Postprint: Relationship Between Severe Low-Temperature Freezing Injury and Standing Bamboo Traits and Forest Floor Mulching Management in Phyllostachys violascens Forests

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Date: 2018-10-26T00:00:00+00:00

Abstract

To investigate the characteristics of severe low temperature freezing injury and its influencing factors in Phyllostachys violascens forests, damage to standing bamboo of different ages and DBH classes was surveyed following the severe low temperature freezing injury event from late January to early February 2016 in forests with varying ground cover management durations. The results indicated that sustained low temperature freezing injury caused leaf water loss and ice formation, chlorosis, yellowing and withering in Phyllostachys violascens, with severe cases exhibiting whole-plant leaf yellowing, withering, and abscission; bamboo culms displayed shrinkage and blackening, leaf sheaths turned yellow and withered, and standing bamboo died. Under severe low temperature freezing injury climatic conditions, standing bamboo with 3 cm $\leq$ DBH $<$ 5 cm primarily exhibited damage types I–III, while the proportion of type IV damage significantly increased in smaller diameter classes (DBH $<$ 3 cm) and larger diameter classes (DBH $\geq$ 5 cm); 2-year-old and 3-year-old standing bamboo primarily exhibited damage degree types I and II, whereas 1-year-old and over-3-year-old standing bamboo primarily exhibited damage degree types III and IV; short-term ground cover management ($\leq$ 3 years) Phyllostachys violascens forests mainly exhibited damage types I–III, while long-term ground cover management ($\geq$ 5 years) forests mainly exhibited types III and IV, with type IV damage rate significantly increased, and restorative ground cover management forests had type IV damage rates below 20%, significantly lower than forests with ground cover management for 3 years or more. The study demonstrates that under severe low temperature freezing injury climatic conditions, standing bamboo age, standing bamboo DBH, and ground cover management all significantly affect the damage degree in Phyllostachys violascens forests. It is recommended to retain standing bamboo of 3–5 cm DBH, rationally regulate the

age structure of standing bamboo to retain sufficient 2–3-year-old culms, adopt restorative ground cover management practices, and that continuous ground cover management duration should not exceed 3 years.

Full Text

Damage Characteristics of *Phyllostachys violascens* Forests and the Relationship with Bamboo Status and Mulching Management Exposed to Freezing Stresses

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Abstract

To investigate the damage characteristics of *Phyllostachys violascens* forests under severe low-temperature freezing stress and their influencing factors, we surveyed the damage status of bamboo stands with different culm ages and diameter at breast height (DBH) under varying mulching management durations following a severe freezing event from late January to early February 2016. The results revealed that prolonged low temperatures caused leaf dehydration, icing, chlorosis, and yellowing, with severely affected culms exhibiting complete leaf senescence and abscission, stem shrinkage, blackening, and death. Under severe freezing conditions, culms with 3 cm $\leq$ DBH $<$ 5 cm primarily exhibited damage types I–III, while smaller (DBH $<$ 3 cm) and larger (DBH $\geq$ 5 cm) culms showed significantly higher rates of type IV damage. Two- and three-year-old culms predominantly suffered type I and II damage, whereas one-year-old and over-three-year-old culms primarily experienced type III and IV damage. Short-term mulching ($ 3*years*)*resultedmainlyintypeI–IIIdamage*, *whilelong* − *termmulching*($5 years) led predominantly to type III and IV damage, with significantly elevated type IV damage rates. Respite-mulching stands (3 years mulching + 2 years respite) exhibited type IV damage rates below 20%, significantly lower than stands mulched continuously for 3 years or more. These findings demonstrate that under severe low-temperature conditions, culm age, DBH, and mulching management significantly influence damage severity. Sustainable management should maintain culms of 3–5 cm DBH, optimize stand age structure by retaining sufficient 2–3-year-old culms, and adopt respite-mulching practices with continuous mulching not exceeding 3 years.

