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# Ecological effects of lawn greens with pure and mixed stands in an urban setting

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**Abstract** We studied the ecological benefits of four types of urban green spaces (lawn, a *Robinia pseudoacacia* stand, a *Pinus tabulaeformis* stand and a mixed stand of both species) in Yuan Dynasty Wall Relics Park, Beijing. Each of the eight sampling sites was about 0.1 hm<sup>2</sup>. The experiment was carried out in June, 2006 over a period of eight consecutive days, during which we continuously measured air temperature, relative humidity (RH) and wind speed at the four green spaces in both horizontal and vertical directions. The results were as follows: in the horizontal direction, the all-day average temperature at the pine stand was the lowest and its RH was the highest under three different climate conditions. During the daytime high temperature period, the temperature of the lawn was the highest and its RH the lowest. The temperature was lowest for the mixed stand, and the RH was highest for the pine stand. The highest average daily temperature occurred in the locust stand. The temperature and RH of the four green spaces were statistically different at the 0.05 level of significance. In the vertical direction, the average daily temperature of the four green spaces increased with height. The average daily RH of the four green spaces decreased slightly with increased height. During the high temperature period of the day, the average temperature of the lawn and the *P. tabulaeformis* stand declined with the increased height, but the temperature at the *R. pseudoacacia* stand and the mixed *P. tabulaeformis*–*R. pseudoacacia* stand fluctuated greatly. With regard to the effect of lowering the wind speed, the mixed stand was better than the other green spaces. Based on these results, it can be

concluded that the mixed Chinese pine and locust stand was the best choice for the establishment of urban green spaces.

**Keywords** urban green space, mixed stand, ecological benefits, temperature, relative humidity, wind speed

## 1 Introduction

Increases in urban populations and the daily expansion of urban areas affect the quality of the ecological environment in cities. The heat generated in urban areas, defined as the heat island effect, representative of the variation in a hot environment as an important negative attribute, has been brought increasingly to the attention of people, especially during summer periods. The feverishly high intense summer heat seriously affects the normal life and work of a city. Urban trees block sunlight, decrease the temperature, increase humidity, reduce wind speed, improve the local microclimate and have many other potential benefits. Therefore, urban afforestation mitigates to some extent the harm inflicted on natural, environmental functions that have been seriously damaged because of urbanization. Large areas of parks, wide forest belts, dense rows of roadside trees and other green spaces offer some relief from the high temperatures and humidity in the various sectors of cities (Wang et al., 2005).

A mixed *Pinus tabulaeformis*–*Robinia pseudoacacia* stand is a cultivated plant community composed of two kinds of trees and other plant species. Mixed stands and pure plantations are the major ornamental plant communities in botanical gardens or green spaces in urban areas. The ecological values of urban green spaces will increase with the growth of ornamental plants and the expansion of urban green spaces (Leng et al., 2004). Improvement of the urban eco-environment can be achieved through selection and a mixture of the right trees, shrubs, and ground cover plants and lawns to form suitable vertical structures of plant communities in order

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to increase green cover, enhance the stability of plant communities, and promote the ecological value of urban green spaces (Liu and Huang, 2000). We must emphasize that we should harmonize the structure and the functional relations of plant communities in order to integrate and optimize the different ecological functions of plant communities into the functions of modern urban ecological plans and designs (Thompson and Steiner, 1997). In recent years, both Chinese and foreign investigators have carried out studies on the quantitative, qualitative and semi-quantitative determination of ecological values of urban green spaces at different scales (Chen and Su, 1998a, 1998b; Huang and Zhang, 1998; Fu et al., 2000; Zhou et al., 2005).

A number of scientists have stressed that quantitative studies on the spatial distributions of humidity and heat in pure and mixed woodlands were overlooked in the analyses of forest microclimate (Mao et al., 1999; Li et al., 2004; Yan and Xiong, 2005). In this sense, our research was conducted to determine quantitatively the spatial distribution of humidity and heat in pure and mixed stands of urban green spaces, which will benefit the clarification of the ecological effect of air humidity and reduce the ambient temperature of different plant communities of urban green spaces, as well as providing a sound theoretical basis for maximizing the ecological values of urban green spaces through an appropriate mixture of different plant communities.

## 2 Experimental site and field survey

### 2.1 Experimental site

Our experimental area was located at the site of the western part of the Yuan Dynasty Wall Relics Park, Haidian District, Beijing, which starts from Mingguang Village in the south to the intersection of Xuezhi Road in the north, turns to the east, and crosses the Jingchang Highway to connect with the eastern part of Yuan Dynasty Wall Relics Park, Chaoyang District. The area of this park in Haidian District is approximately 47 hm<sup>2</sup> in size, with a length of 4200 m, nearly half of the park's total length of 9000 m, and 100 to 160 m in width. The tree cover of the experimental site was increased to 73% since the Yuan Dynasty Wall Relics Park was afforested in 2002. The lawn cover is 100%. A mixture of *P. tabulaeformis* and

*R. pseudoacacia* trees was planted in the form of rows at a ratio of one locust tree to three Chinese pines in 1990.

