The Preliminary Study on Bare Spots Under Populus Euphratica Canopy

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Abstract

Land degradation and desertification are the great concern of arid and semiarid areas. In Euphrates poplar forest, there exists large number of bare spots which have been considered as representative of desertification. In this study, Unmanned Aerial Vehicle (UAV) technology was used to determine the spatial distribution and extract the bare spots area and morphological characteristics of *Populus euphratica* stands. Besides, the physical and chemical properties between soils inside and outside of these spots were compared. We found that: (1) the UAV method could be reliably used to extract the area of bare spots and the morphological characteristics of *Populus euphratica* stands;(2) with Pearson correlation coefficients of 0.673 and 0.894, there were a strong correlation relationship between bare spots area and canopy area in both measured and estimated data rather than other morphological characteristics;(3) electrical conductivity, pH, soil water content, total nitrogen, total phosphorus and soil organic matter has great differences between soils inside and outside of bare spots. These results not only could contribute to further understanding of spatial distribution of bare spots, but also helps to the sustainable management of *Populus euphratica* forest in arid regions.

Introduction

Desertification is a major ecological problem threatening sustainable development in China[1]. The long-lasting land degradation or desert expansion[2]occurred more frequently in the western and northern parts of China, especially in those arid and semiarid environments[3]. Due to its adverse effects on social economics and natural environments, land degradation has become an increasingly concerned ecological issues in northwestern China[4].Therefore, it is crucial to quantify the extent and degree of desertification and to understand the corresponding determinants. According to the fourth bulletin on Desertification in China, the desertified land area of whole country is almost 2.62 million km^2, in which Xinjiang Uygur Autonomous Region has 1.07 million km^2 (United Nations Convention to Combat Desertification, 2017). With the largest area of desertified land and the severe sand deposition in China, Xinjiang has attracted broad attention.

Being a dominant oasis species in northwestern China, Euphrates poplar (*Populus euphratica* Olive.) has played an important role in preventing desertification in Xinjiang[5,6]. Recently, we found that the herbaceous plants are rare under the crown of the natural *P. euphratica* stands (Fig. 6), which corresponding to the emergence of bare spots in the forest. It was believed that the expansion of canopy area of woody plants reduces the resource availability of the herbaceous plants, such as light[7-9], water[10], temperature[11], nutrients[12] and other environmental resources, hence it could limit the growth of under-canopy herbs[13]. Correspondingly, removing tall shrubs and trees might induce the gradual recovering of herbaceous plant[14,15].In contrast, other studies have discussed “fertile island” effect of *P. euphratica* and showed that there is significant difference in soil properties between the ground under and outside of the crown area[16]. Meanwhile, It is suggested that various assayed parts of *P. euphratica* have strong allelopathic potential[17]. These studies have deepened our understanding of nutrient distribution and processes in *P. euphratica* forest. However, it is still not clear how the morphological characteristics of *P. euphratica* affect the growth of understory vegetation. Since the aforementionedbare spots closely related to understory vegetation

degradation in *P. euphratica* forest, it is urgently needed to investigate the bare spots under tree canopies and their relationship with morphological characteristics of *P. euphratica* individual and stands for a better understanding of the mechanism of vegetation degradation and monitoring of the regional desertification in arid environments.

The morphological parameters such as tree height, diameter at breast height (DBH), are generally obtained by field measurement. However, the method based on field measurement is time-consuming. In addition, the parameters corresponding to bare spot are hard to measure via traditional methods. Fortunately, with the development of remote sensing technology, especially the Unmanned Aerial Vehicle (UAV) technology, which has been widely used in studying of vegetation coverage[18,19], may contribute to reliable obtaining of required parameters. The UAV image data, which often has a high spatial resolution and clearer image information including geometric structure, shape, texture and area, is convenient for identifying the parameters of the object[20,21]. Furthermore, the UAV remote sensing not only has the advantages of low cost, simple operation, fast image acquisition and high ground resolution, but also not affected by atmospheric factors in the process of image acquisition[22].

In this study, we aimed to: (1) evaluate the performance of photogrammetric techniques (UAV related techniques) for the estimation of canopy area, tree height, bare spot area and other parameters in *P. euphratica* forest and analyze the spatial distribution of bare spots and morphological characteristics of *P. euphratica* forest;(2) determine the relationships between bare spots area and morphological characteristics of *P. euphratica* fores; and (3) compare the physical and chemical properties between soils inside and outside of bare spots.The results could provide basic evidence for further bare spots studies thereby contribute to restoration and sustainable management of *P. euphratica* fores.

Results

2.1 Reliability of Unmanned Aerial Vehicle (UAV) technology

2.1.1 Statistical analysis of measured data

Tree DBH varied greatly among different groups (Fig.1a). This indicated that these trees that have been selected are representative in this region. Tree height did not show substantial variation in different DBH group (P=0.33, Fig.1b). The variation of tree canopy area and bare spot area increased with DBH (Fig.1c, d).

2.1.2 Reliability of UAV data

The measured and estimated tree height, canopy area and bare spot area are summarized in Table 1. The median and mean of measured bare spot area were 46.3m^2 and 50.7m^2, respectively, and of UAV estimated values are 35.3m^2 and 39.9m^2, respectively. This may suggest that UAV-related method underestimated bare spot area (Table 1). The measured and estimated mean canopy area were 23.8m^2 and 15.7m^2, respectively, indicated that UAV related method also underestimated tree canopy area (Table 1). A comparison between UAV-derived and measured tree height also demonstrated the underestimation of the former approach (Table 1). The linear regression between UAV estimated and field measured bare spot area, canopy area and tree

height revealed the reliability of UAV approach with R^2 of 0.75(Fig. 2a), 0.75(Fig. 2c) and 0.46(Fig. 2e), respectively. It should be noted that the estimated bare spot area, canopy area and tree height have relatively higher variation than measured ones (Fig 2b, d and f). Additionally, the MAE of bare spot area, canopy area and tree height were 8.08 m^2, 3.46 m^2 and 0.52m, respectively (Fig.2g, h, and i).

