Effect of meteorological factor on water consumption of farmland shelterbelt, Northwest China

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Abstract. Estimating farmland shelterbelt water use is important for oasis water resource management and agricultural development. Meteorological measurements combined with sap flow techniques were applied to study the mechanism of water consumption in farmland shelterbelt. Results showed that mean daily sap flow velocity and canopy transpiration of farmland shelterbelt varied from 429±247 kg m⁻² d⁻¹ to 1495±634 kg m⁻² d⁻¹ and from 0.45 mm d⁻¹ to 1.58 mm d⁻¹. A multinomial model account for 81.3% of the variation was applied to explain canopy transpiration. Cross validation showed it provided good predictions of canopy transpiration for farmland shelterbelt. Knowing the relationship between climate variability and farmland shelterbelt water consumption is benefit for the management of water resources in oasis agriculture.

1. Introduction
Farmland shelterbelt is the protection of Oasis ecological and agricultural development in northwestern of China [1]. It is benefit for adjusting microclimate, keeping soil water in the Oasis, and it is widely used for agricultural production [2,3]. Water resource is a limitation for farmland shelterbelt development in the oasis, water management is one of the most important factors considered in Oasis agricultural development [4]. Because of the unreasonable distribution of water resources in the shelter forest, the oasis shelter forest declines and restricts the development of the oasis. It is necessary to know the mechanism of farmland shelterbelt water consumption to deal with oasis water management.

Meteorological factors and soil water controls tree’s transpiration and water use [5,6]. Solar radiation affects the stomatal activity of shelter forest trees and thereby affects the water consumption of shelter forest [7]; the change of temperature not only affects water evaporation but also restricts transpiration [8,9]; Both rainfall and humidity affect the opening and closing of stomata and the transpiration and water consumption of trees; in addition, the change of soil moisture will not only affect the growth of trees, but also restricts the transpiration and water consumption of trees [10-12]. So knowing the relationship between meteorological silver and water consumption in shelterbelt is benefit for the shelterbelt management [13,14]. In recent, researchers focused on study water shortage on crops and forest management [3,6,15], and lack of research has been done on the effects of climate change on water consumption in oasis.

The aim of the research was to: (a) estimate the water use of farmland shelter-belt; (b) identify influence factors to farmland shelterbelt water consumption. Getting influence factor of water...
consumption in farmland shelterbelt and the estimation method are helpful to the development of shelterbelt.

2. Methods

2.1. Study site
The research was carried at northern part of Xinjiang Oasis, northwest China (figure 1). It is a dry and semi-dry climate region, and its annual radiation is 128 kcal cm\(^{-2}\) [15], there are 172 frost-free days in the region, and its annual average air temperature is 6.9°C. The annual average sunshine hours are 2774.1 hours, accumulated temperature of calendar year is 4126.0°C.

![Figure 1. Study site (Northern part of Xinjiang Oasis).](image)

*Populus simonii* Carr trees (spacing 1.5×3 m, a row with five lines) are the main species of farmland shelterbelt, established in 2007. Six sampled farmland shelterbelt trees were selected to measure sapwood areas and diameter at breast height (DBH) [16]. The mean height of the farmland shelterbelt is 14 m with average trunk diameter of 17 cm.

2.2. Data collection
The six *Populus simonii* Carr sampled trees with different DBH were selected to install thermal dissipation sensors (TDP80 Dynamax, USA) [9]. Sap flow (SFD [cm m\(^{-2}\) s\(^{-1}\)]) of each sampled tree was measured, data recorded every 20-min by a data logger (Thermo, USA). Solar radiation (Rn), air temperature (T), relative humidity (RH), wind speed (W) and rainfall (P) were recorded every 30 minutes with an automatic weather station installed near the experiment plot.

All data were analyzed and processed through SPSS software package (version 19.0 for Windows, SPSS Inc., USA).
3. Result

3.1. Variation of meteorological factors
During the growing season, the accumulated precipitation was 129.3 mm (figure 2(a)). From January (from DOY 1 to DOY 30) to April, the precipitation was 26.2 mm (Mosuowan Meteorological Station), low precipitation shown in May, and it varied with the change of transpiration rates. From June to August, the air temperature was higher than that of other months, and the highest mean daily air temperature was 36°C on July 26th (DOY 209). In July, wind got the maximum value by 3.8 m s⁻¹. Vapour pressure deficit and global radiation got their maximum value at 2.1 kPa in June (DOY 150 to 180) and 550 W m⁻² in October (figures 2(b) and 2(c)), respectively.

![Figure 2](image)

Figure 2. Environment conditions during 2013-growing season. (a) Mean daily air temperature (line) and daily precipitation. (b) Mean daytime vapour pressure deficit (red line) and mean daily relative humid. (c), mean daytime global radiation (violet line) and mean daily wind speed (January 1st is DOY 1).