### 2.2 Plant communities of urban green spaces

Four types of plant communities, i.e. locust stand (*R. pseudoacacia*), Chinese pine stand (*P. tabulaeformis*), and a mixture of both species and lawn plants (*Pop. pratensis*), are distributed on our experimental site. The mixed stand, a common urban vegetation type in northern China, dominates the urban green spaces in Yuan Dynasty Wall Relics Park. The plant communities were investigated by following the methods described by Yang (2003). The details of these plant communities are presented in Table 1.

## 3 Field survey and measurements

### 3.1 Survey design

The vertical structure of the vegetation was analyzed by establishing six sampling points starting at a height of 1.5 m and ending at a height of 12 m with 1.5 m intervals. In the horizontal direction we established eight sampling sites at 1.5 m intervals along the diagonal line of each plot. Air temperature, humidity and wind speed at the different sampling sites were measured continuously for three sunny days. Observations on sunny days were replicated twice.

### 3.2 Measurements

The experiment was conducted from June 11 to 18, 2006. Wind speeds in the horizontal and vertical directions were measured every day continuously for 24 h with five weathercock meters located at various green spaces. The data were recorded every 0.5 h. Air temperature and humidity in both horizontal and the vertical directions at the different green spaces were recorded with four TRM-ZS1 meteorological systems simultaneously. The levels of accuracy of this instrument are as follows:  $\pm 0.1$ , 0.1 and  $-40^{\circ}\text{C}$ – $125^{\circ}\text{C}$  for temperature precision, resolution and range respectively;  $\pm 2\%$  relative humidity (RH), 0.5% and 1%–99% RH for humidity precision, resolution and range;  $\pm (0.05+0.03V)$  m/s, 0.1 m/s and 0–60 m/s for wind speed precision ( $V$  is actual wind speed),

**Table 1** Plant community information in the experimental site

green space	height/m	diameter at breast height/cm	number of trees	area of green space/m <sup>2</sup>	density/plant·m <sup>-2</sup>
pure <i>R. pseudoacacia</i> stand	12	24.2	18	900	0.02
mixed <i>P. tabulaeformis</i> – <i>R. pseudoacacia</i> stand	5, 12	15.9, 24.2	18, 6	1000	0.024
pure <i>P. tabulaeformis</i> stand	5	15.9	30	1000	0.03
grass lawn	0.1	–	–	900	–

resolution and range with starting wind speed  $\leq 0.5$  m/s. At the end of our measurements, the data on air temperature and humidity were analyzed by using MICROSOFT EXCEL and SPSS 12.0 software.

## 4 Results and analysis

### 4.1 Horizontal temperature of four kinds of green spaces

#### 4.1.1 Average daily temperature under three kinds of weather conditions

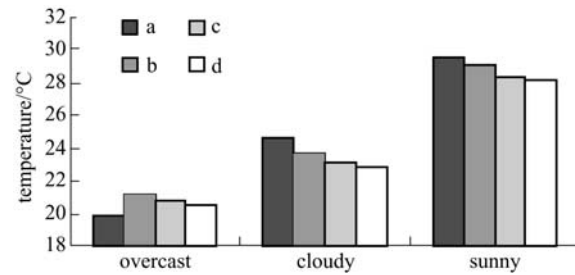
In terms of daily air temperatures observed under three kinds of weather conditions (Table 2), the green spaces are listed in the following order: lawn > *R. pseudoacacia* stand > mixed *P. tabulaeformis*-*R. pseudoacacia* stand > *P. tabulaeformis* stand under cloudy and sunny weather conditions (Fig. 1). Average daily temperature in the *P. tabulaeformis* stand was the lowest, being 1.4°C–1.7°C lower than that of the lawn, followed by the mixed stand, 1.2°C–1.3°C lower than that of the lawn, and finally the *R. pseudoacacia* stand, 0.5°C–0.9°C lower than that of the lawn. Under overcast weather conditions, green spaces are listed in the following order in the temperature gradient: *R. pseudoacacia* stand > mixed stand > *P. tabulaeformis* stand > the lawn. Average daily temperature of the lawn was the lowest and that of locust tree stand the highest. Taking the lawn as our control, the decrease in the average daily temperature in the Chinese pine and mixed stands was about 1.2°C–1.7°C, and the temperature in the locust stand was less than 1.0°C on cloudy or rainy days. Among the four types of green spaces, the lawn was very weak in decreasing urban air temperature, while the other three types were relatively stronger in decreasing urban air temperature.

