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ORIGINAL ARTICLE

Dynamics of common bean web blight epidemics and grain yields in different tillage systems

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Abstract The effects of tillage systems on the dynamics of web blight caused by *Thanatephorus cucumeris* and yield of common bean (*Phaseolus vulgaris*) cv. Pérola were studied in three field experiments during the planting seasons of 2004/2005, 2005/2006 and 2006/2007. Congo grass (*Urochloa ruziziensis*) was managed in a naturally infested field to establish the following cropping systems: no-till (NT), minimum-tillage (MT) (disking with partially incorporated straw); and conventional tillage (CT) (residues burial by soil plowing). The area under disease progress curves (AUDPCs) and the disease progress rates were generally low in the NT system during the three cropping seasons, most likely due to the benefits of grass mulching. In general, AUDPC values were higher in the 2005/2006 compared to the other seasons due to more uniform rainfall distribution during the crop cycle. Bean yield was highest in CT despite a higher the high AUDPC, probably due to immobilization of nutrients in the soil after herbicide-burning of *U. ruziziensis*. An additional study conducted in 2006/2007 showed that distribution of 2 to 10 t. ha^{-1} of *U. ruziziensis* straw over bare soil increased average yield by 29.9 %, while disease severity was reduced by 31.1 %, in comparison to control plots with no mulch.

Keywords *Thanatephorus cucumeris* · *Phaseolus vulgaris* · *Brachiaria ruziziensis* · No-tillage · Crop-livestock integration

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Introduction

Web blight, caused by *Thanatephorus cucumeris* (Frank) Donk (anamorph: *Rhizoctonia solani* Kühn) is a major disease of common bean (*Phaseolus vulgaris* L.) in the humid tropics, where high temperatures and humidity favor disease development. In Brazil, hot and humid conditions are limiting factors to bean crops in the North and locally in the Northeast and Mid-West during the rainy season (Cardoso et al. 1997). Although Costa-Coelho and others (2014) reported a significant effect of plant architecture on web blight epidemics, current levels of genetic resistance are insufficient to prevent epidemics in commercial *Phaseolus* cultivars. In addition, the wide host range of *T. cucumeris*, which has many cultivated and wild hosts (Costa et al. 2007), further limits disease control due to the availability of inoculum for the epidemics.

The pathogen survives in the soil saprophytically or as dormant microsclerotia for several years. Infection begins when basidiospores formed at the soil surface reach the upper parts of the plants after dispersal by wind and rain drops (Galindo et al. 1983a; Ogoshi 1987). In addition, under disease-conducive weather, web blight spreads rapidly to neighbor plants via mycelium bridges (Schwartz 2005). Hence, common bean crops may be affected within a few days.

A positive effect of the use of straw mulch on the soil surface on the reduction of the pathogen's dispersal and web blight severity was reported previously (Galindo et al. 1983a, b). Unfortunately, most cover crops traditionally used for this purpose have high decomposition rates in tropical climates (Braz et al. 2006), resulting in deficient soil cover and insufficient protection of *T. cucumeris* hosts. The adoption of organic inputs to protect soil surfaces also depends on their availability to cover large cropping areas, so options like rice hulls and tree residues, recommended respectively by Galindo et al. (1983b) and Rosemeyer et al. (2000), are not feasible in Brazil. Furthermore, they are demanding on human labor and unlikely to be widely adopted. The *Phaseolus* crop in Brazil is the largest in the world, exceeding 3.2 million tons on more than 3.0 million ha annually (CONAB 2016). Thus, there is a strong demand for farmer-friendly methods that provide efficient soil protection to manage web blight and improve bean production systems (Abawi and Widmer 2000).

