Available online at www.sciencedirect.com
ScienceDirect
Agricultural and Forest Meteorology 141 (2006) 257–262
AGRICULTURAL AND FOREST METEOROLOGY
www.elsevier.com/locate/agrformet

Short communication

Relationship between pathogen splash dispersal gradient and Weber number of impacting drops

S. Saint-Jean [a,b,*], A. Testa [c,d], L.V. Madden [a], L. Huber [b]

[a] *Department of Plant Pathology, The Ohio State University-OARDC, Wooster, USA*
[b] *UMR Environnement et Grandes Cultures, INA P-G & INRA, Thiverval-Grignon, France*
[c] *Polytechnic University of Marches, Institute of Biochemical Biotechnologies, Ancona, Italy*
[d] *University of Naples "Federico II", Department of Arboriculture, Botany, and Plant Pathology, Portici, Italy*

Received 14 June 2006; received in revised form 2 October 2006; accepted 20 October 2006

Abstract

We examined the potential of the dimensionless Weber number of an impacting water drop for predicting the associated gradient of pathogen dispersal. Previously shown to be related to the mechanisms of splash droplet formation, the Weber number compares the inertial forces to surface tension force of the drop. Based on new data on tomato late blight and previously published data on wheat rust diseases and on strawberry diseases, the number of spores splashed by incident drops at a given distance from the source is expressed as a negative exponential function of distance multiplied by the pathogen deposition term in the immediate vicinity of the source. Results show strong evidence that the pathogen deposition term is well described by a power law function of the Weber number.

Keywords: Pathogen dispersal; Rain splash; Weber number

1. Introduction

The main mechanism involved in the dispersal of plant pathogens by rain splash, is the formation of splash droplets in which propagules of the disease-causing agent are held and transported (Madden, 1992; McCartney et al., 1997). Only a few attempts have been made to relate propagule dispersal with the characteristics of rain drops at impact. The kinetic energy, velocity and momentum of rain drops have been used as descriptors of dispersal gradients (Walklate, 1989; Yang et al., 1992; Geagea et al., 1999). These studies point out that the splash dispersal of plant pathogens should be linked with physical properties of rain drop.

Therefore, using a measurement technique of counting spores within droplets (Saint-Jean et al., 2005) applied for the sporangia of *Phytophthora infestans* dispersed by rain splash, we present a description of the dispersal of plant pathogens based on a physical parameter of the mechanism of splash droplet production. This approach is then applied to published results for four other pathogens obtained with single drops in controlled conditions.

2. Splash dispersal mechanisms of pathogen propagules

The dispersal of plant pathogens by rain splash occurs after impact of rain drops on plant surfaces. The rain drop may fragment into several splash droplets and

* Corresponding author at: UMR Environnement et Grandes Cultures, INA P-G & INRA, Thiverval-Grignon, France.
Tel.: +33 1 30 81 55 55; fax: +33 1 30 81 55 63.
E-mail address: Sebastien.Saint-Jean@grignon.inra.fr (S. Saint-Jean).

0168-1923/$ – see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.agrformet.2006.10.009

entrain propagules from infected tissues. When a drop impacts on a surface such as plant leaf, the forces that act on the drop are the inertial forces, the viscous and the capillary forces (Rein, 1993). The inertial forces come from kinetic energy of the rain drop acquired during fall. The kinetic energy is determined by the size of the water drop and its velocity at impact. The viscous forces originate from energy dissipation and are determined by the viscosity of the fluid. In the condition of impact of rain drop, the viscous force is very low and can be neglected (Range and Feuillebois, 1998). The last force is the capillary force or so-called surface tension force, which results from minimising the interface between liquid and air, constraining a drop to a spherical shape. Therefore, at impact, the main forces acting on the drop are the inertial force and surface tension force. In other words, the force balance of the water drop comprises the combination of kinetic energy acquired during fall and the surface tension preventing the water drop interface to increase. When the surface tension force cannot balance the inertial force, the water interface is deformed to the point of, first pinching, then breaking off, and lastly, producing splash droplet.

The dimensionless Weber number (Weber, 1931) has been shown to be a pertinent parameter for the description of splash droplet formation after impact (Range and Feuillebois, 1998) and spray formation (Lefebvre, 1989). The Weber number compares the inertial forces to surface tension force. The Weber dimensionless number is defined for the impacting drop as:

$$\mathrm{We} = \frac{\rho D V^2}{\sigma} \tag{1}$$

where D is the drop diameter (m), V the impact speed (m s^{-1}), ρ the liquid density, and σ is the surface tension. For water at 20° C, ρ and σ equals to 998 kg m^{-3} and 73 mN m^{-1}, respectively.

3. Experimental approaches

We monitored the dispersal of propagules of the Oomycetes pathogens *P. infestans* from infected tomato leaves with sporulating lesions. The description of the inoculation setup which created a generally uniform sporulation pattern on tomato leaves is given in Saint-Jean et al. (2005). The infected leaves were placed on a support at ground level. Incoming drops were generated from a vertically held hypodermic needle connected to a purified water reservoir by a polyethylene tube. Drops of two diameters (2.70 and 3.30 mm) were released from two different heights (1.0 and 1.5 m) and fell onto the infected leaf (Table 1). Calculation of velocity, kinetic energy and Weber number at impact was computed with a mechanistic model that takes into account mainly drag forces and weight of falling drops (Saint-Jean et al., 2004).

Four sequential identical drops were released on the same spot on the leaf. Splash droplets were collected on five pairs of microscope slides (25.4 mm × 76.7 mm) located at the same level as the leaf. Each pair of slides was put side by side along the shortest length and the centre of each pair of slides was located, respectively, at 10, 45, 81, 116 and 151 mm from the source. The experiment was repeated a total of three times for each set of conditions.

Each collecting slide was assessed by image analysis. The methodology of propagules counting within splash droplets was fully described in Saint-Jean et al. (2005). For each set of four drops (Table 1), the log-transformed number of deposited sporangia was related to the distance d (cm) by a linear relationship, (*i.e.* we assume the decrease with distance as exponential):

$$\ln(y+1) = a - bd \tag{2}$$

where y is the total number of sporangia per single impacting drop found at distance d (cm) and a and b

Table 1
Diameter and height of falling water drops, calculated velocity at impact (V) (slightly higher than 50% of drop terminal velocity), mass (m), and Weber number at impact (We) (Saint-Jean et al., 2004), together with estimates of slope and intercept and standard errors found for a regression analysis of log of *Phytophthora infestans* sporangia per incoming drops in relation to distance (see Eq. (2))

Impact drop characteristics					Splashed sporangia gradient		
D(mm)	Height (m)	V (m s^{-1})	m (mg)	We	Intercept (a)	Slope (b) (cm^{-1})	R^2
2.70	1.0	4.05	10.3	604	1.91 ± 0.49	0.150 ± 0.052	0.61
3.30	1.0	4.12	18.8	766	3.47 ± 0.40	0.260 ± 0.042	0.83
2.70	1.5	4.78	10.3	844	4.04 ± 0.60	0.285 ± 0.063	0.72
3.91	1.5	5.00	31.3	1334	4.40 ± 0.44	0.274 ± 0.047	0.81

Four incoming drops were released with three replicates for each incoming drop (the fitting procedure was conduced on all replicates, *i.e.* without any averaging).