**Table 2** Average temperature of three kinds of weather (unit: °C)

green space type	overcast	cloudy	sunny
grass lawn	19.9	24.6	29.6
<i>Robinia pseudoacacia</i>	21.2	23.7	29.1
mixed stand	20.8	23.1	28.4
<i>Pinus tabulaeformis</i> pure stand	20.5	22.9	28.2

#### 4.1.2 Daily variation in temperature during sunny weather

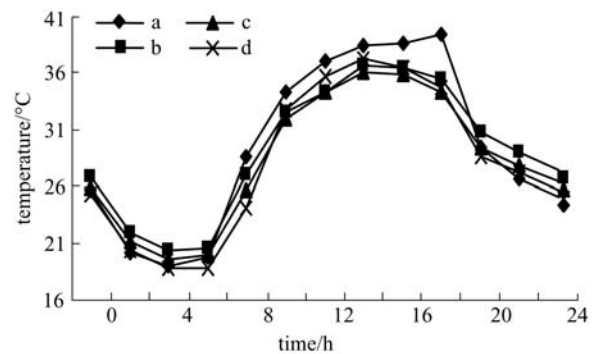
The variations in the average daily temperature in sunny weather were observed at all four types of green spaces (Fig. 2), i.e., the lowest temperature was recorded from 4:00 to 6:00 in the morning and the highest around noon. During the lower temperature period, the temperature in the locust stand was higher than that in the other green spaces. The temperatures at the lawn and the pine stand were the lowest. During the high temperature period



**Fig. 1** Average daily temperature of three kinds of weather conditions

a: grass lawn; b: *R. pseudoacacia* stand; c: mixed stand; d: *P. tabulaeformis* stand. The same below.

between 12:00 and 16:00, the temperature in the mixed stand was lower than that in the other green spaces and the temperature at the lawn was the highest. The temperature in the lawn increased gradually over time until 18:00 when the temperature reached its peak. Thereafter, the temperature dropped sharply. This is associated with the fact that the environment of the lawn was the lowest during the low temperature period and the highest during the high temperature period. The ability of the lawn to mitigate environmental change is poor and the temperature of the lawn changed quickly. Even though after 16:00 the other three green spaces tended to show a decrease in temperature, the temperature at the lawn continued to increase. This is because the lawn is more spacious and open and thus has high temperatures due to heat accumulation over a very long time period until the sudden drop after 18:00.



**Fig. 2** Average daily temperature of sunny days

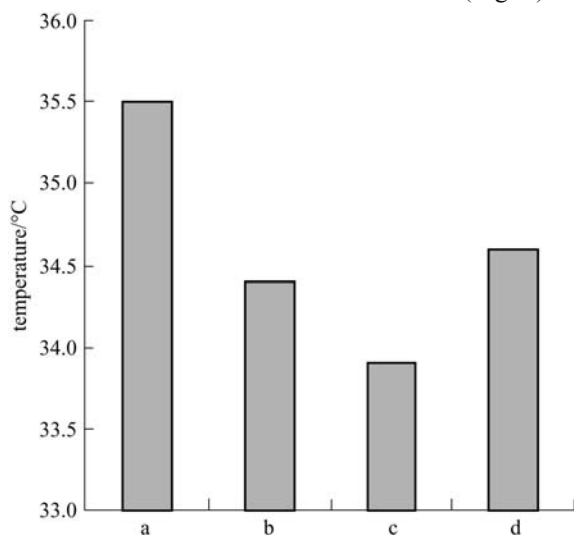
The green spaces with higher coverage such as the pure and the mixed stands varied insignificantly in their temperatures during the daytime. That is because pure and mixed stands can mitigate the temperature changes by way of canopy shade and leaf transpiration. Moreover, as a result of the canopy cover of the forest, the temperature of the forest green space was lower than that of the lawn during periods of high temperature and higher than that of the lawn during periods of low temperature.

Within a day, the temperature of the *R. pseudoacacia* stand was higher than that at other types of green spaces during the low temperature period, which means that the

big, broad-leaf locust tree stand was better for heat preservation in a low temperature environment. During the high temperature period, the temperature of the mixed stand was the lowest, which means that the effect of decreasing temperature in the mixed stand was the highest in a high temperature environment. The mixed stand was stronger than both pure stands in lowering temperatures, since during a hot summer the mixed stand had a niche compensation for light utilization and shade formation.

#### 4.1.3 Temperature at 14:00 on sunny days

In terms of the high temperature at 14:00, the four types of green spaces are listed in the following order: lawn > Chinese pine stand > locust stand > mixed stand. The temperature of the mixed stand was 1.6°C lower than that of the lawn, the temperature of pure locust tree stand was 1.1°C lower than that of the lawn, and the temperature of the pine stand was 0.9°C lower than that of the lawn (Fig. 3).



**Fig. 3** Changes of temperature of four types of green spaces at 14:00

Using a one-way ANOVA design, statistical analysis of the high temperatures at 14:00 indicated that the effects of lowering temperature in the mixed and pure locust stands

were significantly ( $\alpha = 0.05$ ) different from that of the lawn; the difference between the mixed and locust stands was not significant, while the difference between the mixed and pure pine stands was statistically significant (Tables 3 and 4). The effect of decreasing temperature was most evident for the mixed stand.

