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Bean root rot management: Recommendations based on an integrated approach for plant disease control

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ABSTRACT

A systematic understanding of agro-ecosystems suppressing soil-borne plant pathogens is one of the most desired objectives in plant disease management. Large-scale detection of agro-ecological descriptors of variations among crop-disease pathosystems will certainly save time to screen a wider range of conditions and identify more effective factors, to further examine at smaller scales, and to develop an integrated crop-disease management program. Therefore, a fairly comprehensive array of agronomic and environmental traits was examined across commercial fields cultivated with the common bean, *Phaseolus vulgaris* L. Then, ten factors chosen according to practical relevance to root rot epidemics and bean production were studied in laboratory, greenhouse or experimental field. The advantages and findings of this case study as a useful framework in plant pathology were discussed in this short review.

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is the most important food legume in human nutrition worldwide (Broughton et al., 2003). Dry beans were harvested from 30,612,842 ha globally, which produced 26,529,580 t of seeds (FAOSTAT, 2014). The production of bean crops has been mainly threatened by root rot pathogens in most bean growing areas around the world such as northeast Brazil, Mexico, Nicaragua, coastal Peru, and the United States (Abawi, 1989). However, there is no concise information on global yield losses due to root rots in bean crops. Due to difficulties in incorporating root rot resistance into bean cultivars (Miklas et al., 2006), non-economic and ineffective disease control using fungicides is commonly applied by bean growers. Thus, across bean cropping systems, root rot pathogens continue to prevent commercial bean production.

It seems that a study framework is required to gain adequate information based on which more reliable and influential recommendations on root-rot-control can be made to bean farmers. In the present review, findings obtained at various scales from region to experimental-plot, to greenhouse and laboratory studies on bean production and root rots were integrated to develop a more effective and sustainable disease and crop management program. In the first step, associations of a large number of agro-ecological variables with the bean-root-rot pathosystem were explored on a regional or macro-scale basis. Then, such systematic understanding of highly heterogeneous agro-ecosystems allowed the selection of more influential factors to be further examined at small scale. With this approach, uncertainties at regional scale can be addressed at either field-plots or controlled environment scales. This study framework as one of the main promising outcomes of our multi-scale findings has very important significance to advancing the epidemiology of bean root rots, ensuring the efficiency of crop and disease management strategies, saving time and reducing expenses by focusing research on effective management.

In Iran, beans are widely cultivated over more than 109,000 ha of irrigated lands annually (Anonymous 2014). Zanjan province is the second major contributor to dry bean production in Iran, with an average production of 2519 kg/ha harvested from 13,280 ha in 2014 (Anonymous, 2014). A number of recent reports from this area demonstrate that soil-borne root rot diseases are threatening bean production. In Zanjan, *Fusarium solani*, *Rhizoctonia solani*, *Macrophomina phaseolina* and *F. oxysporum*, are the predominant root rot pathogens causing up to 65% yield losses in heavily infected bean crops (Naseri 2007, 2008a, 2008b; Naseri and Moradi, 2007). The distribution of root rot pathogens across the region and the significant yield loss encouraged a systematic epidemiological understanding of bean root rots prevalent in agro-ecosystems to provide recommendations from an

Abbreviations: CRR, Charcoal root rot caused by *Macrophomina phaseolina*; FRR, Fusarium root rot by *Fusarium solani*; FW, Fusarium wilt by *F. oxysporum*; RRR, Rhizoctonia root rot by *Rhizoctonia solani*

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integrated disease-management program. Therefore, Zanjan's main bean growing areas were chosen for this case study.

2. Description of study sites and region

A representative subset of 122 common bean fields (35 in 2008 and 87 in 2009) ranging from 0.5 to 14 ha in size were randomly selected across the main bean growing area of Zanjan province in order to include all common agronomic and environmental conditions. The study region was located between longitudes 48 °20′–49°30′W to E and latitudes 36°–36°40'S to N. The normal bean growing season in Zanjan involves planting in mid to late spring (May–June) and harvesting in late summer (September). Bean growers were queried about their applications of fungicides and herbicides, planting date and rotation program. Then, commercial bean fields were examined for bean market class, planting depth, rhizobial nodulation and root rot diseases at vegetative, flowering, and pod maturity stages. The complete details on confirmation of major root-rot-pathogen infections and pathogenicity tests, disease assessments, status of rhizobial symbiosis were provided in previous reports (Naseri, 2008b, 2014a; Naseri and Marefat, 2011). At vegetative and pod maturity stages, field soils were sampled and analyzed according to standard methods as Naseri (2013a) described earlier. The soil organic matter, pH, clay, sand and silt in the fields were within the 0.4–1.8%, 7.0–7.9, 14–53%, 4–65% and 15–48% ranges, respectively. The field-plot and greenhouse experiments were conducted in the Agricultural and Natural Resource Research Center located at Kheirabad region (36°30’N, 48°47’E, 1770m a.s.l.) during 2009 and 2010. Mean annual rainfall and temperature in Zanjan, with a cold semi-arid climate and a hot and dry season from June to September, is 315.4 mm and 11.7 °C, respectively (Zanjan Meteorological Office 2009).