Table1. Statistics of the measured and estimated bare ground area, canopy area and height variables at the tree level.

	Bare ground area (m^2)		Canopy area (m^2)		Tree height (m)	
	Measured	Estimated(UAV)	Measured	Estimated(UAV)	Measured	Estimated(UAV)
Min	14.7	12.1	4.5	3.3	3.4	3.5
Q1	28.2	25.1	14.6	9.6	6.0	5.1
Median	46.3	35.3	22.0	13.6	6.8	5.6
Q3	67.8	56.0	30.5	22.1	7.8	6.2
Max	110.6	80.3	61.8	41.1	9.2	7.5
Range	95.9	68.2	57.2	37.8	5.8	4.1
Mean	50.7	39.9	23.8	15.7	6.7	5.6
SE	5.2	3.9	2.2	1.7	0.3	0.2
CV	53.6	50.7	48.6	55.8	20.0	17.4

2.2 Spatial characteristic of tree morphological characteristics and bare spots derived from UAV

Totally, the 163 trees canopy and equal number of bare spots were identified. The spatial distribution canopy area and bare spots area interpolated based on UAV data shown in Fig. 3. The bare spots area showed a decreasing trend from south to north part and increasing trend from west to east part of the study area. The spatial distribution of tree canopies showed a similar pattern with the bare spots. Specifically, large canopies were located at south and west part of study area, whereas small and medium canopies could be found in north and east parts. The spatial distribution of tree height showed an irregular pattern with almost all tree height between 5.4-6.0m.

2.3 The correlation analysis

The relationships between bare spots area and morphological characteristics (canopy area, height and DBH) of *P. euphratica*in both measured and estimated data are shown in Fig. 4. We found that the measured bare spots area significantly correlated to measured canopy area (p=0.673, R^2=0.35, P<0.001, Fig.4a) tree height

(p=0.623, R^2=0.39, P<0.001, Fig.4b) and DBH (p=0.527, R^2=0.28, P< 0.001, Fig. 4c). Beside, the estimated bare spots area is highly correlated with estimated canopy area (p=0.894, R^2=0.80, P<0.001, Fig. 4d) and measured DBH (p=0.852, R^2=0.19, P<0.001, Fig. 4f). In contrast, weakly positive correlation between estimated bare spots area with estimated tree height is found in Fig. 4ewith the Pearson correlation coefficient of 0.427(R^2=0.18, P<0.001).

2.4 Physiochemical properties of soil

There are great differences in electrical conductivity (EC), pH, soil water content (SWC), total nitrogen (TN), total phosphorus (TP) and soil organic matter (SOM) inside and outside of the bare spot (Fig. 5). The variation in EC (Fig. 5a), soil water content (Fig. 5c), TN (Fig. 5d), SOM (Fig. 5f) inside the bare spot is relatively larger than that of outside the spot. In contrast, the variation in pH and TP inside the bare spot is lower compare with that of outside(Fig. 5b, 5e). Compare the average value of these six parameters, we found that they are relatively higher inside the bare spot than outside.

Discussion

In the past decades, ecologists have studied the reliability of remote sensing method in land cover change and land management. In recent years, the corresponding applications were advanced with the introduction of UAV equipment. It was proved that such method has the advantages of low cost and better performance compare to traditional methods when used to obtain morphological characteristics of individuals and stands in forest ecosystems [23-27]. Recently our research team found in a lot of field work that in the sparse *P. euphratica* forest located in the Ebinur Lake National Nature Reserve, there are exposed patches of different sizes (abbreviated as bare spots), where there are extremely sparse herbaceous plants (Fig. 6).As a constructive species in riparian desert areas, the sparse herbaceous plants under the canopy may be a manifestation of desertification. In this study both the field monitoring data and the data obtained by UAV image showed that compared with other morphological characteristics, the canopy area of *P. euphratica* and the bare spots area have a stronger positive correlation.

Firstly the canopy area directly affects the intensity of light, which is one of the most important factors affecting the distribution of plants under the canopy [28]. Studies have reported that scattered light under shrubs is one of the most important environmental factors affecting the distribution of plants under shrubs. The abundance of herbaceous plants is negatively correlated with direct light and shrub coverage, and light indirectly changes soil moisture conditions [29]. Other studieshave also shown that light in arid areas has a great influence on the germination of some plant seeds [28,30]. From these points, light under canopy may be a possible factor that further leads to the loss of vegetation cover or the formation of bare spots under the canopy. Secondly, in arid ecosystems, water is the main limiting factor for plant growth. Ecologists have reported thatin *P. euphratica* forest, the depth of groundwater is the determinant factor that restricts the above-ground biomass and distribution of vegetation [31,32]; according to [33] who also found that the species diversity of plant communities has a very significant negative linear correlation with the depth of groundwater; hence, herbaceous plants that grow under the canopy can hardly survive. In addition, previous studies have shown that *P. euphratica* has high salt tolerance and salt absorption [34]. Due to the