#### 4.2 Humidity in four kinds of green spaces

##### 4.2.1 Average daily humidity under three weather conditions

We carried out a statistical analysis and mapping of the relative humidity under three weather conditions, shown in Fig. 4 and Table 5. Among the four types of green spaces, the pure Chinese pine stand had the highest average daily relative humidity under cloudy and sunny weather conditions, i.e., the average daily relative humidity of the pine stand was 6.3%–11.2% higher than that of the lawn. Under sunny weather conditions, the relative humidity of the mixed stand was 4.6% higher than that of the lawn. On cloudy days, the average relative humidity of the locust and mixed stands were lower than those of the pine stand and the lawn.

The reason why the relative humidity of the pure *P. tabulaeformis* stand was high is that the lawn under the pine stand had two structures, the Chinese pine and the lawn, which were actually better than the pure lawn in increasing humidity. Moreover, the relative humidity of the pure stand was higher than that of the mixed and pure locust stands, mainly because the density of the shade in the Chinese pine stand was high, which may limit evaporation in this green space, leading to high humidity. The high shade density at the tree canopy level as well as the low cover of the pure pine stand was the major cause of increased humidity of the green space.

##### 4.2.2 Daily variation of humidity on sunny days

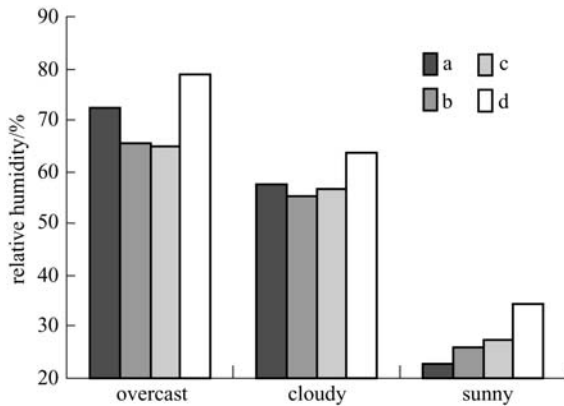
The relative humidity in the four types of green space varied along with the temperature on sunny days. The humidity increased with decreased temperatures. The

**Table 3** Multiple comparisons of the temperature at 14:00

trial sites	types of green space	mean difference	probability
grass lawn	pure <i>R. pseudoacacia</i> stand	1.0667*	0.047
	mixed <i>P. tabulaeformis</i> – <i>R. pseudoacacia</i> stand	1.5667*	0.009
	pure <i>P. tabulaeformis</i> stand	0.2667	0.574
pure <i>R. pseudoacacia</i> stand	grass lawn	–1.0667*	0.047
	mixed <i>P. tabulaeformis</i> – <i>R. pseudoacacia</i> stand	0.5000	0.304
	pure <i>P. tabulaeformis</i> stand	–0.8000	0.117
mixed <i>P. tabulaeformis</i> – <i>R. pseudoacacia</i> stand	grass lawn	1.5667*	0.009
	pure <i>R. pseudoacacia</i> stand	0.5000	0.304
	pure <i>P. tabulaeformis</i> stand	1.3000*	0.021
pure <i>P. tabulaeformis</i> stand	grass lawn	0.2667	0.574
	pure <i>R. pseudoacacia</i> stand	–0.8000	0.117
	mixed <i>P. tabulaeformis</i> – <i>R. pseudoacacia</i> stand	–1.3000*	0.021

**Table 4** ANOVA of temperature at 14:00

source of variation	sum of squares	df	mean square	F value	probability
between groups	4.682	3	1.561	5.021	0.030
within groups	2.487	8	0.311		
total	7.169	11			



**Fig. 4** Relative humidity in three kinds of weather conditions

**Table 5** Relative humidity of green spaces under three different weather conditions

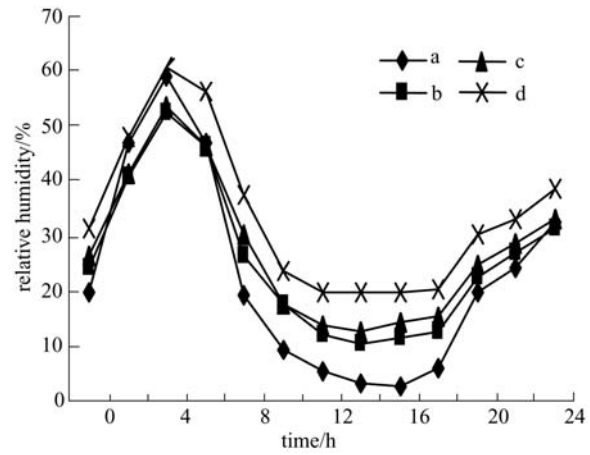
green spaces	overcast	cloudy	cloudy
grass lawn	72.5	57.4	23
pure <i>R. pseudoacacia</i> stand	65.4	55.1	26.1
mixed <i>P. tabulaeformis</i> - <i>R. pseudoacacia</i> stand	65.1	56.5	27.6
pure <i>P. tabulaeformis</i> stand	79.1	63.7	34.2

daily humidity reached its maximum value during the period from 4:00 to 6:00 in the morning and obtained its minimum value during the period from 14:00 to 16:00. The lawn was lower in humidity compared to the other three types of green spaces during the period from 8:00 in the morning to 20:00 in the evening. During the day, the relative humidity in the pine stand was higher than that in the other types of green spaces. The higher humidity of the pure pine stand may be associated with the higher shade density and higher coverage (Fig. 5).

