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RESEARCH ARTICLE

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Water consumption of a single tree from the main afforestation tree species in Western Shanxi Province, a loess area

Abstract Water is the key factor in vegetation growth in a loess area. Researchers have been keen on the study of tree transpiration for a long time. To provide a scientific basis and practical instruction for vegetation reconstruction and recovery in a loess area, the paper measured and calculated the water consumption of potted *Platycladus orientalis*, *Robinia pseudoacacia*, *Armeniaca vulgaris* and *Pyrus hopeiensis* separately during the growing season (from Apr. to Nov.). The four were the main afforestation species in a loess area of western Shanxi based on the principle of water balance. Using data on soil water dynamics and the range of available moisture on potted mature trees, the relationship between water supply and consumption and soil moisture availability and deficit state were analyzed. Several conclusions are listed as follows: 1) In the dry year (2002), during the growing season the precipitation was 430.7 mm and the water consumption of potted trees was from 430 to 490 mm. More water consumption and less available water supply occurred, showing a serious water deficiency. In the rainfall-rich year (2003), during the growing season the precipitation was 870.2 mm and the water consumption of potted trees was from 480 to 515 mm. Due to the uneven distribution of rainfall, the water budget balance was slightly affected in May and November. 2) The curves of soil water content of different species had similar annual changes, although the trends were different in the same month, and those of the same tree species in different test plots also had different trends in the same month. 3) Non-available soil water content of *Platycladus orientalis*, *Robinia pseudoacacia*, *Armeniaca vulgaris* and *Pyrus hopeiensis* was less than 8.0%, 8.4%, 9.2% and 9.7% respectively, which indicated that *Pyrus orentalis* used water more efficiently than the others. In the dry year (2002), for several months, soil water content of potted trees was lower than its threshold value for non-available soil water content, which could influence the healthy growth of trees. After supplements of precipitation of winter in the year and spring in the next year, soil water content was higher than the lower limit of soil readily available moisture content, which implied that a balance between inter-annual water supply and consumption could be maintained.

Keywords afforestation tree species, water consumption of single tree, soil water characteristic curve, loess area

1 Introduction

Water is the key factor to vegetation growth, especially in arid and semi-arid loess areas. Due to limited and uneven distribution of precipitation and loess properties such as a deep soil profile and many porosities, the effect of water re-distribution in soil is apparent. Therefore, soil water becomes a restricting factor in constructing a loess environment (Wang et al., 2000; Wang et al., 2001; Fedick et al., 2004). Since those important ecological projects have been constructed, many protective forests have been planted in loess areas. However, because of a lack of research on water environmental capacity of stands, "fast-senescence forest" and soil drying in forest lands occurred in after-projects (Wei et al., 1999; Zhang et al., 2003). Accordingly, more research focused on the properties of water consumption of forests (Liu et al., 1997; Wullschleger et al., 1998; Ma et al., 2003). The relationship between vegetation and water have been established through research on the physiological characteristics of evaporation, water consumption and drought resistance of forests (Han et al., 1994; Liu et al.,

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2003; Wang and Zhang, 2003; Wang et al., 2004). These results have yielded theoretical instruction on afforestation species selection and stand structure. Another hot spot of research is the precise measurement of forest evaporation and water consumption (Sun et al., 1996; Chen et al., 1999; Alarcón et al., 2000; Lachenaud et al., 2002; Green et al., 2003; Shi et al., 2004; Ferrara et al., 2005). At present, the technique does not only cover a dynamic analysis of the rule of water consumption of a single tree, but also provides a way to measure water consumption in direct combination with the ecological scaling transfer method. This gives a crucial theoretical basis on tree species selection with proper water consumption in different areas with different precipitation (Liu et al., 1997; Ma et al., 2002; Wang et al., 2003; Chen et al., 2004; Su et al., 2004). However, there is limited research on water consumption of a single afforestation species in loess areas. Using the principle of water balance and long-term observation, water consumption of a mature single tree was measured quantitatively. The characteristics of water consumption and soil water balance were analyzed, which could provide a scientific basis and practical instruction for environmental construction in a loess area.