Keywords: *Phyllostachys violascens*, freezing rain and snow hazards, mulching management, bamboo age

Introduction

Climate change has intensified the frequency, severity, and scale of extreme weather events such as freezing rain and snow, high temperature and drought, hurricanes, and heavy rainfall, profoundly affecting ecosystem structure, function, stability, and productivity. These phenomena have become a major focus of international concern (Meehl & Tebaldi, 2004; Richard, 2015; Sohngen & Tian, 2016). Catastrophic weather directly impacts normal forestry production and sustainable management (Su et al., 2008; Ge et al., 2014; Li et al., 2015), emerging as a critical abiotic disturbance factor in forest management. Millions of hectares of forest are affected annually by hurricanes, ice storms, drought, and other extreme weather events worldwide (Galik & Jackson, 2009). Damage severity varies among forest types under equivalent disaster conditions due to differences in species characteristics (height, diameter, age), developmental stages, stand structure, and management intensity (Jentsch & Beierkuhnlein, 2008; Wang et al., 2014). Plantation systems, characterized by single species composition, simple structure, low biodiversity, and intensive management interference, exhibit poor stability and stress resistance, often suffering catastrophic losses during severe natural disasters (Zhang et al., 2008; Zhou et al., 2011; Cui et al., 2014).

Phyllostachys violascens is an excellent bamboo species for shoot production in China, featuring rapid stand establishment, early shooting, delicious taste, and high yield, and has been widely cultivated across southern Chinese provinces. Since the early 1990s, intensive mulching techniques for early shoot production have been extensively promoted in major production regions including Lin' an, Deqing, and Yuhang in Zhejiang Province, significantly increasing both yield and economic benefits. However, from late January to early February 2016, during the peak shooting period in mulched *P. violascens* stands, northern Zhejiang experienced prolonged severe low-temperature freezing weather (approximately 15 days) with local temperatures reaching -15°C, accompanied by extended periods of rain and snow. This caused extensive leaf yellowing, stem shrinkage and discoloration, and even culm mortality, severely impacting stand regeneration and economic output. Continuous mulching management may have contributed to this severe damage by causing soil degradation, declining site productivity, and reduced culm growth activity and resistance (Guo et al., 2013, 2015; Chen et al., 2014; Guo et al., 2014). Therefore, following the 2016 freezing event, we investigated damage severity across different culm ages and DBH classes in stands under varying mulching durations in Lin' an, Zhejiang, to analyze damage characteristics and their relationships with culm traits and mulching management, providing guidance for sustainable management and disaster mitigation.

1. Study Area

The study was conducted in Taihuyuan Town, Lin' an City, Zhejiang Province (30°24 N, 119°32 E), which features a mid-subtropical monsoon climate with distinct seasons. The area has a mean annual temperature of 15.8°C, July mean

of 28.1°C, January mean of 3.4°C, annual sunshine duration of 1,939 hours, and a frost-free period of 234 days. Soils are red earth. Taihuyuan Town is a key region for *P. violascens* management, with over 10,000 ha of bamboo stands. Since the 1990s, intensive mulching for early shoot production has been widely adopted, making bamboo shoots a pillar industry and primary income source for local farmers. However, long-term mulching has caused increasingly severe site productivity decline (Guo et al., 2013, 2015; Chen et al., 2014; Guo et al., 2014) and reduced culm stress resistance. The prolonged severe low-temperature event from late January to early February 2016 severely affected regional *P. violascens* stands, causing extensive leaf desiccation, abscission, and whole-plant mortality.

2. Methods

2.1 Data Collection

In mid-April 2016, we conducted a comprehensive survey of major *P. violascens* distribution areas in the study region. We selected six stands each for different mulching durations (control, 1 year, 3 years, 5 years, 7 years) and respite-mulching management (3 years mulching + 2 years respite), with each stand covering at least 0.2 ha. Within each stand, we established three 5 m × 5 m plots and conducted complete inventories of culm age, DBH, and damage severity. Stand densities ranged from (16,275 ± 495) to (20,535 ± 705) culms · ha^{-1}, with mean DBH of (4.27 ± 0.25) cm and age structure of 1-year:2-year:3-year = 1.62:1.79:1. Damage severity was classified into four types: Type I—normal growth with <30% leaf yellowing; Type II—30–70% leaf yellowing with normal stems and leaf sheaths; Type III—>70% leaf yellowing with normal stems and leaf sheaths; Type IV—complete leaf yellowing, stem shrinkage, blackening, leaf sheath chlorosis, and culm death.

2.2 Data Processing

Damage rate (%) = (Number of culms with specific damage type and DBH/age class / Total number of culms in plot) × 100%. Data were organized and graphed using Excel 2007, and one-way ANOVA was performed using SPSS 16.0.