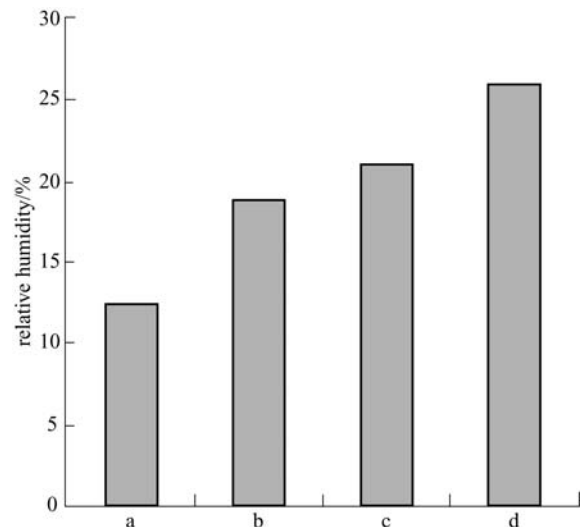
4.2.3 Humidity at 14:00 on sunny days

Our statistical analysis shows that the humidity of the four types of green spaces at 14:00 is listed in the following order: Chinese pine stand > mixed stand > locust stand > lawn. The average relative humidity of the *P. tabulaeformis* stand was 13.4% higher than that of the lawn. The average relative humidity of the mixed stand was 8.6% higher than that of the lawn. The average relative humidity of the *R. pseudoacacia* stand was 6.4% higher than the lawn (Fig. 6).

The relative humidity of the *P. tabulaeformis* stand was higher than that of the other types of green spaces



**Fig. 5** Relative humidity of four green spaces on sunny days



**Fig. 6** Relative humidity of four green spaces at 14:00

at 14:00 under sunny weather conditions, the mixed stand was in second place, the Chinese pine stand in third place and the lawn was the lowest in relative humidity. The reason that the mixed stand was better in increasing humidity than the pure broad-leaved trees may be that the mixed stand has a multi-layered vertical structure, with big trees at the top and the lawn on the ground.

Through a one-way ANOVA design using SPSS, statistical analysis of the relative humidity at 14:00 during the high temperature period indicated that the difference in relative humidity between the three types of green space and the lawn was significant at  $\alpha = 0.05$  level; differences between the mixed stand and the lawn and the pure pine stand were also significant; the difference between the mixed and the pure stands was not statistically significant; the differences between the pine stand and the other three kinds of green spaces was significant (Tables 6 and 7).

**Table 6** Multiple comparisons of the relative humidity of different green spaces at 14:00

trial sites	types of green space	mean difference	probability
grass lawn	pure <i>R. pseudoacacia</i> stand	-6.367*	0.005
	mixed <i>P. tabulaeformis</i> - <i>R. pseudoacacia</i> stand	-7.867*	0.001
	pure <i>P. tabulaeformis</i> stand	-13.367*	0.000
pure <i>R. pseudoacacia</i> woodland	grass lawn	6.367*	0.005
	mixed <i>P. tabulaeformis</i> - <i>R. pseudoacacia</i> stand	-1.500	0.391
	pure <i>P. tabulaeformis</i> stand	-7.000*	0.003
mixed <i>P. tabulaeformis</i> - <i>R. pseudoacacia</i> woodland	grass lawn	7.867*	0.001
	pure <i>R. pseudoacacia</i> stand	1.500	0.391
	pure <i>P. tabulaeformis</i> stand	-5.500*	0.010
pure <i>P. tabulaeformis</i> woodland	grass lawn	13.367*	0.000
	pure <i>R. pseudoacacia</i> stand	7.000*	0.003
	mixed <i>P. tabulaeformis</i> - <i>R. pseudoacacia</i> stand	5.500*	0.010

**Table 7** ANOVA of the relative humidity of green spaces

source of variation	sum of squares	df	mean square	F value	probability
between groups	271.940	3	90.647	22.055	0.000
within groups	32.880	8	4.110		
total	304.820	11			

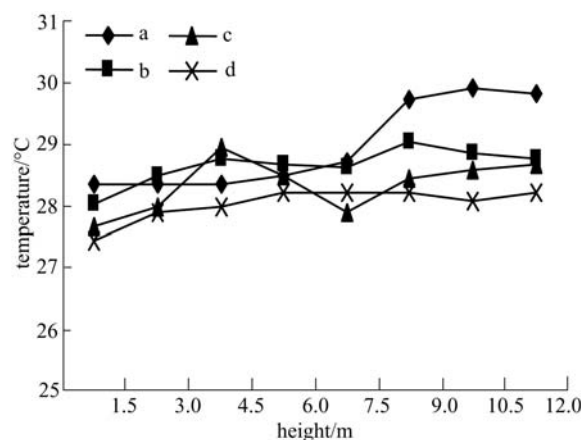
4.3 Vertical temperature patterns of green spaces