2 Study area

We conducted our research at the test area of the Beijing Forestry University, which is located in the Caijiachuan nesting watershed of Jixian County that belongs to Shanxi Province in China, the Southwest of Loss Plateau. Its geographic coordinates: north latitude 35°53′–36°21′, east longitude 110°27′–111°07′. The soil type is drab soil, which is alkaline. This area belongs to a semi-humid warm temperate zone. The yearly average precipitation is 579.5 mm and changes significantly over different years; precipitation during April to June and during July to October takes up 26.9% and 64.2% of the total amount of yearly precipitation respectively. The yearly average evaporation is 1723.9 mm in Jixian County. The mainly protective forest species are *Robinia pseudoacacia*, *Pinus tabulaeformis* and *Platycladus orientalis*. The economic forest species are *Malus pumila*, *Armeniaca vulgaris* and *Pyrus hopeiensis*.

3 Methods

3.1 Testing design

Pots were involved as testing instruments and a single tree was planted in each pot. The pot shape is similar to a cylinder, with 0.5 cm thickness, 2 m height and 1.7 m diameter. The pot has no bottom. The testing tree species were *R. pseudoacacia, Platycladus orientalis*, *Pyrus hopeiensis* and *A. vulgaris*. They were planted in 1996 and transferred into pots in 1998. The transfer method is as follows: First, based on pot diameter, the single tree was set at the center of the circle. The soil was then dug following the pot circumference; the thickness of the soil that was dug was more than the thickness of the pot. The depth of the soil that was dug was approximately equal to the height of pot. Second, the pot was then put into the place where the soil was dug and removed; the pot was 5 cm higher than ground level and the soil in the pot could be considered as undisturbed soil.

Two experiment sites were chosen. One was inside the forest area and the other was outside of the forest area. The potted sample trees were selected from trees in the *Pyrus hopeiensis* forest and *A. vulgaris* forest, respectively, both in the first experiment site. The potted single trees, *R. pseudoacacia, Platycladus orientalis*, *Pyrus hopeiensis* and *A. vulgaris*, were planted in the terrace outside the forest respectively, which were in the latter experiment site. The two experiment sites were both on a sloping terrace and the difference of elevation between the sites was no more than 50 m. Because of the thick soil profile in the forest area, the pot used had a height of 2 m. However, the thin soil profile out of the forest area required that the testing pot height should be cut to 1 m. All testing pots at the bottom were connected with a pipe, which can be used to calculate the amount of rainfall percolation during a storm. Table 1 shows the experiment sites and the characteristics of the testing tree species

Bundles of straws covered the soil surface of the potted single trees. Therefore, the amount of soil evaporation was at a very low level. Because the pot was blocked, soil water in the pot did not exchange with soil water out of the pot. Based on dynamic long term observation of soil water content of potted single trees, the water consumption of single trees during the growing season could be calculated according to the water balance principle.

Table 1 The experiment sites and the characteristics of testing tree species

test plots		tree species	age/year	height/m	DBH/cm	crown/m
Out of forest area		*Platycladus orientalis*	9	1.85	0.98	1.0
		R. pseudoacacia	8	4.15	3.02	1.3
		Pyrus hopeiensis	8	3.26	3.31	1.5
		A. vulgaris	8	2.98	4.0	1.7
In forest area	Semi-shady slope, upper slope, 11°	*Pyrus hopeiensis*	9	3.1	3.14	1.5
	Semi-sunny slope, upper slope, 13°	*A. vulgaris*	9	2.83	3.52	1.6

The formula for water balance is:

$$W_f = W_0 + P - ET - R_s - R_f \quad (1)$$

The parameters in the formula (1) are represented as follows: W_0 is the initial soil water storage (mm); W_f is the terminal soil water storage (mm); P is the amount of precipitation; ET is water consumption of a single tree including soil surface evaporation and tree transpiration (mm); R_s is the amount of percolation into deep soil (mm); and R_f is the amount of surface runoff (mm).

The formula of soil water storage W is:

$$W = \frac{SWC \times SD \times ST \times 1000}{WD} \quad (2)$$

The parameters in the formula (2) are represented as follows: W is soil water storage (mm); SWC is soil water content (g/kg); SD is soil density (mg/m^3); ST is soil thickness (mm); and WD is water density (1.0 g/cm^3).