3. Synthesis of regional findings

Epidemic levels and consequent yield reductions differ between bean fields of the same area, as well as in the same field from season to season. A considerable part of such differences corresponded with variations in agronomic and environmental conditions, which are known as influential factors on the root-rot–bean pathosystem from planting to harvesting time (Table 1). More severe Fusarium root rot (FRR) epidemics occurred in pinto and white beans, frequent irrigations at 2–3 days intervals at flowering growth stage, denser plant population, earlier and deeper sowings, rotations with barley, bean, tomato or wheat, overuse of urea (50–500 kg/ha), soils with greater silt content (30–48%), soil treatment with fungicides, low soil organic matter, non-nodulated roots, pH levels of 7.0–7.5, lacking herbicide and manure use, sowing non-fungicide-treated seeds, mechanical sowing, furrow irrigation, and planting on raised seedbeds (Naseri, 2010; Naseri and Marefat, 2011; Naseri, 2014a; Naseri et al., 2016). Rhizoctonia root rot (RRR) epidemics were restricted in red beans, drought-free fields, irrigations at 6–9 days intervals, shallow planting, lower plant and weed densities, rotations with potato and tomato, non-fungicide-treated soils, at a level of 4–25% sand content, high soil organic matter, highly nodulated roots, lower soil silt, lower soil sand and pH, lacking urea application, later plantings, manure application, sprinkler irrigation, manual cultivation, weed control using paraquat or bentazon (Naseri, 2013a, 2013c, 2016; Naseri and Moradi, 2015). Large field size, high soil pH and sand, early and deep planting, lacking herbicide use, rotations with legumes or cereals, growing pinto and white beans, non-nodulated roots, mechanical cultivation and urea overuse intensified charcoal root rot (CRR) epidemics (Naseri, 2014b). Lower Fusarium wilt (FW) levels were associated with postponing sowing, growing red beans, lacking urea application, rotations with potato and tomato, shallow planting, neutral soil pH, manual sowing, lower soil clay and silt (Naseri, 2014c; Naseri and Tabannde, 2017). Higher yield levels were detected in red beans, lower root rots, proper planting date and density, lower weed density, soils with lower sand (25–45%) and silt (15–30%) contents, greater soil organic matter (1.2–1.8%), higher rhizobial nodulation, fungicidal treatment of seed, lacking urea fertilization, herbicide and manure applications, manual sowing, sprinkler irrigation, rotations with potato and tomato (Naseri and Marefat, 2011; Naseri, 2014a; Naseri and Tabannde, 2017).

Table 1
Soil and agronomic parameters that intensified root rot epidemics in commercial bean fields.

Variable	Fusarium root rot	Rhizoctonia root rot	Charcoal root rot	Fusarium wilt
Bean class	Pinto, white	White	Pinto, white	Pinto, white
Early-season drought	NS[a]	Applied	NS	NS
Irrigation interval	2–3 days	2–3 days	NS	NS
Irrigation system	Furrow	Furrow	NS	NS
Field size	NS	NS	large	NS
Herbicide	Not applied	Not applied	Not applied	Applied
Planting density	8–17 plant/ quadrat[b]	8–17 plant/ quadrat	NS	NS
Weeds	> 16 weed/ quadrat	> 16 weed/ quadrat	NS	NS
Planting date	May 2nd wk	May 2nd wk	May 2nd wk	May 2nd wk
Planting depth	> 5 cm	> 5 cm	> 5 cm	> 5 cm
Soil clay	NS	NS	NS	35–53%
Soil silt	30–48%	15–30%	NS	30–48%
Soil sand	NS	45–65%	45–65%	NS
Sowing technique	Mechanical	Mechanical	Mechanical	Mechanical
Urea	50–500 kg/ha	50–500 kg/ha	50–500 kg/ ha	50–500 kg/ha
Rhizobial nodule	Absent	Absent	Absent	Absent
Soil-fungicide	Treated	Treated	NS	NS
Seed-fungicide	Non-treated	Non-treated	NS	NS
Seedbed	Raised	Raised	NS	NS
Previous crop	Barley, bean, tomato, wheat	Legumes	Legumes, cereals	Legumes
Organic matter	0.4–0.8%	0.4–0.8%	NS	NS
Manure	Not applied	Not applied	NS	NS
Soil pH	7.0–7.5	7.5–7.9	7.5–7.9	7.5–7.9

[a] NS means non-significant association.
[b] Quadrat size was 0.25 m^2.

Understanding how strongly farmers’ operations interact with the plant-disease pathosystem is important if farmers are to achieve recommendations on efficient cultural strategies to control diseases and improve yield. Indeed, this information should help identify agronomic practices that might restrict root rots establishment on bean crops and thus lead to the selection of most relevant root-rot-control strategies for further field experimentations with the purpose of saving study time. However, information on interrelationships among bean production, root rots epidemics, and prevalence of pathogens in roots, seeds and soils was also necessary to optimize control methods. Therefore, attempts were made to meet these research requirements. The soil population and frequency of pathogens isolated from roots and seeds differed between pathogens and bean fields. *F. solani* was the most prevalent pathogen isolated from rotted roots and seeds and bean-field soils in comparison with *R. solani*, *M. phaseolina* and *F. oxysporum* (Naseri, 2008b; Naseri and Mousavi, 2015). Macro-scale findings revealed that the root rot index corresponded more strongly with root and seed infections compared to soil populations. This indicates that the infestation of bean seeds due to late-season epidemics occurs more commonly than the soil-borne infection of bean roots in the pathosystems studied. Therefore, the fungicidal treatment of bean seeds to reduce seedborne infections in bean crops should be considered prior to