Cultural practices recommended for the management of soilborne pathogens such as *R. solani*/*T. cucumeris* should be compatible with no-tillage cropping (NT), considered critical for sustainability of annual crops. The adoption of NT affects the physical, chemical and biological soil components and therefore the dynamics of plant diseases. Studies conducted in the Brazilian Mid-West indicated a decrease in the intensity of some diseases after adoption of no-till, such as soybean stem canker (*Diaporthe phaseolorum* f.sp. *meridionalis* Morgan-Jones), common bean and soybean white mold (*Sclerotinia sclerotiorum* (Lib.) De Bary) and of Fusarium wilt of common bean (*Fusarium oxysporum* f.sp. *phaseoli* Kendrick & Snyder) (Ferraz et al. 1999; Freitas et al. 2002; Napoleão et al. 2005; Görgen et al. 2010; Toledo-Souza et al. 2012). In contrast, Toledo-Souza et al. (2008) found higher soilborne populations of *Fusarium* spp. and *Rhizoctonia* spp. under no-tillage cropping than in conventional tillage. Thus, the effect of conservation soil management practices on plant pathogens is not clear.

The suppressive benefits from the implementation of no-tillage cropping are partially attributed to an increase in the organic matter input from cover crops. Some grasses such as brachiarias (*Urochloa* spp.) have been largely adopted for mulch production in the tropics for soil and water conservation, or integrated in crop-livestock systems, as reviewed by Balbino et al. (2011). In spite of that, and of the importance of common bean web blight, data on the effect of planting systems on the *Phaseolus*-*Thanatephorus* pathosystem is not available. It is hypothesized that heavy grass mulch remaining on the topsoil will hamper the dispersal of *T. cucumeris* and the severity of web blight in areas where the pathogen is endemic. Thus, the objective of this study was to evaluate the effects of tillage systems on the severity of web blight and productivity of common bean, under high disease pressure conditions, in the Brazilian Mid-West during the rainy season.

Material and methods

Field experiments were carried out during three consecutive rainy seasons (2004/2005, 2005/2006 and 2006/2007) on a dystrophic Red-Dark soil (pH 5.4) in Santo Antônio de Goiás, Brazil (16°28′60″S, 49°17′00″ W, 823 m altitude). All fields were set out in a 3600 m^2 area surrounded by native forest, where web blight was frequently found on weeds such as *Acanthospermum australe* (Costa et al. 2007). A randomized complete block design with four replicates and 5 × 2 m plots was adopted. Common bean cv. Pérola (semi-prostrate growth, 90-day crop cycle) was planted on 0.45 m-spaced rows, 18 seeds m^{-1}. Foundation fertilizer was 03:17:00 NPK + Zn at 500 kg ha^{-1}. Potassium was added after emergence, at a rate of 80 kg ha^{-1} of KCl, and N topdressing was delivered as 100 kg ha^{-1} urea, at 15 and 30 days after planting (d.a.p.). Seeds were treated with imidacloprid (200 g.100 kg^{-1} of seeds), carbendazim + thiram (300 mL.100 kg^{-1} of seeds) and pencycuron (300 mL.100 kg^{-1} of seeds).

Congo grass [*Urochloa ruziziensis* (syn. *Brachiaria ruziziensis*) (R. Germ & Evrard.) Morrone & Zuloaga] was sown in mid-March and killed with 5.0 L ha^{-1} of roundup (glyphosate) in October, 30 days before bean planting, throughout the experimental area. The following cropping systems were studied: no tillage (NT); minimum tillage (MT) (disking with partially incorporated straw); and conventional tillage (CT) (burial of cover crop residues by soil plowing). Tilling for the MT and CT treatments was performed 7 days before bean planting. Common bean was sown annually in mid-November to coincide flowering and pod filling stages (susceptible states) with the most favorable weather conditions for web blight. The different tillage treatments were sown using a no-tillage drill, and were kept in their respective locations across years.

Disease severity on each plot was assessed weekly since crop emergence, with the aid of a 1–9 disease scale from Van Schoonhoven and Pastor-Corrales (1987), where score 1: no symptoms; score 3: up to 30 % necrotic leaf area; score 5: 31 to 60 % necrotic leaf area; score 7: 61 to 90 % necrotic leaf area; and score 9: over 90 % necrotic leaf area. Yield was assessed at the end of the season, after manual harvest and grain moisture adjustment to 13 %. The area under disease progress curve (AUDPC) was estimated according to Shaner and Finney (1977) after conversion of severity scores to the midpoint percentage of each respective class as recommended by Madden et al. (2007). All statistical analyses were performed with SAS statistical package 9.2 (SAS Institute, Cary, NC, USA). Data were subjected to linear mixed model analysis with the GLIMMIX procedure at $P = 0.05$, with cropping systems and block respectively treated as fixed and random effects. Rates of disease progress in different tillage systems were estimated and compared after fitting logistic model to the disease progress data (Madden et al. 2007).