Because the pot was 5 cm higher than ground level and the experiment sites were on a level terrace, no surface runoff occurred during the observation period, which means $R_f = 0$. Hence, the formula of the increment of soil water storage ΔW (mm) could be expressed as follows:

$$\Delta\, W_f - W_0 = P - ET - R_s \quad (3)$$

According to the formula, the positive value of ΔW represents surplus of soil water storage, and the negative value of ΔW represents deficit of soil water storage.

Based on formula (3), the transpiration of a single tree could be expressed as follows:

$$ET = P - \Delta W - R_s \quad (4)$$

When $R_s = 0$, the formula (4) can be transferred into formula (5)

$$ET = P - \Delta W \quad (5)$$

Table 2 shows soil density in different testing plots, used in formula (2).

3.3 Precipitation

Automatic turnover-bucket precipitation gauges recorded rainfall amount and process. The daily meteorological data were also documented by the observation station.

3.4 Soil water measurement

The soil auger method was employed to measure soil water content in 2002. During the growing season (from April to October), the total soil water content in five soil layers of potted single trees (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm) were measured twice in the first and second ten days of the month respectively, and for each layer should be repeated twice. The TDR method was used in 2003 to take the damage of soil into account. Buried depth was the same as the layer classifications of the soil auger method. Soil water storage was calculated by formula (2).

Table 2 Soil density in different test plots (unit: mg/m^3)

soil layer/cm	out of forest area				in forest area	
	R. pseudoacacia	*Platycladus orientalis*	*A. vulgaris*	*Pyrus hopeiensis*	*A. vulgaris*	*Pyrus hopeiensis*
0–20	1.12	1.05	1.06	1.06	1.08	1.07
20–60	1.16	1.23	1.10	1.10	1.13	1.16
60–100	1.21	1.26	1.14	1.14	1.17	1.21

3.5 Measurement of soil water characteristic curve for potted single trees

Two original soil samples for each potted single tree were collected using the cutting ring sampler of a centrifugal machine. The soil samples were place in water until saturation. The centrifugal machine was then used for 60–70 min at different centrifugal speeds which could keep the soil water balance, after which the samples were weighed. When centrifugations were finished, the soil sample was baked under 105°C and weighed again. Finally, soil water content was calculated under different water potentials.

When the centrifugal speed is n_i (r/min), soil water potential ψ_i (10^5 Pa) is:

$\psi_i = -1.12 \times 10^{-8}\, r \cdot n_i^2$ (r is centrifugal radius, cm)

When soil water potential is ψ_i (10^5 Pa), soil water content is:

$SWC = [(W\psi_i - W_B)/W_B]$

where $W\psi_i$ is the wet weight of soil sample and W_B is the dry weight of soil sample after baking.

The soil water characteristic curve could be drawn using data on soil water content under different water potentials.

4 Results and analysis

4.1 Calculation and analysis of water consumption of single trees during growing season

4.1.1 Calculation and analysis of water consumption of single trees during growing season in the forest area

Observation of the period of water consumption of single trees concentrated from April to October, which is considered as growing season in the loess area.

Therefore, the period of water consumption in growing season in this research is from April to October (He et al., 2002).

The average growing season precipitation of the research area was 521.4 mm from April to October. The growing season precipitation was 430.7 mm in 2002, lower than the average growing season precipitation which was considered a dry year. The growing season precipitation was 870.2 mm in 2003, higher than the average growing season precipitation which was considered a rainfall-rich year (Zhang et al., 2004). Table 3 shows monthly precipitation during growing season in 2002 and 2003.

Table 3 Monthly precipitation during growing season in 2002 and 2003 (unit: mm)

year	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Apr.–Oct.
2002	29.2	41	101	52.5	55	112	40	430.7
2003	60.2	36.2	55.2	69.2	440.2	134.2	75	870.2

In 2002 (dry year), there was no percolation into deep soil of potted single trees out of the forest, which means $R_s = 0$. According to formula (2) and formula (5), water consumption of single trees during growing season was calculated (Table 4).