4.3.1 Vertical variation of average daily temperature on sunny days

Under sunny weather conditions, 48 observations at the same height in the vertical structure of the green spaces were averaged as the daily temperature at this height. The results show that the temperatures of the four kinds of green space increased gradually with an increase in height. Significant differences in temperature gradients were observed between these four green spaces at the various height levels (Fig. 7). The temperatures of the Chinese pine and the locust stands at 1.5 and 12 m increased by 0.8 and 1.3°C, respectively, compared with those observed on the ground. The average daily temperature of the lawn increased by 2°C. The changes in temperature in the vertical direction were slight for the pure locust and pine stands, but more complex for the mixed stand due to its multi-layered structure. In the vertical direction, the average daily temperature was lowest at a height of 1.5 m.

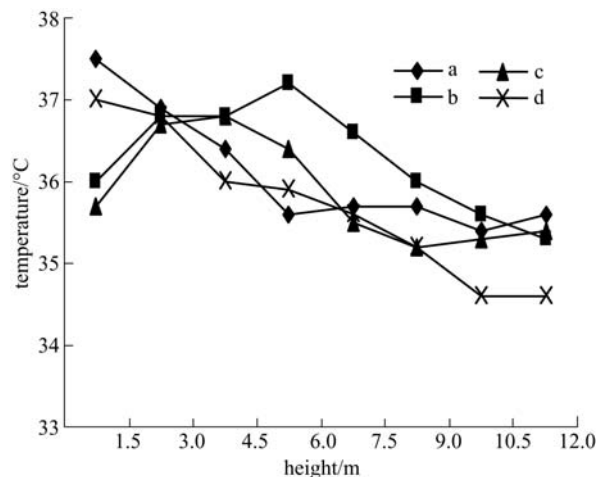
4.3.2 Vertical variation in temperature at 14:00 on sunny days

Figure 8 shows the temperatures of green spaces at 14:00, which were observed continuously for three days under sunny conditions. Temperature of the lawn and pine stand dropped continuously with increased height, but the temperature of the mixed stand changed irregularly, with a slight decline from 1.5 to 12 m in height, increasing at first but declining later. Temperatures of the four green spaces were nearly the same at a height of 3 m, but quite different at the other heights. Temperatures at the lawn and pine



**Fig. 7** Vertical variations of temperature of four green spaces on sunny days

stand peaked at the height of 1.5 m and dropped significantly when the height was above 1.5 m. The tendency of the temperature to change was similar in the locust and pine stands at a height over 6 m, but that of the mixed stand showed fluctuations. This is because the micro-environment



**Fig. 8** Vertical variation of temperature of four green spaces at 14:00

differs between the mixed and pure stand green spaces. The pure stands have two-layered vertical structures and the mixed stand has a three-layered vertical structure. The difference in vertical structure may result in great spatial differences in temperature.

4.4 Vertical variation in humidity of green spaces

4.4.1 Vertical variation of average daily relative humidity on sunny days

Under sunny weather conditions, 48 observations at the same height in the vertical structures of green spaces were averaged to a daily relative humidity at this height. In the vertical direction, the average daily relative humidity of the four kinds of green spaces declined by about 4% to 8% with an increase in height (Fig. 9). The relative humidity of the Chinese pine stand was clearly higher than that of the other three types of green spaces. At a height of 9 m, the relative humidity of the Chinese pine stand peaked. This may imply that the height of the pine canopy played an important role in altering the micro-environment of the plant community. The average daily relative humidity of the lawn was the lowest among all the green spaces.

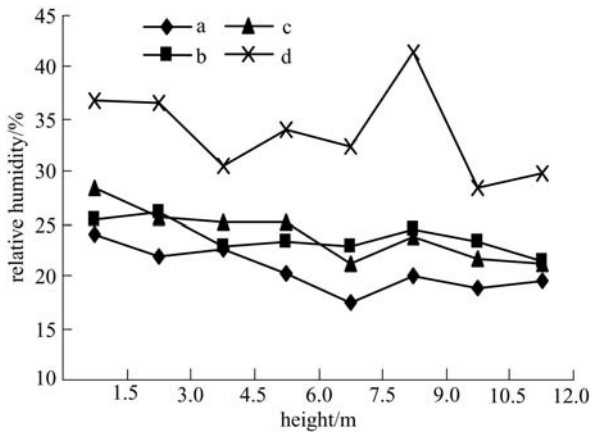


Fig. 9 Vertical average relative humidity of four green spaces on sunny days

4.4.2 Vertical variation of relative humidity at 14:00 on sunny days

Figure 10 presents the vertical variation of relative humidity at 14:00. In the vertical direction, relative humidity of the lawn rose with an increase in height, while that of the other green spaces fluctuated with a slight decline when the height increased from 1.5 m to 12 m. The relative humidity of the lawn was the lowest at each height and that of the pine stand was the highest at each height, while that of the locust and the mixed stands fell in between. The highest relative humidity of the pure Chinese pine stand may be associated with its height and cover. Compared to the other green spaces, the lawn

cover under the Chinese pine stand was spacious, resulting in good humidity. Therefore, we can infer that the effect of humidity is obvious for the pure Chinese pine stand.