3. Results and Analysis

3.1 Effects of Culm DBH on Freezing Damage Severity

Analysis of Table 1 shows that with increasing DBH, damage rates for type I and II damage first increased then decreased, while type III and IV damage showed the opposite pattern. For 3 cm ≤ DBH < 5 cm culms, damage rates among all severity types showed no significant differences, but type I and II rates were significantly higher than those for DBH < 3 cm and DBH ≥ 5 cm culms. Conversely, type III and IV rates were significantly lower than in smaller and larger DBH classes, which also differed significantly from each other. These results indicate that DBH substantially influences damage severity under freez-

ing conditions. Culms of 3 cm ≤ DBH < 5 cm primarily exhibited type I–III damage (combined >55%), while smaller (DBH < 3 cm) and larger (DBH ≥ 5 cm) culms showed substantially elevated type IV damage (>25%). Therefore, for disaster mitigation, stands should maintain culms of 3–5 cm DBH, avoiding excessively small or large diameters.

Table 1 Damage ratio (%) of *Phyllostachys violascens* with different DBH under severe freezing conditions

DBH (cm)	Type I	Type II	Type III	Type IV
DBH < 3	30.26 ± 2.11 b	14.64 ± 0.92 c	28.47 ± 2.39 a	26.63 ± 2.11 b
3 ≤ DBH < 4	38.44 ± 3.02 a	21.22 ± 1.11 a	21.19 ± 2.57 c	19.15 ± 1.68 c
4 ≤ DBH < 5	35.02 ± 1.98 a	23.89 ± 1.68 a	20.27 ± 2.34 c	20.82 ± 3.05 c
DBH ≥ 5	24.88 ± 1.23 c	19.58 ± 1.26 b	25.99 ± 1.12 b	29.55 ± 4.98 a

Note: Values within the same column followed by different lowercase letters indicate significant differences ($P < 0.05$). The same below.

3.2 Effects of Culm Age on Freezing Damage Severity

Figure 1 [Figure 1: see original paper] reveals that with increasing culm age, type I and II damage rates first increased then decreased. Type I damage showed no significant difference between 2- and 3-year-old culms, both significantly higher than 1-year-old and >3-year-old culms, with >3-year-old significantly higher than 1-year-old. Type II damage differed significantly among all age classes, being lowest in >3-year-old, intermediate in 1-year-old, and highest in 2-year-old culms. Type III and IV damage rates showed the opposite trend, first decreasing then increasing with age. Two- and three-year-old culms showed no significant differences and had significantly lower type III and IV damage than 1-year-old and >3-year-old culms. For type III damage, >3-year-old culms were significantly more damaged than 1-year-old, while type IV damage showed no significant difference between 1-year-old and >3-year-old culms. These findings indicate that age substantially affects damage severity, with mild damage (types I–II) concentrated in 2- and 3-year-old culms, while severe damage (types III–IV) occurred primarily in 1-year-old and >3-year-old culms. Therefore, stand management should optimize age structure by retaining sufficient 2–3-year-old culms and implementing protective measures for 1-year-old culms.

Figure 1 Damage ratio (%) of *Phyllostachys violascens* with different culm ages under severe freezing conditions

Note: Different lowercase letters indicate significant differences ($P < 0.05$) among culm ages for the same damage type.

3.3 Effects of Mulching Duration on Freezing Damage Severity

Analysis of Table 2 shows that with extended mulching duration, type I and II damage rates decreased continuously, while type III and IV rates generally increased. Damage rates for types I, II, and IV differed significantly among mulching durations. Type III damage rates showed no significant differences among stands mulched for $ 3*yearsbutweresignificantlyhigherthancontroland*1−*yearmulchedstands.Theseresultsdemonstratethatmulchingdurationcriticallyaffectsdamageseverity.Short-termmulching*(3*years*)*resultedprimarilyintypeI–IIIdamage,withstandsretainingstrongregenerationcapac**termmulching*($5 years) caused predominantly type III-IV damage, particularly increased type IV damage, seriously threatening sustainable management.