In August 2003 (rainfall-rich year), precipitation in this month was the maximum amount of precipitation for the whole year. Runoff of potted single trees out of the forest occurred during the growing season. According to formula (2) and formula (4), water consumption of single trees during growing season was calculated (Table 4).

Precipitation during the growing season in 2002 was 430.7 mm. According to formula (5), the water income of single trees during this season was the amount of precipitation, while the water payment was the amount of evaporation. In April, it is the initial period of tree growth. The evaporation by trees was scarce. Besides, due to the low temperature, the water consumption of potted trees was limited and equaled the amount of precipitation. In May, because of fast rising temperatures, the amount of evaporation increased;, the amount of precipitation did not vary too much compared to April. Therefore, an imbalance of soil water occurred. During June, July and August, the amount of evaporation and water consumption were increasing dramatically, and water consumption in this three month period accounted from 50% to 60% of total water consumption in the growing season. However, precipitation in the period was 208.5 mm, or 48.4% of total precipitation in the growing season. Therefore, balance between the water supply and its consumption was lost, and a deficit of soil water occurred. Until the end of growing season in September and October, the water consumption of trees was reduced gradually and precipitation did not reduce dramatically. The imbalance of water supply and its consumption was relieved and soil water content was increasing. The total amount of precipitation was lower than the total amount of water consumption for single trees during the growing season. In the dry year, the balance of water supply and water consumption was lost and the loss of soil water occurred.

The properties of water consumption of single trees during the growing season in 2003 (rainfall-rich year) were mostly the same as those in 2002 (dry year). During the whole growing season, the precipitation was sufficient but distribution was uneven. In May and October, the balance of water supply and water consumption was lost. The total amount of precipitation was higher than the total amount of water consumption for single trees during the growing season. But due to the uneven distribution of precipitation, balance between water supply and consumption was not well maintained.

The amounts of water consumption of single trees during the growing season in 2003 were all higher than those in 2002. Besides, the amount of water consumption of *P. orientalis* was the lowest among that of *R. pseudoacacia*, *Pyrus hopeiensis* and *A. vulgaris*. This conclusion is the same as other research drawn before (Han et al., 1994; Ma et al., 2003). It clearly shows that *Platycladus orientalis* is a kind of low water consuming tree species compared to other testing trees.

4.1.2 Calculation and analysis of water consumption of single trees during the growing season out of the forest area

In 2002 and 2003, the calculation methods of water consumption of single trees during the growing season out of the forest area are the same as those in the forest area (Table 5).

Table 4 Water consumption of single-testing trees out of the forest area during growing season of 2002 and 2003 (unit: mm)

year	species	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Apr.–Oct.
2002	*R. pseudoacacia*	22.58	128.71	131.81	39.29	47.14	92.84	28.41	490.78
	Platycladus orientalis	33.65	61.59	167.21	21.64	20.37	96.47	29.92	430.85
	A. vulgaris	22.98	74.06	135.32	80.56	83.25	64.26	12.01	472.44
	Pyrus hopeiensis	24.04	73.12	118.8	73.84	103.46	62.5	15.68	471.44
2003	*R. pseudoacacia*	39.03	120.82	80.8	57.6	75.26	73.97	66.68	514.16
	Platycladus. orientalis	65.09	41.16	85.1	53.3	84.28	49.23	105.97	484.13
	A. vulgaris	54.16	113.9	59.76	62.93	66.93	66.75	89.23	513.66
	Pyrus hopeiensis	54.47	85.16	58.08	63.68	84.89	80.15	82.35	508.78

Table 5 Water consumption of single-testing trees in the forest area during growing season of 2002 and 2003 (unit: mm)

year	species	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Apr.–Oct.
2002	*A. vulgaris*	26.79	52.48	58	83.25	104.64	95.89	19.48	440.53
	Pyrus hopeiensis	24.75	53.57	91.6	96.51	73.8	83.65	22.11	445.99
2003	*A. vulgaris*	79.66	38.58	77.53	61.7	66.8	77.79	81.15	482.21
	Pyrus hopeiensis	60.85	38.67	65.76	74.62	84.57	82.43	74.07	480.97

Comparing water consumption of *Pyrus hopeiensis* and *A. vulgaris* both in and out of the forest area in 2002 and 2003, the water consumption of *Pyrus hopeiensis* and *A. vulgaris* in the forest area in 2003 (rainfall-rich year) was dramatically higher than that in 2002 (dry year). In either 2002 (dry year) or 2003 (rainfall-rich year), the variety of water consumption of *Pyrus hopeiensis* and *A. vulgaris* in the forest area was the same as those out of the forest area. Due to the influence of other trees in the forest area on the potted single trees, the water consumption of *Pyrus hopeiensis* and *A. vulgaris* in the forest area was 0.93–0.95 times that out of the forest area. This conclusion could provide a basis for the scaling transfer of water consumption from the forest area to the outside.