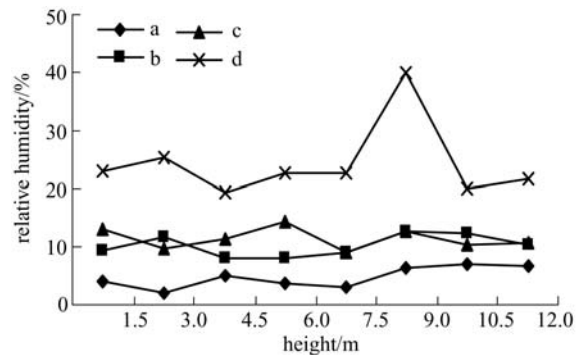


Fig. 10 Vertical variation of relative humidity of four green spaces at 14:00

4.5 Wind speed at four kinds of green spaces

4.5.1 Daily variation of wind speed in the horizontal direction

Figure 11 displays the diurnal variation of wind speed in the four types of green spaces in a horizontal direction at 1.5 m under sunny weather conditions. It can be seen that the wind speed fluctuated greatly from 8:00 to 18:00. The wind speed increased three times in the pine stand and achieved its peak of 4.2 m/s at 12:00. The wind speed in the locust stand increased four times and peaked at 2.4 m/s, also at noon. The wind speed of the pure Chinese pine stand was higher than that of the locust stand. The wind speed of the lawn and the mixed stand was comparatively low, which is related to differences in the location of the four green spaces. In our experiment, the *P. tabulaeformis* and *R. pseudoacacia* stands were close to the road, where the wind speed in these two green spaces were relatively high.

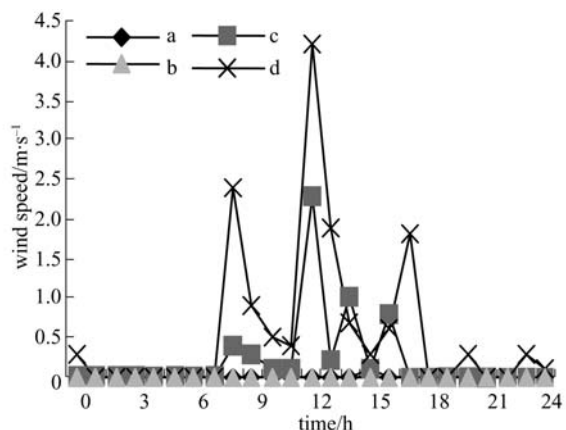
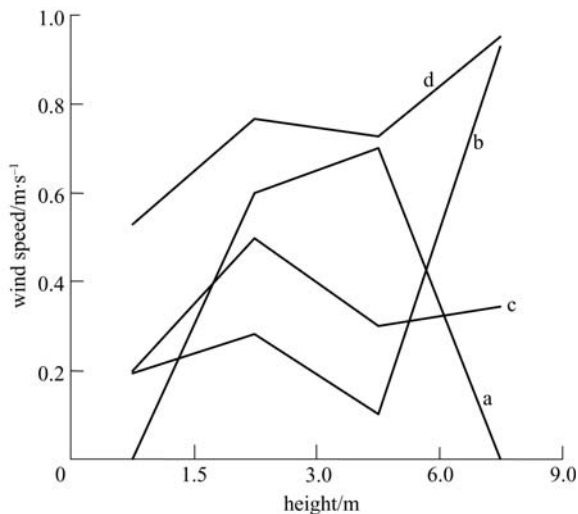


Fig. 11 Average daily wind speed of four green spaces on sunny days

There were also differences in the wind speed between the Chinese pine stand and the locust stand at a height of 1.5 m, i.e., the wind speed in the pine stand was higher than in the locust stand. The Chinese pine stand experienced some wind at night but the pure locust stand did not. This difference can be attributed to the structure of the two plant communities, i.e., the broad-leaved stand is stronger in reducing wind speed than the coniferous stand. The lawn and the mixed stand were slightly further from the road and their wind speeds were lower than in the other two green spaces.

#### 4.5.2 Average daily wind speed in vertical direction

The average daily wind speeds in the vertical direction of our green spaces under sunny weather conditions were all below 1 m/s (Fig. 12). The daily vertical wind speed in the Chinese pine stand was the highest at both the overall height and at each specific height. The wind speed in the locust stand was relatively low. The wind speed of the mixed stand at each height fell between that of the locust and pine stands. For the lawn, the vertical wind speed was high at heights of 3 and 6 m, and low at 1.5 and 9 m.



**Fig. 12** Average daily wind speed of four green spaces on sunny days

The pine stand was not very effective in reducing wind speed, which is most likely related to the structure of the plant community. The canopy height of the pine stand was less than 6 m and its ability to reduce wind speed decreased gradually above 6 m. This is why the wind speed in the Chinese pine stand increased when the height reached over the canopy layer. The mixed stand was between the two pure stands in its potential to reduce wind speed. The wind speed of the mixed stand showed no large variations among its different heights, which may be associated with the scattered, multi-layered structure of this plant community. The wind speed of the lawn was

low at heights below 3 m and above 6 m but high between 3 and 6 m. The green space of the lawn is quite large and its effect on wind speed may be related to its size. The relationship between wind speed and the area of the lawn needs to be studied further.