To study the relationships between the amount of Congo grass dry matter, web blight intensity and grain yield, an additional trial was conducted in the 2006/2007 season. For this, 1 ha was planted with *U. ruziziensis* and killed with glyphosate (5.0 L ha^{-1}) after 8 months. Dry mass samples of the cover crop were harvested in a separate field, transported to the experimental site, and uniformly distributed in 5 × 2 m experimental plots, soon after planting common bean cv. Pérola in mid-November. Treatments were arranged in a randomized complete block design with four replicates. They consisted of dry matter equivalents to 2.0, 4.0, 6.0, 8.0, 10.0 t ha^{-1} of mulch spread over topsoil and a control treatment without straw. The relationships between yield or disease severity and mulch dry matter were studied using regression analysis at $P = 0.05$, with the REG procedure from SAS.

Results

Weather conditions were very conducive to web blight in all trials. Average maximum temperatures were similarly warm in all seasons (28.6–30.1 °C), and rainfall was abundant (respectively 567, 729 and 595 mm for 2004/05, 2005/06 and 2006/07). In addition, rain distribution differed in the vegetative crop stages, when rainfall was lower in the first and third seasons and very high in the second (Costa-Coelho et al. 2012). There was no significant interaction between cropping systems and season. The lowest AUDPC values were associated with NT cropping, and the highest with CT (Table 1). Minimum tillage ranked in an intermediate position in the first two trials, but it didn't differ from CT in 2006/2007.

A delayed disease onset was observed in the first season, and disease progressed fast after flowering and canopy closure, *c.* 58 d.a.p. (Fig. 1). First disease symptoms appeared at 43 d.a.p. in the first season when plants were at the R6