4.2 Analysis on soil water availabilities of single trees

4.2.1 Analysis on the season variety of soil water availabilities of single trees

When the imbalance of water supply and water consumption occurred, soil water availabilities were employed to analyze whether soil water consumption would influence tree growth. Soil water characteristic curve is a type of relationship curve of two factors: soil water energy (soil water potential) and soil water quantity (soil water content). It reflects the protective ability of soil water and can identify the range of available soil moisture of testing soil. Soil water was classified with different levels based on wilting point, soil water content of retarded growth and field moisture capacity based on the principle of soil water effect on vegetation growth. The model of soil water characteristic curve could be calculated using field moisture capacity of the original soil. The field moisture capacity of testing soil equaled soil moisture-holding capacity under −0.02– −0.03 MPa of soil water potential. The bottom boundary of available soil moisture was −2 MPa, because the permanent wilting point was −2 MPa for the afforestation species. Given the range of available soil moisture, decreasing soil water potential, either the amount of soil water content decreased or the difficulty of absorbing water uptake by forest roots increased. Because the temporal wilting point could fall under −1 MPa, −1 MPa of soil water potential was a key point of the soil water variety and was considered as the upper boundary of hard available water. Fitted equations to measure and calculate the soil water characteristic curves of *Platycladus orientalis*, *R. pseudoacacia*, *Pyrus hopeiensis* and *A. vulgaris* were derived and soil water content of these single trees were classified (Table 6).

When soil water content was under unavailable soil moisture, soil water could not be absorbed and used by vegetation; the period during this phenomenon had a direct effect on tree growth. According to Table 8, the water usage ability of *Platycladus orientalis* was best among the single trees outside the forest area, and its bottom boundary of available soil moisture was up to 8.0%. This water usage ability of *Platycladus orientalis* was followed by that of *R. pseudoacacia*, then *A. vulgaris* and *Pyrus hopeiensis*. This phenomenon could adequately explain why, during a drought, *A. vulgaris* and *Pyrus hopeiensis* are the first to be affected and their growths were influenced.

Figure 1 shows the comparison between average soil water content in the layer from 0 to 1 m during growing season of potted single trees and their soil water content

Table 6 Equations for soil water characteristic curve and the range of available soil moisture of single trees out of the forest area

species	equation for soil water characteristic curve	depth/cm	gravitational water/% (≥−0.03 MPa)	range of available soil moisture/%		range of unavailable soil moisture/% (≤−2 MPa)
				readily available water (−0.03– −1 MPa)	hard available water (−1– −2 MPa)	
R. pseudoacacia	$SWC = 14.03\psi^{-0.1707}$ $R^2 = 0.914, n = 25$	40–60	>17.2	17.2–9.5	9.5–8.4	<8.4
Platycladus orientalis	$SWC = 13.67\psi^{-0.1783}$ $R^2 = 0.939, n = 25$		>16.9	16.9–9.1	9.1–8.0	<8.0
A. vulgaris	$SWC = 15.428\psi^{-0.1624}$ $R^2 = 0.871, n = 25$		>18.8	18.8–10.6	10.6–9.2	<9.2
Pyrus hopeiensis	$SWC = 17.024\psi^{-0.1514}$ $R^2 = 0.892, n = 25$		>19.8	19.8–11.6	11.6–9.7	<9.7

