Agricultural and Forest Meteorology 234–235 (2017) 203–211

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

The trade-off between grape yield and grapevine susceptibility to powdery mildew and grey mould depends on inter-annual variations in water stress

Nicolas Guilpart[a,b,c,*], Sébastien Roux[b], Christian Gary[b], Aurélie Metay[d]

[a] Institut Français de la Vigne et du Vin Pôle Rhône-Méditerranée, 30230, Rodilhan, France
[b] INRA, UMR System, 34060, Montpellier, France
[c] AgroParisTech, UMR Agronomie 211 INRA AgroParisTech Université Paris-Saclay, F-78850 Thiverval-Grignon, France
[d] Montpellier SupAgro, UMR System, 34060, Montpellier, France

ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form
16 December 2016
Accepted 26 December 2016
Available online 12 January 2017

Keywords:
Vitis vinifera L.
Grape yield
Powdery mildew
Grey mould
Water stress
Trade-off

ABSTRACT

Reducing plant growth to limit their susceptibility to diseases has been proposed as a way to reduce pesticide use, but reducing crop growth may have detrimental effect on yield. In this paper, we test the hypothesis of a trade-off between maintaining grape yield and reducing grapevine susceptibility to powdery mildew (*Erysiphe necator*) and grey mould (*Botrytis cinerea*), two major diseases of the grapevine (*Vitis vinifera* L.). Grapevine susceptibility to these two diseases was measured by relevant features of grapevine vegetative development identified in previous studies: leaf biomass at flowering for powdery mildew and pruning mass for grey mould. Data were collected during a 3-year field experiment in a vineyard located in the south of France, in which pests and disease were controlled by spraying pesticides. The two pathogens studied in this paper were chosen because they differ in terms of their biology (biotroph vs necrotroph) and their interaction with the grapevine (the highest grapevine susceptibility occurs early in the cycle for powdery mildew and late in the cycle for grey mould), in order to give genericity to the results. Results confirmed the hypothesis of a trade-off between maintaining grape yield and reducing grapevine susceptibility to both pathogens through reduced vegetative growth, but provided evidence that win–win situations (high yield, low susceptibility) do exist. Moreover, we found a synergy between reducing grapevine susceptibility to powdery mildew and grey mould. These results suggest opportunities to reduce fungicide use when a win–win situation occurs as the risk of yield and quality losses may be lower in those years. Inter-annual variation in water stress at flowering was found to be a key driver of the balance between grape yield and grapevine susceptibility to both pathogens through their effect on the source–sink balance of the grapevine. Water stress at flowering appeared as a relevant indicator to inform the probability of occurrence of a win–win situation. Our results suggest that it could also be used to adapt management practices like irrigation, cover cropping or a combination of both, to reach a win–win situation. The relevance of these findings to vineyards in similar semi-arid environments is discussed.

1. Introduction

The use of pesticides to control pests and diseases of agricultural crops has undesirable side effects on human health and the environment (Enserink et al., 2013). Hence, reducing their use while maintaining crop yields has become a major challenge (Tilman et al., 2002). For this reason, the manipulation of architectural features of crop canopies has received increasing attention over the past few years (Ando et al., 2007; Andrivon et al., 2013). Disease development has been shown to be mediated by plant growth and architecture for a wide range of crops and diseases: in most cases, a reduction in plant growth combined with an increase in crop canopy porosity reduces infection efficiency and spore dispersal (Calonnec et al., 2013; Tivoli et al., 2013). Decreasing plant growth would be a way to decrease crop disease susceptibility and consequently to reduce fungicide use. However, plant growth also determines light interception and biomass production by photosynthesis (Monteith and Moss, 1977): lower plant growth may induce lower yield and slow down harvested organ maturation.

* Corresponding author at: AgroParisTech, UMR Agronomie 211, BP 01, F-78850 Thiverval-Grignon, France.
E-mail address: nicolas.guilpart@agroparistech.fr (N. Guilpart).

http://dx.doi.org/10.1016/j.agrformet.2016.12.023

Hence, there may be a trade-off between reducing crop disease susceptibility by reducing vegetative development and maintaining crop yield. This paper investigates this hypothesis for two major diseases in viticulture: powdery mildew (*Erysiphe necator*) and grey mould (*Botrytis cinerea*).

We focused on these two grapevine (*Vitis vinifera* L.) diseases for the following reasons. First, as a pesticide-intensive activity, viticulture is highly affected by the challenge to reduce pesticide. For instance, in France viticulture accounted for only 3.3% of national agricultural land but for as much as 14.4% (in value) of phytochemicals sprayed in agriculture in 2006 (Butault et al., 2010), of which about 80% target only three pathogens: powdery mildew (*E. necator*), grey mould (*B. cinerea*) and downy mildew (*Plasmopara viticola*) (Mézière et al., 2009). Second, grapevine susceptibility to powdery mildew and grey mould has been shown to be positively influenced by grapevine vegetative development (Calonnec et al., 2013), and relevant features of grapevine canopy architecture have been identified for both pathogens: leaf number at flowering for powdery mildew (Calonnec et al., 2009; Valdés-Gómez et al., 2011; Burie et al., 2011) and pruning mass for grey mould (Valdés-Gómez et al., 2008). Third, the two pathogens differ in terms of their biology – *B. cinerea* is a necrotrophic fungi (Williamson et al., 2007) whereas *E. necator* is biotrophic (Gadoury et al., 2012) – and their interaction with the host, the grapevine. Most noticeable here is the opposite trend in grapevine berries susceptibility to both pathogens over time: while they become less susceptible to powdery mildew as they mature (Doster and Schnathorst, 1985; Merry et al., 2013), grapevine berries become more susceptible to grey mould during their development (Deytieux-Belleau et al., 2009), which contributes to explain that grapevine vegetative development is more relevant to powdery mildew early in the cycle (around flowering) and to grey mould late in the cycle (from veraison to maturity).