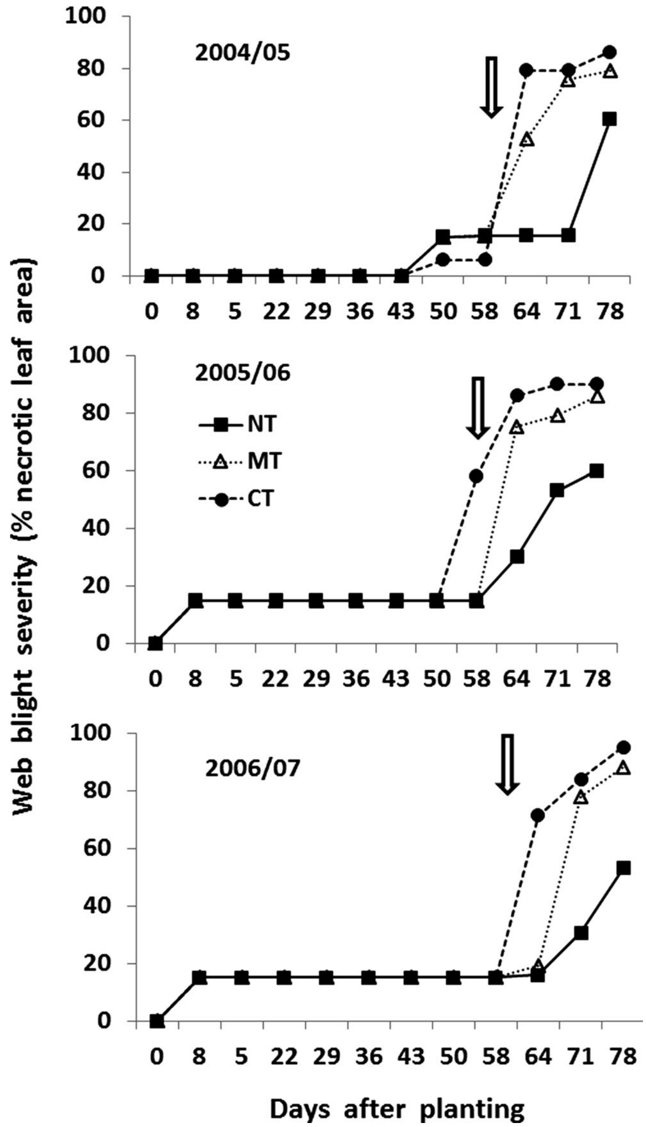

Fig. 1 Disease progress curves of web blight on common bean cv. Pérola, cropped under no-tillage (NT), minimum tillage (MT), and conventional tillage (CT), in the Brazilian Mid-Western rainy seasons of 2004/2005, 2005/2006 and 2006/2007. *Arrows* indicate approximate date of canopy closure

phenological stage (Laing et al. 1984), a more advanced stage when compared with the second and third season, when first symptoms were found soon after plant emergence at the V2 stage, 7 d.a.p. (Fig. 1). Web blight progressed rapidly after canopy closure reaching approximately 90 % of disease severity in plants under MT and CT in two out of three seasons. Usually, disease progressed slowly until 64 d.a.p., whereupon severity of web blight increased in a very fast pace up to 78 d.a.p., when plants entered into the pod ripening stage (R8) earlier and were harvested. Disease progress rates were high in all seasons (averages of 0.2035, 0.1989 and 0.2022 % diseased leaf area day^{-1}, respectively to the 1st, 2nd and 3rd seasons) and generally higher for the CT and lowest for the NT system, with MT intermediate (Table 2).

Table 1 Area under disease progress curve (AUDPC, % diseased leaf area.day) of web blight on common bean cv. Pérola at the pod ripening stage, assessed in three different years during the 2004/2005, 2005/2006 and 2006/2007 seasons

Planting system	AUDPC			
	2004/2005	2005/2006	2006/2007	Average
Conventional tillage	2150.31 aA	2584.75aA	2259.25 aA	2331.43 a
Miminum tillage	1431.5 bB	2110.5 bA	1828.75 aB	1790.25 b
No-tillage	855.75 cB	1580.75cA	1351.0 bB	1262.5 c
Average	1479.19 B	2092.00 A	1813.0 A	–
C.V. (%)	42.08	27.25	44.86	39.14

Means followed by the same capital letters in the rows and lowercase in the columns are not different at 5 % significance level

Table 2 Parameters of a logistic model fitted to disease progress curves of web blight in common bean cv. Pérola in different cropping systems and planting seasons: no-tillage, minimum tillage, conventional tillage, after fitting of the model ($y = 1/[1 + \exp(-\{\ln[y_0/(1-y_0)]+r.t\})]$), where y = disease severity r = disease progress rate and t = time

Planting season / cropping system	Intercept	Slope	R^{*2a}
2004/2005			
No-tillage	−12.040	0.1645	0.65
Minimum tillage	−14.020	0.2152	0.76
Conventional tillage	−14.060	0.2308	0.61
Season average rate		0.2035	
2005/2006			
No-tillage	−14.225	0.1677	0.94
Minimum tillage	−15.476	0.1829	0.93
Conventional tillage	−16.438	0.2462	0.95
Season average rate		0.1989	
2006/2007			
No-tillage	−13.182	0.1596	0.77
Minimum tillage	−15.245	0.2101	0.63
Conventional tillage	−16.208	0.2369	0.85
Season average rate		0.2022	

[a] Coefficient of determination of a linear regression model fitted to the relationship between observed and predicted severity values

Grain yields were generally very low due to the high severities of web blight (averages of 70.1 to 608.7 kg ha^{-1}, Table 3). Nevertheless, yields tended to increase in response to plowing in the CT system, which lead to incorporation and faster decomposition of the grass mulch. The complementary study on the effect of volume of Congo grass dry matter on yield and severity of web blight confirmed that yield increased in an average of 29.9 % with the addition of 2 to 10 t. ha^{-1} of *U. ruziziensis* straw over bare soil. Further, disease severity was reduced in 31.1 %, in comparison to control plots with no mulch. Second-order linear models best fitted data on the relationships between web blight severity and mulch dry matter ($R^2 = 0.91$), and between yield and mulch dry matter ($R^2 = 0.77$) (Fig. 2).