## 5 Conclusions and suggestions

### 5.1 Conclusions

The horizontal temperature and humidity patterns of the four kinds of green spaces indicate that the mixed stand was the best ( $\alpha = 0.05$ ) in decreasing air temperature and increasing ambient humidity under sunny conditions. There are three layers in the horizontal structure of the stand of broad-leaved trees mixed with coniferous trees and the lawns, i.e., the locust–Chinese pine–lawn. This structure allows the mixed stand green space to be covered with a multiple-overlapping coat to provide shade from the sunshine and reduce evaporation. At 14:00, the relative humidity of the mixed stand was 13.4% higher than that of the lawn and its temperature was 1.6°C lower than that of the lawn. The temperature gradient was in the order of the lawn > Chinese pine stand > locust stand > mixed stand. The humidity gradient was in the order of Chinese pine stand > mixed stand > locust stand > lawn. During the hot summer, the mixed stand was the best green space and the lawn the poorest in decreasing temperature and increasing humidity.

In the vertical direction, the temperature and humidity of the mixed stand fluctuated greatly, while they remained more stable in the two pure stands. The relative humidity, including the daily average humidity of the Chinese pine stand, was high. It can be concluded that the plant community with a high canopy at 5–6 m is strong in increasing humidity. The canopy density had a significant ecological effect on humidity of the plant community; there may be good correlation between canopy density and relative humidity. The average daily temperature of green spaces increased with an increase in air temperature. At 14:00, the temperatures of the pine stand and the lawn declined gradually with an increase in height, while the temperature of the locust stand and the mixed stand increased. This implies that the height of trees, the composition, and the structure of plant communities may greatly affect the energy flow and material circulation in the micro-environment, leading to large variations in vertical temperature and humidity between the pure and mixed stands.

Wind speeds in the four green spaces during the daytime were all higher than those in the evening. In the horizontal direction, the wind speed started to rise in the morning, reached its high point at noon, and dropped in the afternoon. The wind speed in the pure pine stand was higher than that in the locust stand under similar conditions,

implying that the pure broad-leaved green space was better in reducing wind speed than the pure conifer and broad-leaved green spaces. The wind speed of the mixed stand was stable and fell between that of the *R. pseudoacacia* stand and that of the *P. tabulaeformis* stand at each height. Due to the scattered, multi-layered structures of its plant community, the mixed green space was very good in reducing wind speed.

The mixed stand is a kind of plant community usually composed of more than two different species. The interspecific relationship among different species within a mixed stand may improve the ability of the plant community to use its space and resources more efficiently and effectively and increase their stability, compared with pure stands. Different plant community structures may cause different spatial effects and energy flows, as well as different ecological benefits on a spatial scale. If a cultivated plant community does not conform to rules of natural vegetation community development, the ecological effect of green spaces cannot be activated due to poor growth and development of the plant community.

In our study, the mixed stand had considerable effects in temperature decrease and humidity increase. The mixed stand was better in reducing wind speed than the two pure stands. Therefore, the plant community composed of coniferous and broad-leaved trees was better than the pure stands in terms of ecological value. It is noteworthy that in this experiment the increasing humidity effect of the pure Chinese pine stand was considerable. The composition of a plant community, its canopy height, coverage of plant community and plant density are highly related to the humidity effect of the green space. Further studies are needed to support this conclusion. The wind speed at the lawn was affected by its environment. Further studies are also required on the characteristics of wind speed at green spaces.

## 5.2 Suggestions

Through our investigation of plant communities in Beijing urban green spaces, we found a certain ratio of pure stands to the mixed stands. However, it is not yet clear which ratio is better in decreasing temperature and increasing humidity. Through this study, we can conclude that the mixed stand is better under conditions of high temperatures. Therefore, a mixed stand with a suitable composition and structure should be considered in the first instance when planning and designing botanical gardens and green spaces in urban areas.

The green space of a plant community is an important component of the urban landscape and has ecological connections with organisms and the environment. Its structure is often a temporary frame of an immature system, which developed and evolved not only over time, but

also with human disturbances. The true function of afforestation technology in botanical gardens should be the natural potential display of its success to enable human sentiment to dwell on its poetic nature, but not to change nature at will. A suitable and good structure of the plant community of a green space needs to be developed to utilize efficiently and effectively the space and resources available. Harmony with the natural environment in color and structure should be stressed in urban afforestation endeavors. Moreover, low input in management should be emphasized for sustainable landscape maintenance and its development.

From both the vertical and the horizontal structure, photosynthesis and co-existence of species should be fully considered in the establishment of urban green spaces. By doing so, the diversity, stability and the ecological benefit of green spaces can be enhanced through planting well-structured, dominant plant communities.

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