Several levels of canopy growth were generated by implementing four soil management strategies: i) perennial cover crop in the inter-row, ii) annual cover crop in the inter-row, iii) chemical weed control over the entire soil surface, iv) chemical weed control all over the soil surface and drip irrigation and fertilization in the row. Powdery mildew was artificially inoculated on experimental sub-plots with *Erysiphe necator* [Schw.] Burr. conidia. The most vigorous vines developed a larger number of diseased leaves and a higher percentage of mildewed berries compared to low-vigour vines. The major explanatory variable highlighted in these experiments was the shoot leaf number, mainly early in the season. A higher leaf population generated a larger number of powdery mildew colonies close to grapes and consequently a higher probability of berry infection. Our experimental results provide evidence of a positive relationship between powdery mildew development and grapevine vegetative development. These results provide an opportunity to develop new IPM strategies in vineyards.

1. Introduction

Obligate parasites are recognized as particularly sensitive to ontogenic resistance i.e. to change the susceptibility of their organs during plant development (Develey-Rivière and Galiana, 2007). The former was documented for the main diseases of grapevine: black-rot (Hoffman et al., 2002), botrytis (Salzman et al., 1998; Kretschmer et al., 2007), powdery mildew (Ficke et al., 2003; Gadoury et al., 2003) and downy mildew (Kennelly et al., 2005). In various crop species, high levels of powdery mildew infection and severity have been associated with plant development under conditions of high vegetative vigour or tissue turgescence (Jarvis et al., 2002). In wheat, powdery mildew increases when nitrogen fertilization rate increases (Broscious et al., 1985). Models were developed to account for the effect of host development on disease progress (Hau, 1990). For wheat, models were developed to account for the susceptibility of host tissue and for the effects of leaf position or plant architecture on powdery mildew (Rossi and Giosue, 2003) or *Septoria tritici* Roberge (Robert et al., 2008). For apples, Lalancette and Hickey (1986) designed a model where leaf number is a key variable to simulate powdery mildew development, explaining the importance of plant growth in disease attacks.

A positive relationship between grapevine growth and susceptibility to fungal pathogens has also been observed by vine growers, pathologists and extension services (de la Rocque, 2002; Goulet et al., 2006). In several studies concerning the effects of crop practices on grapevine yield and quality, interactions between diseases and vine growth were observed (Reynolds and Wardle, 1994; Intrieri et al., 2001; Zahavi et al., 2001; Pellegrino et al., 2004; Evans et al., 2006; Morlat and Bodin, 2006). For example, grey mould incidence was positively correlated to canopy development, and variables such as leaf number, leaf dry weight and area were identified as key variables associated with the disease

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development (Valdés-Gómez et al., 2008). The development of powdery mildew was found to be higher in pruning systems favouring a high vegetative expression on the cultivar Concord (Gadoury et al., 2001). Powdery mildew incidence and severity on grapes were shown to be twice as high and five times higher respectively in a vigorous grapevine plot compared to a non-vigorous plot on cv. Chardonnay (Evans et al., 2006). Recently, a characterization of the spread of epidemics in the vineyard showed a more rapid spread of the disease on plots with higher vegetative vigour (Calonnec et al., 2009). A set of deterministic epidemiological models was developed to take into account the dynamics of the grapevine's susceptibility, its growth and/or architecture, and their interaction with powdery mildew (Sall, 1980; Blaise and Gessler, 1992; Gessler and Blaise, 1992; Calonnec et al., 2008). However, few studies have been conducted to investigate and quantify the relationship between the grapevine's vegetative development and the development of powdery mildew.

In all the examples above, the interactions between the dynamics of secondary infection of powdery mildew and plant growth certainly explain the differences in disease damage levels. Several factors could explain the positive relationship between powdery mildew development and grapevine vegetative vigour: i) a higher plant leaf number, as deduced from one experiment conducted by Gadoury et al. (2001) on Concord grapes; ii) a longer period of susceptibility of the affected organs; berries are very sensitive to infection between their setting stage and bunch closure; young leaves are very susceptible and they turn more resistant with ageing, so that any factor that slows down the maturation process of the organs may increase the plant's susceptibility to the disease (Doster and Schnathorst, 1985); iii) favourable changes in tissue properties, for example structural changes (formation of suberized epidermis, cellular necrosis etc.) or physiological and chemical changes (synthesis of proteins or other compounds, changes in cellular osmotic potential, etc.) (Goheen and Schnathorst, 1963; Adrian et al., 2000; Deloire et al., 2000; Jeandet et al., 2002); iv) more favourable microclimatic conditions; in vigorous vineyards, dense and poorly ventilated canopy and poorly illuminated bunches (Pellegrino et al., 2004), which favours the development of powdery mildew (Halleen and Holz, 2001; Zahavi et al., 2001).