decomposition of litter, this may lead to a relatively high salt content under the canopy area, which further increases the difficulty of survival of herbaceous plants, and might ultimately lead to the reduction of plant coverage under the canopy or the appearance of bare spots.Next possible reason for the formation of bare spots is soil nutrients. In arid and semi-arid areas, researchers found that there is a big difference in soil nutrients inside and outside the bare spots under shrubs, showing obvious enrichment characteristics as well [35].[36] Showedthere is a phenomenon of accumulation of soil nutrients in the arid desert area under *Caragana microphylla* shrub canopy. In the former study of *P. euphratica*"fertile island" effect [16], it was shown that the surrounding soil nutrients also have a strong enrichment intensity, which is consistent with our research result 3.3 that the physical and chemical properties of bare spots are higher than those outside naked spots.Some researchers reported that the size of shrub canopy is positively correlated with the amount of litter accumulated under the canopy [37-39]. Although there is insufficient evidence to provide a convincing explanation for the sparse vegetation mechanism under the *P. euphratica* canopy in arid and semi-arid areas, yet [40] showed that the “fertile island” effect of plants promoted their own expansion, inhibited the growth of other plants, and led to a decline in ecosystem biodiversity, which may have accelerated the desertification process of arid grasslands in North America.Last but not least, some scholars believe that sparse trees will produce special microenvironmental conditions and metabolically release allelochemicals in their vicinity, and their canopy plays a vital role in microbial function and nutrient turnover, which depends on the interception effect of light canopy [41].

In summary, the possible factors that lead to the loss of vegetation cover or the formation of bare spots under each canopy of *P. euphratica* might be the light, water, soil salinity, nutrients, microbial community and allelochemicals.In order to find out the main reason of appearance of bare spots under the *P. euphratica* prosthesis, more in-depth research should be carried out.

However it is interesting to note that *P. euphratica* is always known as protector of the oasis from the desertification because of their characteristics of storm prevention and sand immobilization[5]. Also it has been suggested spatial heterogeneity of soil properties can be counted as one of the important factors of desertification [40], since it changes the spatial pattern of soil properties and constituents including soil water and nitrogen, which are the primary limiting factors for the structure, production and dynamics of the vegetation in arid ecosystems [42]. Hence, if the bare spot was caused by heterogeneity of soil properties, it will bring up the question whether it is good for *P. euphratica* in arid environment to have larger canopy size to prevent further desertification.

Conclusion

In this study, we firstly discussed the capability of UAV method in obtain the morphological characteristics of tree individuals and stands in *P. euphratica* forest. We then explored the spatial distribution of bare spot in the forest and analyzed the correlation between the area of the spots and morphological characteristics of trees. Finally we tested soil properties inside and outside of the bare spots area. We found that: (1) Goodness of fit analysis results show the good fitting effect with R^2=0.756, R^2=0.756 and R^2=0.456 for estimation of tree canopy area, bare spots area and tree height respectively; (2) totally, 163 *P. euphratica* were identified

with its morphological characteristics in 25 ha study plot, which showedthere is a strong significant positive correlation between bare spots area and tree canopy area in both measured or estimated data analysis rather than other morphological characteristics; (3) large variation among the bare ground area under tree canopy and outside of the bare ground patches was found for EC, pH, SWC, TNC, TP and, SOM.

Materials And Methods

3.1.1 Study area

This study was carried out in Ebinur lake basin (83°34'53.976"E to 83°35'18.37"E, 44°36'55.13"Nto 44°37'12.09"N) at southwest of the Junggar Basin in Xinjiang Province, China (Fig. 6). The climate is dominated by temperate continental climate with mean annual precipitation of 100 – 200mm, mean annual temperature of 6.60 - 7.80°C and annual potential evaporation of 1, 500–2, 000mm [43]. The dominant factor affecting the climate of the basin is the perennial gale from the Alashan Pass. The basin has 160 days with wind speed exceeds 8m/s per year and instantaneous maximum wind speed is 55ms^{-1}[44].

1.2 Ground-based data collection

Our sampling was conducted in a 25ha plot near Ebinur Lake during July, 2019. The sampling plot was evenly divided into 25 sub plot with an area of 1 ha. We randomly selected nine sub plots and measured DBH of all *P. euphratica* individuals. We then selected 27 trees (9 large, 9 medium, 9 small based on DBH) and measured their morphological characteristics. Subsequently, the area of bare spot under 27 trees was measured with real time kinematic (RTK). Finally, the crown widths (north-south and west-east direction) were measured (with an accuracy of less than 0.1m) and the canopy area of the 27 *P. euphratica* trees were calculated using established equation [45].

2.3 UAV data collection

The morphological characteristics of *P. euphratica* individuals and area of bare spots were also obtained based on UAV approach, to this end, we obtained the 0.04m×0.04m spatial resolution images (blue, green and red band) of the study area use Phantom 4 Pro Unmanned Aerial Vehicle with Digital Camera (DJI Enterprise, 2020). The images were taken between 14:00 and 20:00 at 20th September, 2018 at a height of 20 m. totally, 1200 images covering our study area were obtained and preprocessed use Photo Scan (DJI Enterprise, 2020). Finally, the Digital Terrain Model (DEM) of the study area was extracted from Ortho Photo Map.

The canopy area and bare spots area were obtained by using visual interpreting method. With the help of QGis, we extracted canopy areas of 163 *P. euphratica* individuals and the bare spots area in the forest from Ortho Photo Map. During this process, the method of calculate canopy area was improved based on our own knowledge and previous results [46].

