Growth dynamics of deciduous species during their life period: A case study of urban green space in India.

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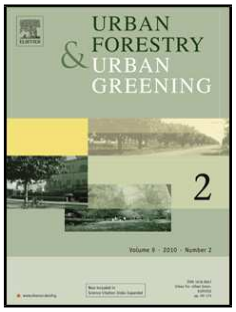

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Growth dynamics of deciduous species during their life period: A case study of urban green space in India

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Highlights

- spatial and temporal dynamics of grass density and shoot growth rate in urban green space were rarely explored
- Field monitoring was conducted in the urban green space for one year (i.e., life period of selected species).
- The hypothesis of uniformity in grass density and shoot growth rate during life period of deciduous species was not found to be true

- Significant spatial and temporal variations in growth dynamics were found during monitoring period.

Abstract

It is evident that grass density (GD) and shoot growth rate (SGR) governs the differential settlement of substructure, groundwater recharge, and stability of green infrastructure. GD and SGR are usually assumed to be constant during the entire life period of vegetation. However, spatial and temporal dynamics of GD and SGR in urban green space were rarely explored previously. The main objective of this study is to explore the spatial and temporal dynamics of GD and SGR in urban space vegetated with deciduous species (mix grass i.e., Poaceae and Bauhinia purpurea). Field monitoring was conducted in the urban green space for one year (i.e., life period of selected species). The monitoring period includes the growth period and gradual wilting period. Substantial spatial variation of GD was found during the first six months. GD away from the tree trunk was found to be 1.02-56.3 times higher than that near the tree trunk during the first six months. Thereafter, any spatial variation of GD was not found in the next six months. Unlike the GD, SGR was found to vary during the entire life period of mix grass. In addition, SGR away from the tree trunk was found to be 1.1-4.6 times higher than that near the tree trunk. Any relationship between GD and rainfall depth was not found. Whereas, SGR mainly depends on rainfall depth. The hypothesis of uniformity in GD and SGR during the life period of deciduous species was not found to be true.

Keywords: urban green space; deciduous species; grass density; shoot growth rate

1. Introduction

Implications of vegetation in green infrastructure (i.e., ecological and geotechnical infrastructure) are widely recognized (Pollen et al., 2004; Schwarz et al., 2010; Bordoloi et al., 2018). Applications of vegetation in various green infrastructures are pictorially shown in Fig. 1. It is known that vegetation exists in the surroundings of buildings. Differential settlement of foundation may be caused by vegetation in the surroundings of buildings (Li and Guo, 2016). Mental and physical health of urban residents is improved by sports fields and parks (Gascon et al., 2015; Lee and Maheswaran, 2011). Bioretention units reduce runoff and improve groundwater recharge (Passeport et al., 2009; Garg et al., 2019; Gopal et al., 2019). Vegetation is an eco-friendly solution to stabilize the riverbank and slope (Leung et al., 2015a, b; Gadi et al., 2016).

The growth dynamics of vegetation in green infrastructure are expressed in terms of the normalized surface area of green grass (NSA). NSA is generally considered as the function of GD or shoot length (Allen et al., 1998). GD is defined as the ratio of surface area covered by grass to the total surface area of soil (Gadi et al., 2017a). GD indicates the surface area of grass, which intercepts radiant energy (Monteiro et al., 2006). Evapotranspiration induced suction depends on radiant energy intercepted by leaves (Leung et al., 2015b). Evapotranspiration induced suction governs the performance of green infrastructure (Gadi et al., 2016). Researchers widely use the NSA of grass (Claassen and Marler, 1998; Allen et al., 1998) to interpret suction induced in vegetated soil. NSA of grass was presumed to be constant during entire life period of vegetation in previous studies (De Silva et al., 2008; Deb et al., 2013; Zhu and Zhang, 2015; Garg and Ng, 2015; Kokutse et al., 2016; Gadi et al., 2018a, b). However, tree shade and atmospheric parameters affect GD (Dodd et al., 2005) and SGR (Ludwig et al., 2001; Laporte et al., 2002). Previous researchers rarely considered the effects of tree shade and variation of atmospheric parameters with time.

The authors have conducted basic numerical analysis to demonstrate the importance of the normalized surface area of grass. Axi-symmetric root water uptake is assumed for numerical simulation. Richards equation, coupled with sink term, was numerically solved using a commercial finite element package "Hydrus". Evapotranspiration was simulated for 10 hours under the atmospheric conditions of northeast India. The suction profiles of soil under two different normalized surface areas are shown in Fig. 1. The suction is observed to increase by 2 - 248 % in the case of less NSA. Whereas, such an increase in suction is found to be 2 – 1925 % when NSA was relatively high. The difference between suction values of the higher and lower NSAs is found to be 2-1490 % in the root zone. Furthermore, Gadi et al. 2017a show that infiltration may vary by 250-400 % due to change in GD. This indicates that the actual value of the normalized surface area of grass needs to be adapted to interpret suction and infiltration accurately. However, long-term field monitoring was rarely conducted to explore the effect of seasonal change and tree shade on GD and SGR during the life period of vegetation in urban green space.