Analysis of the relationship between grape yield and grapevine susceptibility to powdery mildew and grey mould requires highlighting some key features of grape yield formation and vegetative development. On the one hand, leaf number at flowering and pruning mass are determined in the *current* year by growing conditions between budburst and harvest like temperature (Schultz, 1992), water availability (Pellegrino et al., 2006; Lebon et al., 2006; Celette et al., 2005) and nitrogen availability (Metay et al., 2015). On the other hand, grapevine yield formation extends over two consecutive years[1] (Vasconcelos et al., 2009; Meneghetti et al., 2006), and it is now well established that (i) bunch number per vine and berry number per bunch are the main components of grape yield, accounting together for about 90% of seasonal yield variation (Dry, 2000; Clingeleffer et al., 2001; Clingeleffer, 2010; Guilpart et al., 2014), (ii) these two components are determined by temperature (Buttrose, 1970; Vasconcelos et al., 2009), light and assimilate supply to the buds (Keller and Koblet, 1995; Dry, 2000; Lebon and Wojnarowiez, 2008), and grapevine water and nitrogen status around flowering in the *previous* year (Guilpart et al., 2014; Buttrose, 1974b; Keller, 2005; Vasconcelos et al., 2009).

As grape yield is mostly determined in *year 1* and grapevine susceptibility to powdery mildew and grey mould is mostly determined in *year 2*, the following hypothesis can be formulated: a *year 1* with favourable growth conditions followed by a *year 2* with unfavourable growth conditions should result in a high yield and a low susceptibility to these two diseases, and conversely. Moreover, as the field experiment analyzed in this paper was located in a semi-arid environment (a Mediterranean vineyard) in which water is the main limiting factor (Jones et al., 2005; Flexas et al., 2010), it can be proposed that the balance between grape yield and grapevine susceptibility to powdery mildew and grey mould depends on inter-annual variation in water stress experienced by the grapevine. The objectives of this paper are to test (i) if there is a general trade-off between maintaining grape yield and reducing grapevine susceptibility to powdery mildew and grey mould through a reduced vegetative development, and (ii) if inter-annual variations in water stress can explain variations of the balance between grape yield and grapevine disease susceptibility within this trade-off. These hypotheses were tested in a 3-year field experiment (2010–2012) located in the south of France, in which pests and diseases were controlled by spraying pesticides and varying levels of grape yield and grapevine vegetative development were set through irrigation, fertilization and cover cropping.

[1] The two years of grape yield formation will be referred to as *year 1* and *year 2* hereafter, *year 2* being the year of production.

2. Material and methods

2.1. Experimental site and design

An experiment was carried out from 2010 to 2012, on a vineyard located near Montpellier (Domaine du Chapitre) in the south of France (43° 32′ N; 3° 50′ E). The climate was Mediterranean (mean annual rainfall about 700–750 mm). Grapevines (*V. vinifera* L. cv. Shiraz) were planted in 2002, at a density of 3333 vines per hectare (2.5 m × 1.2 m). Vines were spur pruned to 12 nodes per vine (6 spurs and 2 nodes per spur). About one month after bud burst, the number of shoots per vine was manually adjusted to a target of 12 shoots per vine. Contrasted levels of water and nitrogen supply were set by irrigation, fertilization and cover cropping, leading to five treatments (from low to high resource availability): (i) cover cropping with a mix of annual medics (*Medicago truncatula, Medicago rigidula, Medicago polymorpha*) in the inter-row (hereafter referred to as 'medics'), (ii) bare soil obtained by mechanical weeding in the inter-row, (iii) fertilization, (iv) irrigation, and (v) irrigation plus fertilization (hereafter referred to as 'irr-fert'). Mechanical weed control was applied to all vine rows. Irrigation and/or fertilization were applied in 2011 and 2012, not in 2010, but the vines were monitored over the 3 years. When applied, fertilization was provided as 120 kg N ha^{-1} $year^{-1}$ divided up into three applications of 40 kg N ha^{-1} (amonitrate 50–50%) each (2–3 weeks after budburst, at flowering and harvest) applied under the grapevine row. When applied, drip irrigation accounted for between 40 and 60% of potential evapotranspiration between budburst and harvest, which represented 240 mm in 2011 (applied between April 18th and August 18th) and 160 mm in 2012 (applied between May 4th and August 3rd, Fig. S1). Pests and diseases were controlled by spraying pesticides in all treatments (see Table S1 for a list of applied fungicides). Treatments were applied as strips (Guilpart et al., 2014). The 'medics' and bare soil treatments were composed of 185 vines (37 vines per row and 5 rows). Due to practical constraints of water availability for irrigation, the 'irr-fert' and irrigated treatments were composed of 55 vines (11 vines per row and 5 rows) and the fertilized treatment was composed of 70 vines (14 vines per row and 5 rows).

2.2. Measurements

2.2.1. Grapevine yield and yield components

The grape yield and its components were measured once at harvest time. For the 'medics' and bare soil treatments, grape yield, bunch number and shoot number per vine were measured on 16–30 vines. On each of these vines, two bunches were selected at random to count berry number per bunch and measure the fresh mass of 200 berries. From these same bunches, four samples of 200 berries were collected to measure total soluble solids by