Tree height was estimated based on difference between crown height and ground “height”. These two heights are actually the average of four height value extracted from crown and ground. The calculation

procedure is explained in Fig. 7 and the following formula:

$$H = \frac{a+b+c+d}{4} - \frac{e+f+g+h}{4} (1)$$

Where H is the height of trees. a, b, c, d are height of the canopy obtained at four sites on canopy and e, f, g, h are height of the four sites on the ground .

2.4 Statistics and validation of data

In the present study, liner regression was used to test the relationship between measured and estimated parameters, the coefficient of determination (R^2) was also calculated as a metric for accuracy. Box-and-whisker plots were applied to demonstrate the variability of measured and estimated parameters. The mean absolute error (MAE) was calculated use the following formula to evaluate the performance of regression model:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|E_i - M_i| \quad (2)$$

Where MAE is the mean absolute error, E and M are UAV derived parameters and field measured parameters, respectively.

2.5 Soil sample collection and measurements

Surface soils (0-20cm) inside and outside of the bare ground were sampled under the canopy of selected 27 trees. Inside and outside of each bare ground, we collected five parallel samples and mixed to one average sample. Thus, the number of soil samples was54.

Soil samples were air-dried in the laboratory and passed the 16 mesh sieve. 10 g soil samples were weighed for the determination of pH value (soil-water ratio 1:5 suspension) and electrical conductivity (EC) the remaining soil samples were used for the analysis of soil organic matter (SOM), total nitrogen (TN) and total phosphorus (TP). SOM was determined by potassium dichromate oxidation-external heating method, TN by Kjeldahl method and TP by per chloric acid, sulfuric acid digestion and Molybdenum-Antimony anti-colorimetric method.

Declarations

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Authors' contributions

Conceived and designed the study: WY and YJ. Analyzed the data and wrote the paper; WY and KM; XZ polished language; help acquiring UAV data and field survey data: XX and LY. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and material