The objective of the present study is to explore the spatial and temporal dynamics of GD and SGR in an urban green space. The urban green space vegetated with deciduous species (i.e., Poacea and Bauhinia purpurea) was selected for the present study. Field monitoring was conducted during the entire life period of selected species (for a year) to explore the spatial and temporal dynamics of GD and SGR.

2. Materials and Methods

2.1 Site description

Location of the selected urban space is shown in Fig. 2. The site consists of mix vegetation on flat ground. Poacea and Bauhinia purpurea were found on the flat ground. In addition, Pongamia pinnata trees also exist in the site. Field monitoring was conducted on the mix vegetation in the urban space to understand the spatial heterogeneity of GD and SGR.

2.2 Soil properties

Six soil samples were collected from different locations on the site. Three samples were collected from the right side of the center of the edge and the remaining samples were taken from the left side. Average dry density was found to be 1352 kg/m^3 from field tests (ASTM D4914/D4914M-16, Standard Test Methods for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit). The average proportions of gravel, sand and, silt and clay were observed to be 0%, 2% and 98%. The soil in the green space is categorized as poorly graded sand (SP; ASTM D2487-11) according to the unified soil classification system (USCS). Saturated permeability of the existing soil was observed to be 2.6 ± 0.3 x 10^{-4} m/sec.

2.3 Overview of the green space

Bauhinia purpurea is broadly acknowledged as an anti-diabetic, anti-inflammatory and thyroid hormone regulating agent (Zakaria et al., 2007). Furthermore, Bauhinia purpurea, Poacea, and Pongamia pinnata are recognized for their (i) drought tolerance (Cheplick, 2004; Cai et al., 2007), (ii) ornamental values (Bouldin et al., 2004; Arifin and Nakagoshi, 2011) and (iii) commonness in semi-arid regions (Leishman and Westoby, 1994; Shukla et al., 2015). The site is categorized into five concentric half circles to understand the spatial variation of GD and SGR. Radii of these half circles are 1 m, 2 m, 3 m, 4 m, and 5 m, respectively. These dimensions were considered based on trial measurements.

2.4 Instrumentation used in the study

The site is categorized into 170 small grids to quantify the grass growth in the selected site. The size of the grid was selected based on trial measurements of shoot length and GD. An unmanned air vehicle (UAV; DJI Phantom) was used to capture the images of grass under ambient light. UAV consists of a camera attached to the aircraft, which is adapted for field monitoring. The scale was used to measure shoot length. It must be noted that the surface area of vegetation cover is usually quantified from satellite images (Elmore et al., 2000). However, vegetation in the densely populated urban areas could not be captured using satellite. Therefore, the UAV based approach has been developed for the present study.

2.5 Field monitoring programme

The field monitoring programme was designed to quantify the spatial and temporal dynamics of GD and SGR in the 170 grids. The field was monitored from 1st January 2016 to 31st December 2016. A micro-climate monitoring system was used to monitor meteorological parameters such as rainfall depth, relative humidity, air temperature, and net radiation. Rainfall depth from as high as 275 mm during April to 5 mm during February was observed. Relatively high rainfall depth was found during April, May, June, July, September, and November. Hence, this duration can be termed as wet period. The remaining six months can be referred as the dry period.

2.6 Non-destructive image analysis to quantify the GD

UAV's maximum service sealing level is 6000 m above the sea level. ISO speed, focal length, and exposure time are maintained at ISO-640, 35 mm and 1/8000 s, respectively. Constant ISO speed, focal length, exposure time were maintained to avoid observational errors.

2.7 Image analysis using ImageJ

Changes in surface area of grass cover during the monitoring period are expressed in terms of GD. Various colour spaces i.e., HSB, Lab, and RGB are commonly used to differentiate the soil surface and vegetation (Koschan and Abidi, 2008). Among these, RGB colour space was found to be appropriate for the present study. The mixture of different proportions of R, G, and B produce distinct colours. Range of R, G, and B is 0 – 255 (Ferreira and Rasband, 2012). Step by step procedure to determine the surface area using ImageJ was demonstrated in Gadi et al., 2017b. ImageJ is a public domain image processing program, which quantifies the pixel statistics in the image (Ferreira and Rasband, 2012). The captured image of the site is imported into ImageJ. Thereafter, the desired portion in the image is cropped. Adjustable colour scales of R, G, and B are used to differentiate the soil and grass. Surface area covered by grass in the grid is quantified using "measure option". The same procedure is repeated for all the grids. Area of leaves below the top portion of canopy would be relatively high in case of tree species (Gadi et al., 2016). Hence, the canopy area of tree species could not be quantified using 2D images. Furthermore, the plants below the canopy cannot be monitored from 2D images. Therefore, 3D images may be needed to quantify the canopy area of treed species (Gong et al., 2016).