Table 3 Common bean cv. Pérola yield in a field naturally infested by *Thanatephorus cucumeris* in three consecutive rainy seasons, under different cropping systems in the Brazilian Mid-West

Planting system	Yield (Kg ha^{-1})			
	2004/05	2005/06	2006/07	Average
No-tillage	141.9 a	218.2 c	289.7 b	216.6 b
Minimum tillage	50.7 b	540.2 b	219.0 b	269.97 b
Conventional tillage	17.8 c	1067.0 a	627.2 a	352.46 a
Average	70.1 A	608.7 B	378.6 C	–
C.V. (%)	39.4	7.9	26.4	28.8

Means followed by the same lowercase in columns are not different at 5 % significance level

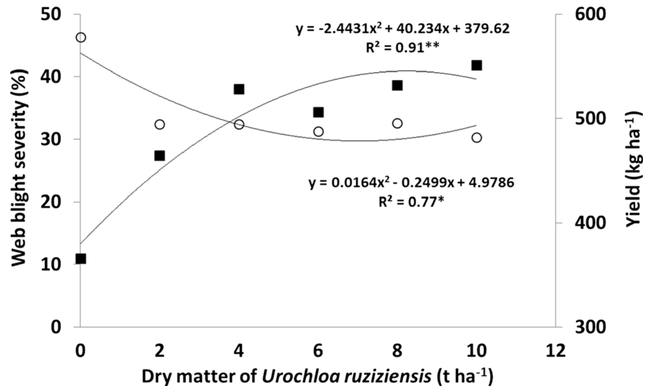

Fig. 2 Relationship between biomass of Congo grass (*Urochloa ruziziensis*) mulch dry matter and web blight (*open circles*) and yield (*filled squares*) of *Phaseolus* bean cv. Pérola in a field naturally infested with *Thanatephorus cucumeris*. * and ** correspond to significance at 5 % and 1*, respectively

Discussion

During the three cropping seasons, mulch from Congo grass likely provided a long-lasting physical barrier that obstructed dispersal of *T. cucumeris* inoculum by rain splash. Probably, other known benefits of NT such as increased activity of microbial antagonists and improvements on soil structure may also play a role in disease management, but were not investigated here. The reduced progress rate of web blight and AUDPC are likely due to a sum of benefits due to the implementation of NT.

Conventional tillage resulted in the opposite result, with higher AUDPCs in the three field trials. The AUDPC didn't differ between the three cropping seasons with CT. With regard to NT and MT treatments, higher AUDPC values were recorded in 2005/2006, in comparison to the 2004/2005 and 2006/2007 seasons. Higher disease severities in 2005/2006 were associated to early infections that expanded under the heaviest rainfall in that season (729 mm), especially in the early stages of the bean crop (513 mm). Furthermore, keeping the same treatments in their respective plots may have contributed to cumulative effects on disease reduction by NT over the three seasons.

The disease progress rates determined in this study, although high, differed among cropping systems, with lower progress rates in the no-till system in the three seasons (Table 2). The overall high disease progress rates late in the season are consistent with reports from Galindo et al. (1983a) and Prabhu et al. (1983), who also observed an early disease onset (a few weeks after planting) followed by a rapid increase during the flowering and pod filling stages. These authors associated the increase of web blight after row closure and bloom to a higher probability of infection, in response to larger leaf areas concomitant with highly favorable microclimate under the canopy. We hypothesize that the consistent reduction of web blight progress rate in response to mulching and absence of tillage is mostly due to the physical barrier of straw that delays disease spread, even though other consequences of NT, such as increased microbial activity and improvement of soil physical attributes may have their role in reducing disease severity. However, in the extremely favorable conditions that prevailed each season, the effect of mulch was not sufficient to control disease completely.

The logistic model described disease progress curves well, with high coefficients of determination (Table 2), as anticipated for this polycyclic pathosystem (Madden et al. 2007). Disease progress parameters (Table 2) were consistent with the visual analysis of disease progress curves and the analysis of AUDPC values: the NT system showed lower averages for disease progress rate in the three seasons. In contrast, the highest rates were found in CT while the MT system had intermediate values.