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

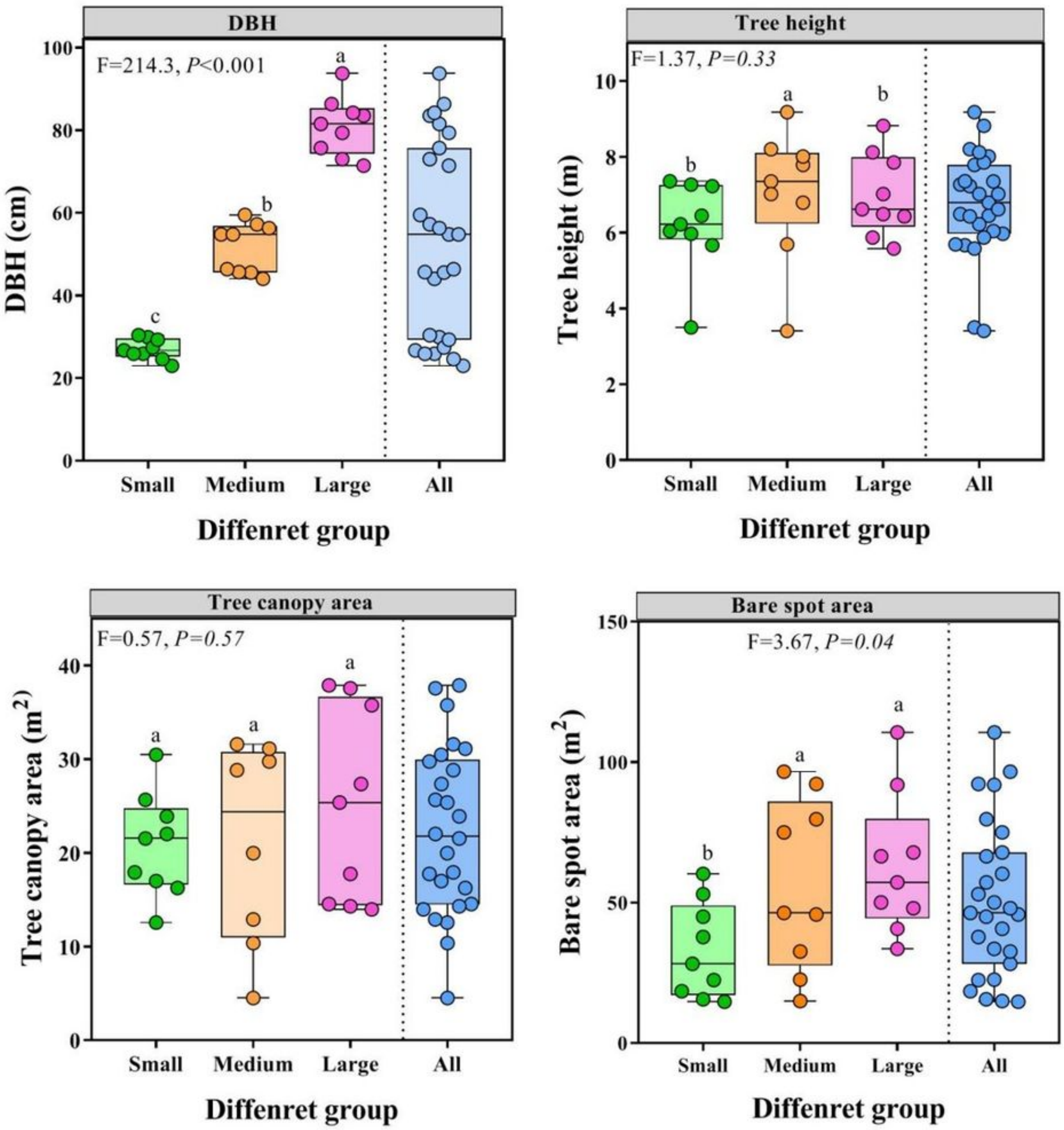

Figure 1

Statistical analysis of field measurement data

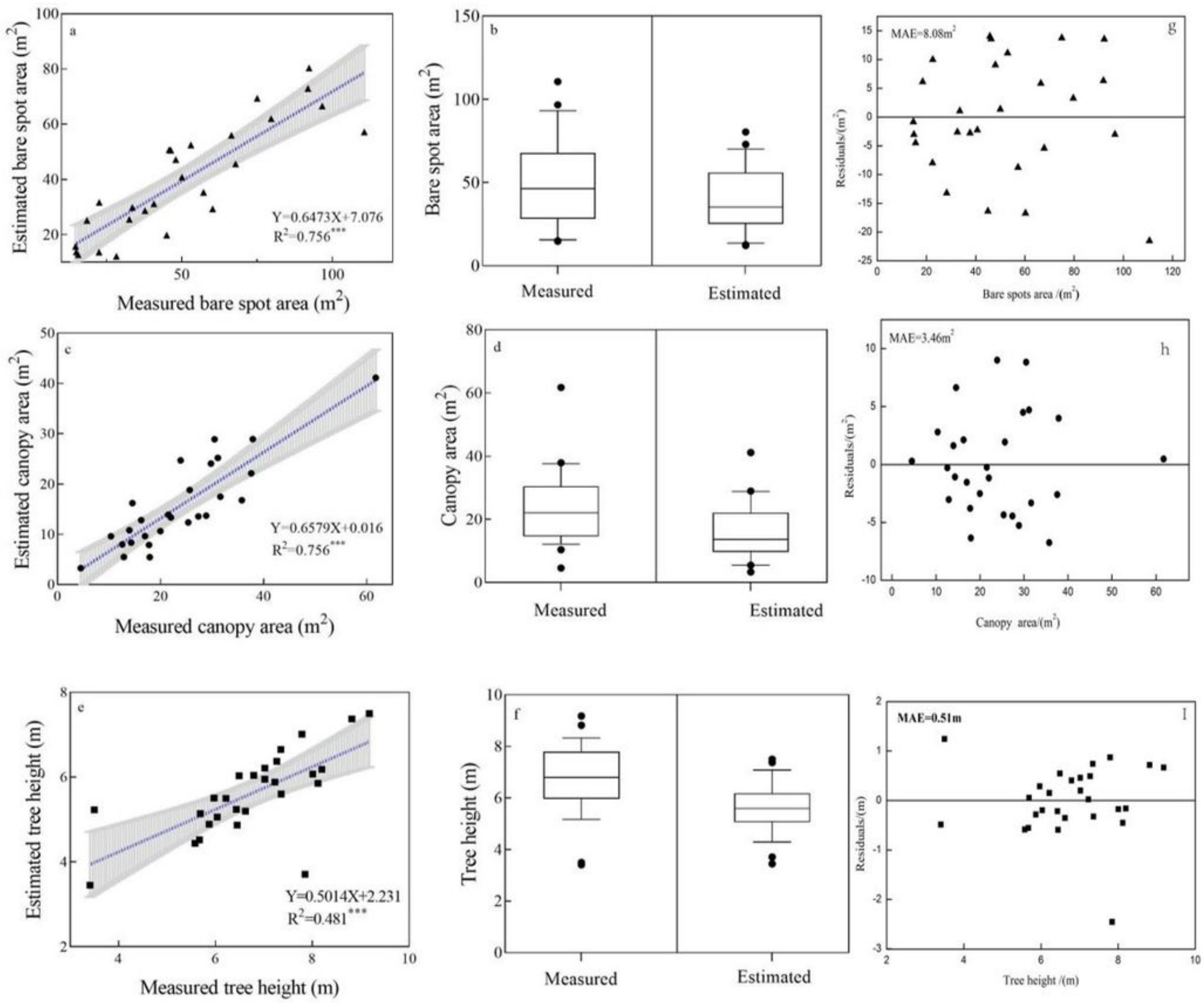

Figure 2

Linear regression models of the estimated (UAV) and measured

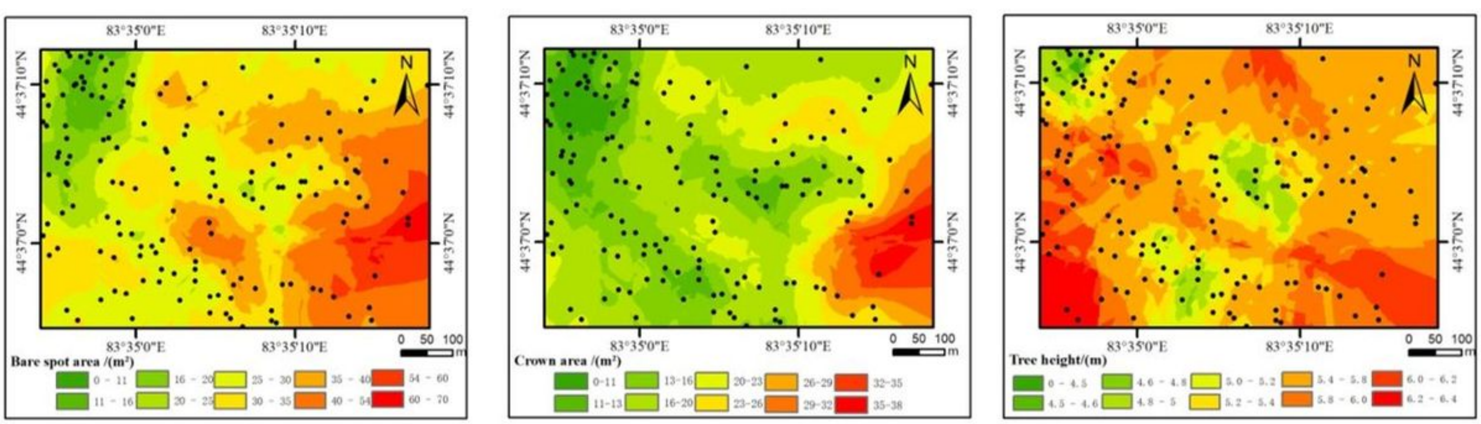

Figure 3

spatial distribution of Morphological characteristics of P. euphratica and bare spots