Therefore, all cultural practices that favour vegetative vigour may predispose the host to an increased development of powdery mildew. High grapevine vigour could modify ontogenic resistance of leaves (particularly delaying grapevine phenological stages such as veraison or harvest (Matthews et al., 1987; Keller et al., 2001), or stretching the duration of the flowering, fruit set or bunch closure periods (Gadoury et al., 2006). This study was undertaken to investigate the relationship between the development of powdery mildew on leaves and berries for various levels of canopy growth, and thus to quantify the relationship between the pathogen and its host. To this end, several policies of soil management – irrigation, nitrogen fertilization and cover cropping – were used in order to generate various levels of nutrient supply and hence of grapevine growth.

2. Materials and methods

2.1. Experimental field and cropping practices

Field experiments using *Vitis vinifera* L. cv Aranel (a white cultivar) grafted onto Fercal rootstock were conducted in 2005 and 2006. The vines were planted in 1998 at a density of 3333 vines ha^{-1} (2.5 m $\times$ 1.2 m) in a vineyard of 1.5 ha located near Montpellier, France (43°31′N–3°51′E, 10 m a.s.l.). The area is characterised by a typical Mediterranean climate with an average annual rainfall of 749 mm with 520 mm (70%) of the rain falling in autumn and winter (from September to March). The average annual water deficit (PET—rainfall) was about 174 mm (1975–2005). The soil was deep (more than 3 m) and homogeneous, classified as calcaric Fluvisol (FAO classification), containing 31% sand, 35% silt and 34% clay. The vines were trained to a vertical shoot positioned system with a canopy height of 1.9 m, with rows aligned W–NW. In the entire experimental vineyard, shoots were topped and trimmed once per year.

Four types of cropping systems were used in order to generate various levels of canopy development:

i) Perennial cover crop in the inter-rows sown in 2002 with a mixture of tall fescue (*Festuca arundinacea* Shreb) and Perennial ryegrass (*Lolium perenne* L.) (PI);
ii) Annual cover crop of barley (*Hordeum vulgare* L.) sown every autumn in the inter-rows (1.5 m wide) and destroyed by surface tillage just after grapevine flowering (mid-June) (NPI);
iii) Chemical weed control with glyphosate (Roundup Bio Forces®, 2%) over the whole soil surface (WC); and
iv) Chemical weed control as above and drip irrigation in the row with a water application of 100% of the Penman–Monteith reference evapotranspiration (3400 m^3 ha^{-1} in 2005, 7400 m^3 ha^{-1} in 2006) from grapevine bud break to harvest (Allen et al., 1998), and fertilised with N (80 kg N ha^{-1} in 2005, 120 kg N ha^{-1} in 2006) (WCI).

In each cropping system, sub-plots of three adjacent vines were selected for vine growth and powdery mildew assessments. Each year, the sub-plots were distributed in the field using as selection criteria the pruning weight map of the previous season (2004 or 2005) in order to get the largest range of plant growth (Fig. 1). In 2005, three sub-plots per cropping systems were selected and four in 2006, except in the WC area. These sub-plots were artificially inoculated with *Erysiphe necator* conidia to get a uniform intensity of primary infection as presented in Table 1. Inoculations were performed on 29 April 2005 and 26 April 2006 (4–6 leaves unfolded) on the central shoot of the central vine, as described by Calonnec et al. (2009).

Inoculated sub-plots were protected from any fungicide spray by wrapping the three vines in plastic film at the time of spraying. The remaining vines were protected against powdery mildew infection using two fungicide treatments every year: tebuconazole (Corail®,EW 0.15 kg a.i. ha^{-1}) at flowering and tryfloxistrobin (Natchez®, WG, 0.06 kg a.i. ha^{-1}) 14 days after flowering. To control downy mildew, one treatment was applied at flowering with the fungicides cimoxanil (0.12 kg a.i. ha^{-1}) + mancozeb (1.4 kg a.i. ha^{-1}) formulated as Sitolan® WG. To control insects, three treatments were applied every year by using chlorpyrifos-ethyl (Dursban 2®, 0.37 a.i. kg ha^{-1}) and cypermetrin + diazinon (Socavers®, 1.2 l. ha^{-1}) in the whole experimental vineyard. With these treatments no disease developed in the vineyard except in the inoculated sub-plots.

2.2. Assessment of vine growth

Leaf number was measured every 10 days from 8 leaves unfolded stage to bunch closure. To identify these grapevine phenology stages, the Eichhorn and Lorenz phenological scale modified by Coombe was used (Coombe, 1995). This phenological scale is a system of growth stage identification that contains a succession of developmental events that always follow each other, having 35 stages that are easily described, and clearly identified from "winter bud" to "end of leaf fall". Leaf number was measured on twelve shoots for each sub-plot throughout the experimental period - six on the central vine and three on each lateral vine. A distance of about 30 cm separated the shoots. The