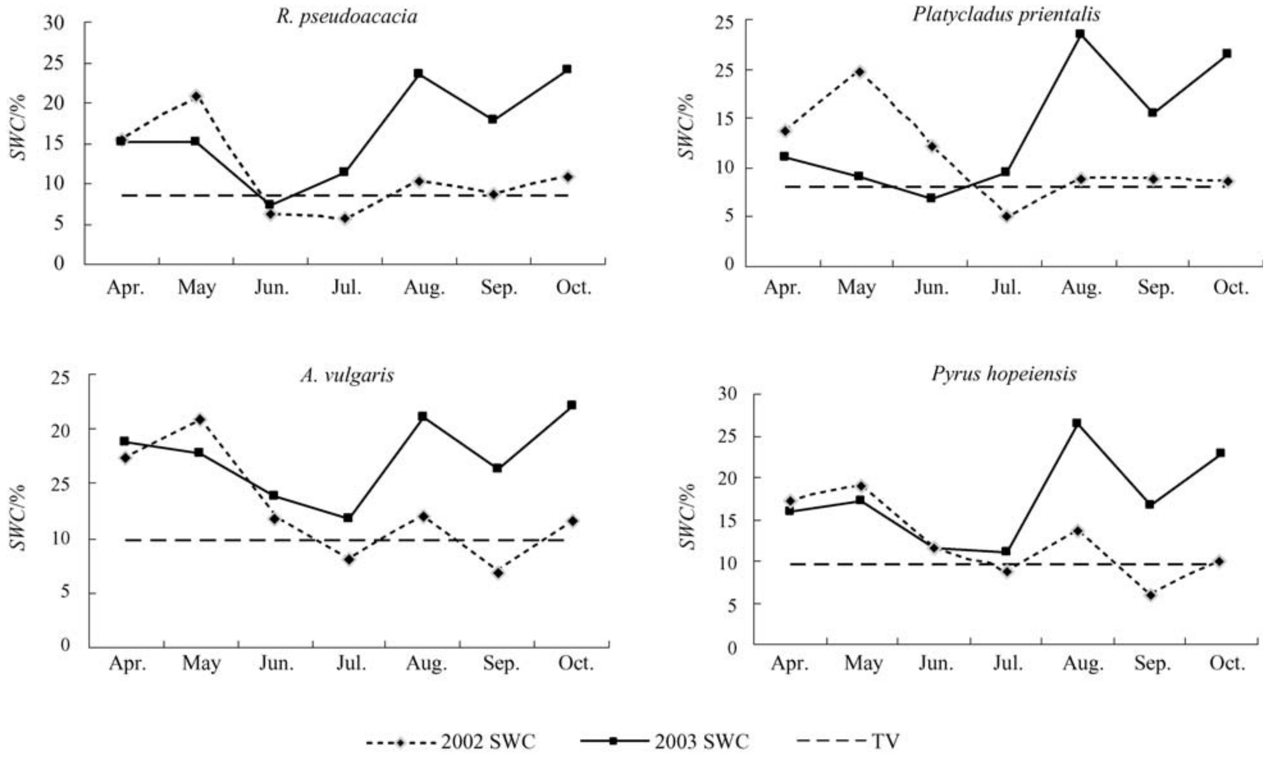

Fig. 1 Change of soil water content of single trees out of the forest area during the growing season of 2002 and 2003
SWC: soil water content; TV: the threshold value for non-available soil water

with its unavailable water moisture threshold value respectively. According to Fig. 1, the tendency of monthly soil water content of potted single trees to vary almost correspondingly matched not only that in the rainfall-rich year, but also in dry year, and only the variable-amplitudes were different. From April to June, because of rapidly rising temperatures, the amount of evaporation increases dramatically and soil water content, which is in water consumption condition, decreases and is consumed gradually.

From July and August, when tree growth and temperature are highest, evaporation from trees increases. Due to limited rainfall during the rainy season in 2002 and the absence of a timely supplement to soil water, soil water content were all under the unavailable soil moisture value except of *Pyrus hopeiensis*, and tree growth was restricted. However, limited supplement by precipitation enabled the potted single trees to remain alive. Due to much rainfall during the rainy season in 2003, the amount of water infiltration was higher than that of water consumption and soil water content, which is in water accumulation condition, could be absorbed and used completely. At the end of August, soil water content reached the highest value during the rainy season.