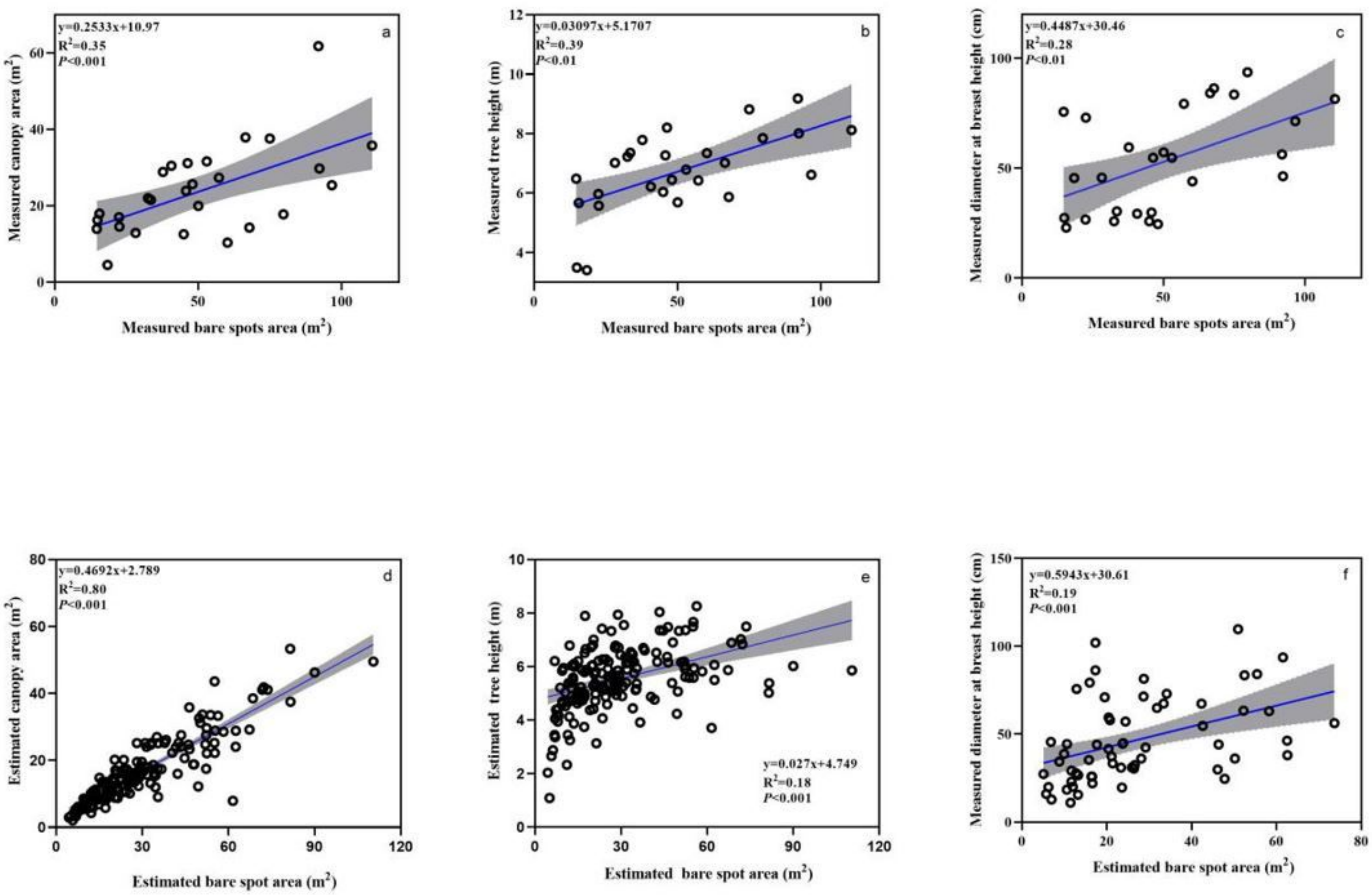

Figure 4

correlation analysis between bare spots area and morphological characteristics

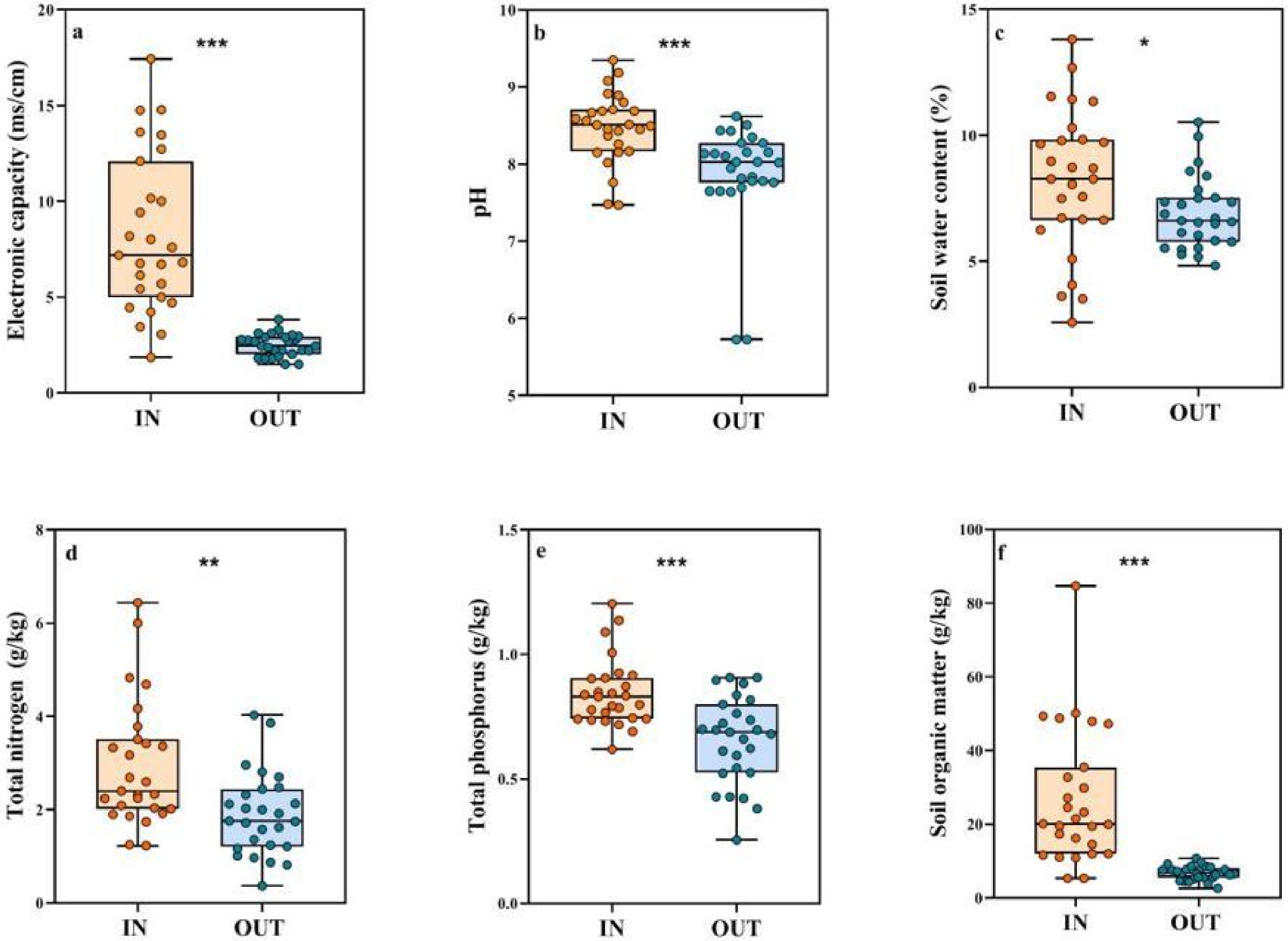