3.2. Water consumption of farmland shelterbelt
Sap flow is greatly affected by meteorological factors, such as solar radiation intensity, air humidity and temperature, etc. The mean sap flow velocity of the six sampled trees was between 1495±634 and 429±
247 kg m\(^{-2}\) d\(^{-1}\) in September (figure 3). When the farmland shelterbelt was irrigated on 29\(^{th}\) September (DOY 274), sap flow velocity rose from 384±149 on 28 September to 527±251 kg m\(^{-2}\) d\(^{-1}\) on 30\(^{th}\) September, thereafter, there was a gradual decrease trend. When *Populus simonii* Carr shelter-belt point was raining on 11 September (DOY 256), sap flow velocity decreased to 724±358 kg m\(^{-2}\) d\(^{-1}\) from 1123±627 kg m\(^{-2}\) d\(^{-1}\) on 10 September (DOY 255), and raise gradually to 927±451 kg m\(^{-2}\) d\(^{-1}\) on 12\(^{th}\) September (DOY 257). The impact of relative humid on sap flow is evident, some research showed that the stand transpiration improved 3.5-5.4 times after raining [17].

![Figure 3](image-url)

Figure 3. The diurnal mean sap flow velocity on a sapwood area basis (Es,kg.m\(^{-2}\).d\(^{-1}\)) for *Populus simonii* Carr. The bars represent the S.D about the mean.

The mean daily stand transpiration of farmland shelterbelt trees ranged from 1.13 to 10.68 kg d\(^{-1}\) (figure 4). And the highest stand transpiration reached 32.26 kg d\(^{-1}\) (DBH=187 mm). Higher transpiration showed in larger trees. And the tree with 134 mm DBH had little change in seasonal transpiration.

![Figure 4](image-url)

Figure 4. Daily tree transpiration (Et) in different DHB. (Et:kg d\(-1\), DHB: mm).

From linear regression analysis (SPSS, V19.0, SPSS Inc.), an accurate equation was found to predict farmland shelterbelt transpiration as follow:

\[
E_m=46.379-2.288T-1.541RH+9.334VPD+0.216R-4.493W
\]

The equation explained of the trees' transpiration variability. According to the F test, F (0.01, 5, 52) is 3.39, the value of F is 17.89. It indicated that the equation is effective to forecast farmland shelterbelt water consumption.
4. Discussion

Daily transpiration of farmland shelterbelt ranged from 0.3 to 1.2 mm in September and October of 2013. It appears to be closed to broadleaf trees’ transpiration [18,19], and it was lower than that of Xinjiang Populus [20,21]. This huge variation of transpiration caused by species and regions different, it is important for regional water budgets [18], and the period of the growing season is also the reason to cause the difference [16].

Stand transpiration of trees increased after rain [17]. Which indicated the relative humid is an important case in tree transpiration, as it showed the correlation in table 1. The stand transpiration of Populus simonii Carr farmland shelterbelt was from 384±149 to 527±251 kg m⁻² d⁻¹ after the shelter belt irrigated. It indicated soil moisture content affected strongly the variation of farmland shelterbelt stand transpiration [22,23].

| T   | W   | RH  | VPD  | Rn  | Gc  |
|-----|-----|-----|------|-----|-----|
| T   | 1   |     |      |     |     |
| W   | 0.246| 1   |      |     |     |
| RH  | -0.137| 0.177| 1    |     |     |
| VPD | 0.702(**)| 0.316(*)| 0.583(**)| 1  |     |
| Rn  | 0.516(**)| 0.185| -0.121| 0.295(*)| 1  |
| Gc  | 0.055| -0.044| -0.614(**)| -0.358(**)| 0.470(**)| 1  |

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Solar radiation, wind velocity, temperature and soil moisture are the main factors impacting the sap flow. In this study, g, and RH had negative correlations, and significant correlations were found between g, and Rs. And the transpiration of the trees showed varied in daytime, and keep balance at night similar with present research [24]. Stomatal conductance is the key factor of forest water consumption [19,25]. Stomatal was complex responded to environmental factors, the influence on stomatal conductance by solar radiation and saturation vapor pressure difference is not independent, they showed cooperating and restricting each other, air temperature and relative humidity were affected by solar radiation, and temperature and relative humidity affected the saturated vapor pressure [19,25], so get clear environmental factors influence on wood tree canopy conductance of comprehensive mechanism, still needs further research.

5. Conclusion

Farmland shelterbelt is the protection of Oasis ecological and agricultural development in oasis systems. It is benefit for adjusting microclimate, keeping soil water in the Oasis, and it is widely used for agricultural production. In this study, the relationship between climate variability and farmland shelterbelt were researched. Canopy transpiration rate of the farmland shelterbelt ranged from 0.45 to 1.58 mm d⁻¹, and their daily stand transpiration ranged from 1.13 to 10.68 kg d⁻¹. Higher stand transpiration showed in larger trees, and the highest showed at the largest tree (DBH=187mm) with 32.26 kg d⁻¹. The multivariate linear model plays well in predicting farmland shelterbelt water consumption in the study. It is helpful to forecast farmland shelterbelt water consumption. And get clear environmental factors influence on wood tree canopy conductance of comprehensive mechanism, still needs further research.

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