From September to October, because of a lack of precipitation and high temperatures, evaporation from trees was still strong, and there was a soil water loss. In 2002, soil water content of *Platycladus orientalis* and *R. pseudoacacia* were slightly higher than soil water content with unavailable soil moisture value; that of *A. vulgaris* and *Pyrus hopeiensis* were all lower than the preceding value. In 2003, soil water content was descending. But due to available accumulation in August, soil water content remained at a high level.

4.2.2 Analysis of annual soil water supply and consumption of single trees

The period of water consumption is concentrated on the growing season. Coming into November, tree growth ceases, soil is going to freeze and the form of water consumption is mainly evaporation. Due to the litter and snow cover, soil water consumption is prevented. Until next April, if there is a large amount of snow melting or precipitation, soil water content will increase continuously and reach the level last April. This could help ensure that normal tree growth is sustainable. Table 7 shows soil water content in mid-April of single trees out of the forest area from 2000 to 2004, except 2001.

Except for a large of variation of soil water content of *Platycladus orientalis* in the middle of April in 2000 and 2003, variation of other single trees were not obvious. Compared with Table 6, the values of soil water content of single trees were all in the range of readily available water. Based on analysis, from 1999 to 2003 the precipitation is 402.3, 489.8, 432.6 mm (April to

Table 7 Comparison of soil water content of single trees out of the forest area (unit: %)

date	*R. pseudoacacia*	*Platycladus orientalis*	*A. vulgaris*	*Pyrus hopeiensis*
2000	11.28	9.61	18.36	17.37
2002	14.81	12.39	16.80	15.21
2003	15.18	9.14	19.22	15.02
2004	16.33	14.25	17.42	17.05

October), 485.5 and 922.5 mm, which were considered as dry year, normal year, dry year, normal year and rainfall-rich year respectively. The low values of soil water content of *Platycladus orientalis* in the middle of April in 2000 and 2002 were because of the dry years (1999 and 2001) when soil water consumption was high. When the year was a normal year or rainfall year, soil water content could reach a high level in the coming year. Therefore, after precipitation gained in winter and next spring, soil water content of single trees during 2000 to 2004 could reach the level of readily available water at the start of growing season.

When the suitable nutrition volume of potted single trees was maintained (in this research the diameter of pot is 1.7 m), soil water content could recover back to the same level of the next initial growing season and stable tree growth is achieved. This conclusion could serve as an instruction for planting trees in returning land for farming to the forestry area in the loess area of western Shanxi Province.

5 Conclusions

According to the water balance equation, monthly water consumption of tested single trees were calculated. Precipitation during growing season in the dry year was lower than water consumption of single trees during the corresponding period, and balance between water supply and consumption was lost dramatically. Due to sufficiency and uneven distribution of precipitation during growing season in the rainfall-rich year, this balance was slightly affected in May and October. The water consumption levels of single trees during the growing season in 2003 were all higher than those in 2002. Water consumption of *Platycladus orientalis* was the lowest among a group that also included *R. pseudoacacia, Pyrus hopeiensis* and *A. vulgaris*. Due to the influence of other trees in the forest area on the potted single trees, the water consumption of *Pyrus hopeiensis* and *A. vulgaris* in the area was 0.93–0.95 times those out of the area.

The curves of soil water content of different species had similar annual changes but different trends in the same month, and those of the same tree species in different test plots also had different trends in the same month. Non-available soil water content of *Platycladus orientalis*, *R. pseudoacacia*, *A. vulgaris* and *Pyrus hopeiensis* was less than 8.0%, 8.4%, 9.2% and 9.7% respectively, which indicated that *Platycladus orientalis* used water more efficiently than the others. In the deficit water year (2002), for several months, soil water content of potted trees was lower than its threshold value for non-available soil water content and possibly influenced healthy tree growth. After supplements of precipitation of winter in the year and spring in the next year, soil water content was higher than the lower limit of soil readily available moisture content, which implied that balance between inter-annual water supply and consumption could be maintained.

Platycladus orientalis, *R. pseudoacacia*, *A. vulgaris* and *Pyrus hopeiensis*, which are considered afforestation tree species in returning land for farming to the forestry area in the loess area of western Shanxi Province, could grow stably when the suitable nutrition volume of trees is maintained.

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