Figure 5

Physiochemical properties of inside and outside soil

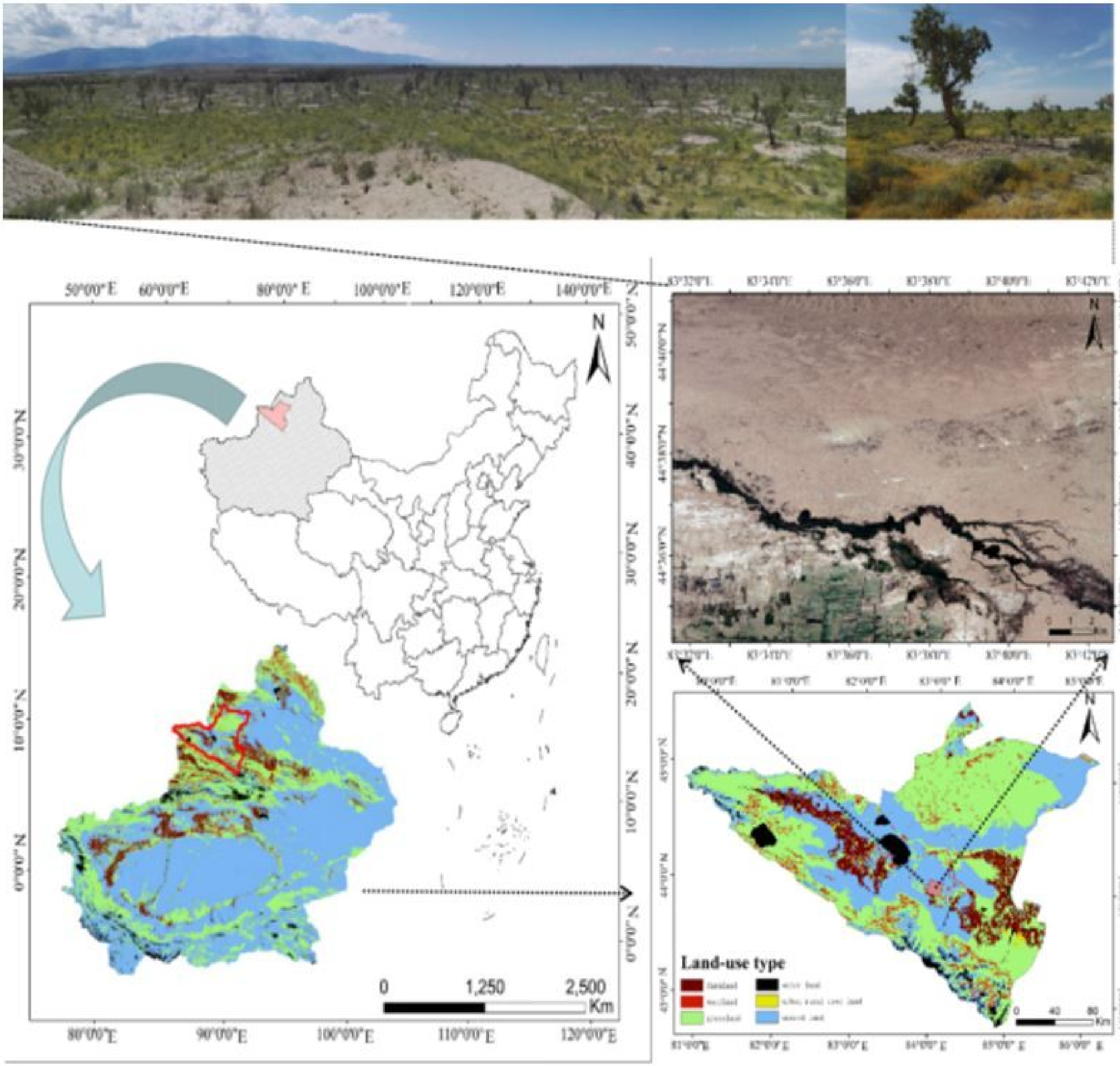

Figure 6

the study area and the sampling sites in P. euphratica