Agricultural Water Management 205 (2018) 81–89

Contents lists available at ScienceDirect

Agricultural Water Management

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

The influence of irrigation frequency on the occurrence of rust disease (*Melampsora apocyni*) and determination of the optimum irrigation regime in organic *Apocynum venetum* production

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ARTICLE INFO

Keywords:
Disease intensity
Irrigation schedule
Organic crop
Leaf production
Economic values

ABSTRACT

In the Altay Prefecture, serious rust disease develops on *Apocynum venetum* in the organic farming systems that apply water every two to three days using trickle irrigation. A two-year field experiment was conducted to study the influence of extending the irrigation frequency on rust development and the economic viability of *A. venetum*. The maximum disease index (DI_{max}) and the area under the disease progress curve (AUDPC) with an irrigation interval of three days (T1 treatment, control in this study) reached 48.4% and 718 in 2012 and 54.4% and 1561 in 2013. With irrigation extended out to intervals of seven (T3 treatment), nine (T4 treatment) and eleven days (T5 treatment), the DI_{max} were 35.4% to 61.9%, and the AUDPC were 36.4% to 65.6%, lower than that of the T1 treatment. For all irrigation treatments, the AUDPC had a significant positive correlation with the soil water content of the surface (0–20 cm in depth) and the main distributing regions of roots (20.1–40 cm in depth), as well as the density of *A. venetum*. For the T3 treatment, the economic value of applied irrigation water was the highest and the amount of water applied was 54.8% lower than that of the T1 treatment, and thus it was determined as the optimum irrigation regime.

1. Introduction

Apocynum venetum (Apocynaceae) is a perennial herbaceous plant (Thevs et al., 2012). The extracts of leaves of this plant have been proven to effectively lower blood pressure and have cardiotonic, anti-depressant, anxiolytic and antioxidant activities, and so it has been used to produce medicinal products (Xie et al., 2012). Since 2009, more than 7300 ha of *A. venetum* fields have been established in the Xinjiang Uygur Autonomous Region, China, of which 2000 ha have been established in certified organic agricultural land near the Alakak township of the Altay Prefecture in this region.

Rust caused by *Melampsora apocyni* is the major disease affecting *A. venetum* and has been reported in some countries of Northern Europe and Asian (Gao et al., 2017). In the Altay Prefecture, the rust disease on cultivated *A. venetum* was first observed in 2009, and later on, the attempt of a grower of *A. venetum* to increase leaf yield through using frequent irrigation (interval of two or three days) couldn't continue as the rust disease became too severe. The disease incidence maximums reached 100%, causing leaf yellowing, wilting and defoliation, and even the death of the overwintering plant parts, leading to huge economic loss (Gao et al., 2017). The organic farming of *A. venetum* crops prohibits the use of chemical fungicides to control the rust disease and no cultivars of the species with durable rust resistance exist, thus there is an urgent requirement to utilize cultural practices such as optimization of irrigation schedules to improve rust disease management in the organic farming systems.

Previous studies have shown that frequent irrigation increases the foliar rust intensity on some plants such as wheat (*Triticum aestivum*), soybean (*Glycine max*) and willow (*Melampsora epitea*) resulting from changes of topsoil water content (Rotem and Palti 1969; Toome et al., 2010a). Attempts to provide protection against the onset of foliar rust diseases and to decrease severity through decreasing irrigation frequency or the amount of irrigation have had some success in controlling rust disease (Palti and Shoham 1983; Dixon 2015). For example, Black et al. (2001) reported that rust (*Puccinia arachidis*) intensity of peanut (*Arachis hypogaea*) plants under the lowest amount of irrigation treatment was 60% to 70% less than that of the highest amount of irrigation. In Altay Prefecture, water-saving trickle irrigation using groundwater is

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https://doi.org/10.1016/j.agwat.2018.04.026
Received 20 July 2017; Received in revised form 9 April 2018; Accepted 18 April 2018
Available online 30 April 2018

in widespread use in organic *A. venetum* fields to afford water for plant growth. If the optimization of irrigation schedules has been applied to control rust disease of plants caused by the genus *Melampsora*, including on *A. venetum*, published reports are lacking.

The irrigation of *A. venetum* fields not only influences the soil water content but also affects indirectly the density of *A. venetum* plants, the total coverage and also the diversity of weeds (Ping et al., 2014), all of which may affect rust disease occurrence. Wennstrom and Ericson (1991) had found that the change of vegetation coverage by grazing significantly reduced rust (*Puccinia pulsatillae*) on *Pulsatilla pratensis*. Another experiment by Mitchell et al. (2002) found that increased density of individual host species increased plant infection and disease severity. In addition, decreased plant species diversity increased pathogen load and the loading of the pathogens was almost three times greater in the average monoculture than in the average plot planted with 24 grassland plant species. Eleven individual diseases increased in severity (percentage of leaf area infected by a single disease) at low plant species diversity (Mitchell et al., 2002). The density of *A. venetum* plants and vegetation conditions may be modified by irrigation frequency adjustment, and thus it is necessary to explore the relationship between these factors and the rust disease development. The information gained would help explain how this agricultural practice affects rust development with cultivated *A. venetum* plants in organic farming systems.