Damage severity differed markedly between mulching regimes (Table 2). Respite-mulching stands showed type I and II damage rates significantly lower than control but not significantly different from 1-year mulched stands, while being significantly higher than stands mulched for $ $3 years. Type III damage was slightly higher than control and 1-year stands but significantly lower than stands mulched for $ $3 years. Type IV damage was significantly higher than control and 1-year stands but significantly lower than stands mulched for $ $3 years. Comprehensive analysis indicates that respite-mulching stands had >80% of culms in the first three damage categories and <20% mortality, demonstrating superior regeneration capacity and stress resistance compared to continuously mulched stands. Thus, respite-mulching represents an appropriate management approach, while continuous mulching should not exceed 3 years.

Table 2 Damage ratio (%) of *Phyllostachys violascens* under different mulching durations in severe freezing conditions

Mulching duration (years)	Type I	Type II	Type III	Type IV
Control (CK)	32.36 ± 2.62 a	36.25 ± 2.68 a	20.12 ± 2.01 b	11.27 ± 1.06 f
1	29.90 ± 2.15 b	32.50 ± 2.63 b	21.15 ± 1.39 b	16.45 ± 1.94 d
3	23.26 ± 1.35 c	27.79 ± 2.36 c	24.17 ± 2.55 a	24.78 ± 1.98 c
5	18.11 ± 0.94 d	20.36 ± 1.58 d	24.49 ± 2.11 a	37.04 ± 3.59 b
7	15.21 ± 0.49 e	18.93 ± 1.06 e	24.42 ± 2.15 a	41.44 ± 4.68 a
Respite-mulching (3 years + 2 years respite)	27.23 ± 2.06 b	31.46 ± 2.68 b	22.03 ± 1.98 b	19.28 ± 0.86 e

4. Conclusion and Discussion

Individual tree characteristics determine the degree of damage from ice and snow disasters. Different forest types exhibit varying damage levels due to growth characteristics (Zhu et al., 2006), and even within the same species, differences in age, size, and developmental stage lead to varying adaptability to stress (Kenderes et al., 2007). This study found significant differences in freezing damage severity among *P. violascens* culms of different DBH classes. Small to medium DBH culms (DBH $<$ 5 cm) primarily suffered type I–III damage, while larger culms (DBH $\geq$ 5 cm) experienced type III–IV damage, with 3 $\leq$ DBH $<$ 5 cm showing the lowest comprehensive damage and strongest freezing resistance. This contrasts with studies reporting severe damage to smaller trees in ice storms (He et al., 2010; Li et al., 2010; Zhang et al., 2010), possibly due to bamboo' s unique allometric growth pattern where height increases substantially faster than DBH. Small DBH differences result in large height variations, and larger culms typically exceed the mean stand height, making them more vulnerable to low-temperature injury (Kenderes et al., 2007). Conversely, excessively small culms below mean stand height are also prone to freezing. In managed *P. violascens* stands, 3–5 cm DBH culms constitute the majority, forming a relatively uniform canopy that collectively resists freezing damage, resulting in milder injury. Damage also varied significantly with culm age, with 2- and 3-year-old culms suffering less damage than 1-year-old and >3-year-old culms. This may be because 1-year-old culms have lower lignification, tender tissues, and higher water content, making them vulnerable to freezing (Yin et al., 2008; Li et al., 2015), while >3-year-old culms exhibit significantly reduced growth activity and resistance, particularly in mulched stands (Guo et al., 2015). Therefore, stand management should adjust structure to retain moderately sized culms and prioritize vigorous, resistant 2- and 3-year-old culms to enhance resistance to ice and snow disasters.

Mulching for early shoot production can substantially increase economic returns. However, long-term continuous mulching has caused soil degradation, reduced photosynthetic capacity and growth activity, and significantly decreased stress resistance (Guo et al., 2013, 2015; Chen et al., 2014; Guo et al., 2014). This study demonstrates clear differences in freezing damage among stands with different mulching durations. Short-term mulching ($ 3*years*)*resultedprimarilyintypeI–IIIdamage*(> 75 $5 years) caused significantly increased damage, with type III–IV damage exceeding 60% and mortality >35%. Respite-mulching stands showed markedly lower damage than continuously mulched stands, with >80% of culms in types I–III and <20% mortality, demonstrating superior regeneration capacity and stress resistance compared to stands mulched continuously for 3 or 5 years. Thus, respite-mulching represents a suitable intensive management approach, while continuous mulching should not exceed 3 years. If bamboo stands experience prolonged freezing during mulching, the mulch should be removed promptly to prevent secondary freezing damage from ice formation in water-saturated

mulch materials.

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Note: Figure translations are in progress. See original paper for figures.