forest Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

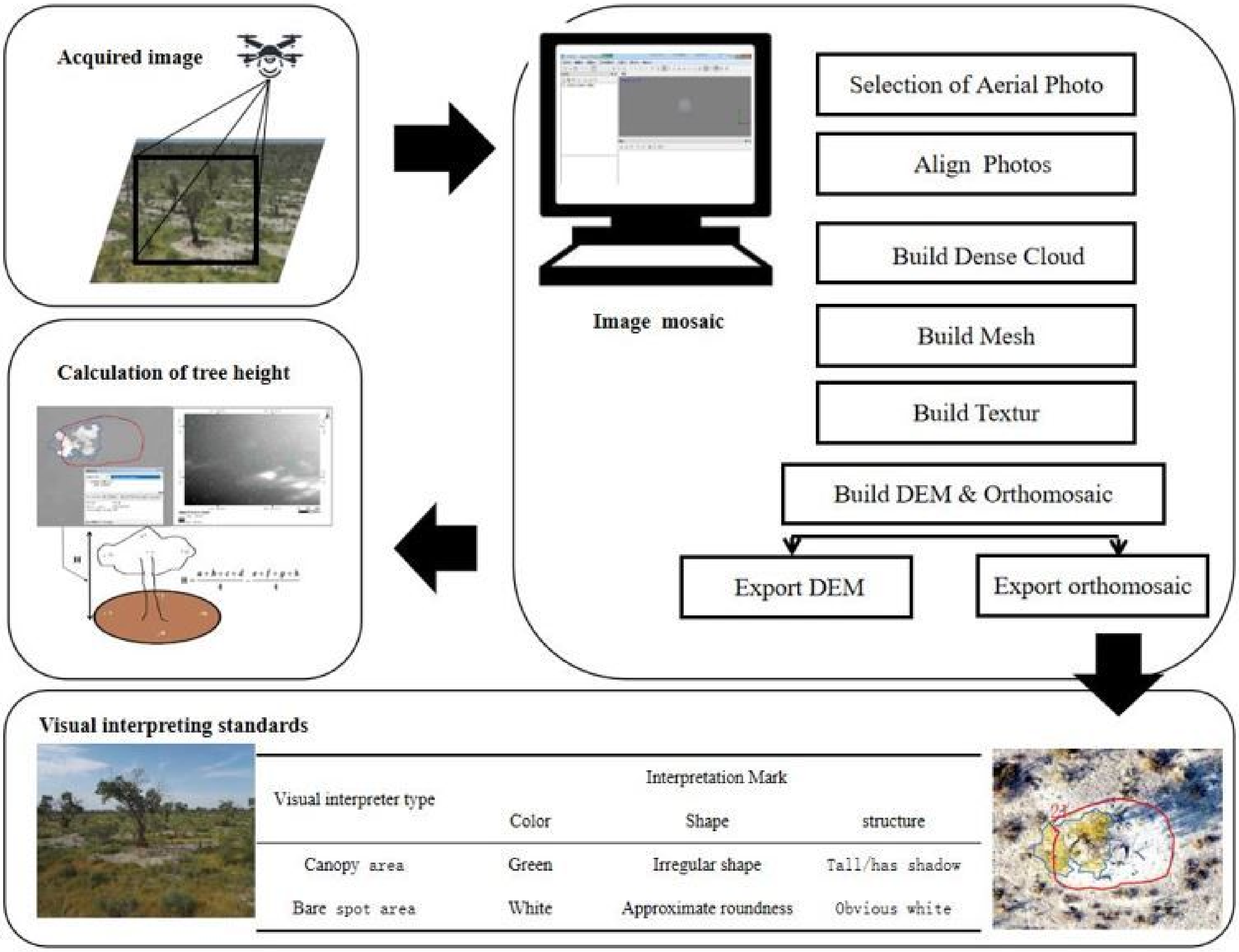

Figure 7

UAV data collection Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.