In this study, a two-year monitoring of the rust was implemented to characterize the temporal development of rust disease under five irrigation frequencies. In addition, the association of rust intensity with the soil water content, the density of the *A. venetum* crop, and vegetation conditions were determined. We hypothesized that the rust disease intensity will decrease with extending of irrigation interval. As the irrigation adjustment will reduce the leaf yield, the economic viability of *A. venetum* crops was assessed, including the net profit of *A. venetum* leaf production and economic values of applied irrigation water. The aim was to determine an optimal irrigation frequency through achieving a favorable balance between the reduction of rust and the economic viability of *A. venetum* crops.

2. Materials and methods

2.1. Study site

The study site was located in an organically cultivated field of *A. venetum* (47°43′N, 87°32′E, at an altitude of 482–516 m, area 866 ha) in the Alakak township of the Altay Prefecture, China. This region of China experiences a northern temperate zone monsoon climate with an annual rainfall of 126.7 mm and an annual average temperature of 4.5 °C over the past 50 years.

The cultivated *A. venetum* field was established in the early spring of 2011. The seedlings were grown from seeds that were collected from wild *A. venetum* plants neighboring the cultivated field. The plants were spaced at 1 m within rows and 3 m between rows. As the site was initially too dry for the establishment of *A. venetum*, plants were irrigated every 2 or 3 days in 2011 by a trickle irrigation system. The cultivated field was uniformly divided to provide blocks, each within easy access to a water pump. There were ten rows in each block, and twenty of the multi-stemmed plants in each row. Each block was separated by a 5 m wide pathway and could be irrigated independently through control valves. The inner inlay drip irrigation piping (Tianye Co., Ltd., Xinjiang, China) was laid on the surface of soil along rows and there was one drip emitter at the center of each *A. venetum* plant. The spacing of neighboring dripper emitters was 1 m and the discharge rate was 4 Lh^{-1}.

2.2. Soil properties

The soil type was a sandy loam soil (pH = 7.91, organic matter = 1.03%, available K = 212.1 ppm, and available P = 6.3 ppm). To determine the hydraulic properties of the soil, undisturbed soil was extracted by a drilling machine, down to 80 cm. The soil was used to fill a PVC pot (diameter 15 cm, height 80 cm), watered to saturation and covered with a black plastic film to prevent evaporation. After water ceased to flow from the pot, it was weighed and dried in an oven at 70 °C for 7 days. The pot was then weighed to determine the mass of water and of the soil. The upper limit of the soil water content (θ_{UL}) was determined according to the gravimetric method using the following formula: $\theta_{UL} = (W_w)/(W_s) \times 100$, where W_w = the mass of water and W_s = the total mass of soil. The θ_{UL} value calculated for this soil was 13.7%. The available water in the soil was also assessed by measuring the lower limit of the soil water content (θ_{LL}). To calculate this variable, *A. venetum* seedlings were sown in the pot that contained a core of undisturbed soil. After the plants had been growing for one year, no water was further added to the pot. After all the leaves of plants had wilted from lack of water the soil water content was immediately determined using the above formula. The θ_{LL} value calculated for this soil was 3.0%.

2.3. Plant roots distribution characteristics

By using a soil-drilling method, the root distribution of *A. venetum* in this study site was determined. There was a small quantity of horizontal rhizomes and root hairs in the soil of the 0–20 cm depth (topsoil). In the soil of 20.1–40 cm in depth, a large quantity of lateral roots and root hairs grew from taproots, thus it was the main distributing root zone. In the lowest soil that was from 40 cm to the end of taproots (80 cm), there were less lateral roots and root hairs.

2.4. Experimental design

The experiments were conducted in 1 June to 31 August of 2012 and 2013 in a flat area in the cultivated *A. venetum* field (altitude of 495 m, area approximately 60 ha), with uniform soil properties. Before the experiment, the irrigation frequency in this commercial field was an interval of every three days. This interval of three days served as the control treatment, denoted as T1. Four irrigation frequencies extending the spacing of the irrigation were applied in the study: interval of five (T2 treatment), seven (T3 treatment), nine (T4 treatment) and eleven (T5 treatment) days. The time of irrigation was between 10.00 am and 5.00 pm. There were four replications of each treatment, arranged in a randomized complete block, with a total of 20 plots.

2.5. Measurement

2.5.1. Disease evaluation

Each year the disease was evaluated every 7–10 days from June to August. Ten *A. venetum* shrubs of a roughly similar size and height were marked in each plot, and five stems of each shrub, including one at the center, were marked for a rust survey. Three leaves taken at each of three sampling heights, 10 cm, 11–50 cm, and > 50 cm above the ground, of each marked stem, were used to assess the disease severity of rust. 450 leaves from each plot were sampled non-destructively for each evaluation. Rust severity was recorded as one of six discrete levels by visually estimating the percentage of observed leaves that were covered by uredinia: 0 for no signs of infection; 1 for 0.1% to 5% of leaf area covered with pustules; 2 for 5.1% to 20%; 3 for 20.1% to 75%; 4 for 75.1% to 90%; and 5 for 90.1% to 100%. The disease index (DI) was calculated by the following formula and used to assess rust disease intensity,

$$DI = {}^{100\times\Sigma_i^0(i\times Ln)}/_{5\times LN} \quad (1)$$

where i is the disease severity scale (i = 0, 1, 2, 3, 4, 5) and LN and Ln are the total number of leaves and the number of leaves of each disease severity, respectively (Zhang et al., 2007). For each plot, the mean