We observed an overall reduction of *c.* 30 % in web blight in the NT system, as compared with the CT system, possibly due to the grass straw preventing the spread of basidiospores of *T. cucumeris* from resident soil inoculum, as previously reported by Galindo et al. (1983a); Ogoshi (1987) and Cantonwine et al. (2007). Plant mulch with high lignin content and high C/N ratio has a slow decomposition rate and keeps the soil covered for a longer time. Beyond the long-lasting protective effects of mulch, other components of Congo grass straw may have additional features important to disease management. For instance, lignin content in grasses with high C/N ratio were found to increase populations of bacteria that degrade *R. solani* microsclerotia (Van Beneden et al. 2010), and are associated with soil suppressiveness to diseases.

Therefore, cultural practices for web blight management should avoid conventional tillage and residues with low C/N ratio. Cover crops with low C/N ratios should not be recommended because they provide ineffective soil protection (Braz et al. 2006) and are also known as a predisposing factor to diseases caused by *R. solani* (Michereff et al. 2005; Toledo-Souza et al. 2008).

Grain yield was strongly impacted by the high severity of web blight and of tillage system (Table 3). According to the Brazilian National Food Supply Agency, common bean yields were 958 kg ha^{-1} during the rainy season on average, from 2004 to 2007 (CONAB 2016). Therefore, yield losses were estimated at 85–98 %, 44 to 77 % and 35 to 77 % in the first, second and third seasons, respectively. Nevertheless, lower yields cannot be disregarded as due to the frequent rainfall and temperatures that in the summer may be above the requirements of common bean. It's also possible that soil management was improved with the succeeding experiments, resulting in increased productivities after the first trial. Although this study did not explore the effect of grass mulch on soil fertility, lower yields of plots under NT may be attributed to immobilization of N by soil microorganisms, a side effect typically found in the first years of implementation of no-tillage practices and previously reported by Silveira et al. (2011); Jantalia et al. (2006) and Severino et al. (2006). Such drawback can be overcome with adjustments on soil fertility (Rosolem et al. 2012), to avoid nutrient competition between common bean plants and the microbial community, until a favorable mineralization rate promotes a satisfactory nutrient availability in NT to the bean crop. In contrast, soil plowing in CT may have favored common bean root development and higher yield in two seasons, somehow compensating higher disease severities.

Such a hypothesis is supported by the complementary trial with different amounts of mulch, where there was no organic matter input on soil with dead roots of Congo grass. Amendment of 2.0 to 10.0 t ha^{-1} dry matter to the top soil decreased the severity of web blight by 31 % as compared with the 0 t ha^{-1} treatment and increased yields by almost 30 %. However, there were no differences in severity within the range of 2 to 10 t ha^{-1}, while yield increased only 86.75 kg ha^{-1} (Fig. 2). Others (Görgen et al. 2010) suggested that dry mass production of *U. ruziziensis* above 7.0 t ha^{-1} in the NT system has no impact for reduction of inoculum, in the *Sclerotinia sclerotiorum* - soybean pathosystem.

This study showed that in soils infested with *T. cucumeris* and at conditions very conducive to the disease, no-tillage cropping over Congo grass mulch reduced the severity of web blight on common beans in comparison with other tillage systems. These benefits may be attributed mostly to the restrained spread of *T. cucumeris* basidiospores, which may reduce both the effectiveness of the initial inoculum as well as disease progress. Additionally, the mulch possibly enhances activity of microbial antagonists to the pathogen. Congo grass seems to be a cover crop well adapted to NT bean cropping in the tropics, despite the need for adjustments in plant nutrition during the first years of no-tillage. Web blight management necessitates a combination of multiple strategies, including choice of planting date, control of weeds (Costa et al. 2007), fungicide applications (Costa-Coelho et al. 2012) and a choice of plant growth habit (Costa-Coelho et al. 2014). Nevertheless, the adoption of the no-till system under grass mulch is likely a valuable component to the integrated management of common bean web blight. The adoption of Congo grass mulch may also be adequate for web blight management in other hosts, such as soybean and cowpea (Nechet and Halfeld-Vieira 2007; Nechet et al. 2008).

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