3. Results and discussions

3.1 Grass cover change during the monitoring period

Changes in surface area and shoot length during the monitoring period can be seen in Fig. 3 (a) – (l). Surface area covered by grass is relatively low during January. The grass was observed to wilt gradually during February. Regrowth of grass was found during March. Surface area and shoot length are observed to be relatively low during the first three months. Unlike those during the previous three months, a large increase in surface area and shoot length was observed during April (Fig. 3 (d)). Only Poaceae species were observed to grow during the first three months. Whereas, the simultaneous growth of Poacea and Bauhinia purpurea was found after March. Growth of Bauhinia purpurea and Poaceae was found to continue from May to October. Relatively long shoots can be seen from May to October (see Fig. 3 e-j). Gradual wilting of vegetation was observed during November and December (see Fig. 3 k and l). Completely wilted grass was found at the end of December.

3.2 Variation of GD in the site

Fig. 4 a-l show the spatial variation of GD in the green space. Spatial and temporal variation of GD is shown in contour plots. The difference between the minimum and maximum GDs was categorized into eight different ranges (see colour scale). Center of the edge was marked as a reference to discuss the variation in GD. GD is found to vary between 0.001 m^2/ m^2 and 1.000 m^2/ m^2 during the first six months.

Spatial heterogeneity of GD at the end of January is shown in Fig. 4 a. GD is found to vary considerably with change in radial distance from the center. In addition, GDs in the left and right sides of the center are found to be dissimilar. Five distinct GD ranges can be observed on the left side of the center. Whereas, two GD ranges are found on the right side of the center. Spatial heterogeneity of GD at the end of January is shown in Fig. 4 b. Unlike that during January, considerable spatial heterogeneity in GD is not observed at the end of February. GD near the tree trunk (i.e.., within 2 m longitudinal distance) is found to increase due to the presence of shredded leaves. Any change in GD is not found at longitudinal distance greater than 2 m.

Spatial variation of GD at the end of March is shown in Fig. 4 c. GD is found to be more heterogeneous in the left side as compared to that in the right side of the center. Re-greening of grass shows the regrowth of grass during March. Although regrowth was found, GD is observed to decrease at distance less than 2 m from the center. This can be attributed to the decomposition of shredded leaves. In addition, any notable change is not found during March at longitudinal distance greater than 1.2 m in the right side of the center. This trend is observed to hold true up to 3.3 m in the left side of the center. Spatial heterogeneity of GD at the end of April is shown in Fig. 4 d. Unlike that in other months, a significant change in GD was observed during April. GD in the entire site is found to become 1 m^2/m^2 at the end of August. Thereafter, GD was found to remain 1 m^2/m^2 up to the end of December.

3.3 Comparison of average GD in various annuli

Fig. 5 shows the variation of average GD in various annuli. The first annulus is approximately 0.14 m from the center of the edge. GD is observed to rise with increase in radial distance over the major region of the site when shredded leaves were absent during the first six months. This trend is not found to be consistent near the trunk of the tree. The noticeable change in GD with the change in radial distance is not found at longitudinal distance less than or equal to 2 m. This can be attributed to growth competition between tree and grass roots (Belsky, 1994; Dohn et al., 2013). In addition, the shade of the trees may also be the reason for relatively less GD near the tree trunk (Kolb and Steiner, 1990; Benavides et al., 2009). GD at longitudinal distance less than 2 m is relatively high when shredded leaves were present. Hence, any trend was not found in GD variation with respect to radial distance during February and March. Average GD in five annuli is observed to remain constant (i.e., $1m^2/m^2$) during the last six months (July – December).

Difference between highest and lowest GDs is observed to be relatively high at the end of January and March as compared to that during other months. Highest GD is found to be 56.3 times higher than the lowest GD at the end of January. Likewise, the highest GD is observed to be 23 times higher than the lowest GD at the end of March. Whereas, the highest GD is only 1.02 - 2.54 times higher than that during the remaining period in the first six months. Previous studies (Guevara-Escobar et al., 2007) also show that GD under light could be 1.02 – 56.3 times higher than that in the shade. Relative humidity, air temperature, and net radiation were found to vary diurnally throughout the monitoring period. However, diurnal variation of vegetation growth was not found.

3.4 Variation of SGR in the site

Fig. 6 a-l show the spatial variation of SGR of the mix grass. It can be seen that grass is absent at few locations. The average SGR of the surrounding grass was considered when the vegetation was absent in few locations. The range of SGR is found to be 1 - 443 mm/month. The difference between the minimum and maximum SGR was categorized into eight different ranges (see colour scale). Center of the edge was marked as reference to discuss the variation in GD. Unlike the GD, SGR is found to vary during ten months of the monitoring period (January to October). In addition, SGR in right and left sides of the center are observed to be similar over the major portion of the considered surface area. Spatial heterogeneity of SGR during first three months is shown in Fig. 6 a-c. Only one SGR range is found during the first three months. Whereas, two SGR ranges are observed during March. Spatial heterogeneity of SGR at the end of April is shown in Fig. 6 d. Unlike that in the first three months, 4-8 SGR ranges are found from April to October. Thereafter, only two SGR ranges are found at the end of November and December.

3.5 Comparison of average SGR in various annuli

Average SGRs in the five annuli were compared to understand the significance of the change in shoot length quantitatively (see Fig. 7). Very low SGR is found during the first three months. This may be attributed to relatively low rainfall depth during the first three months. Low rainfall depth implies less available water content. Average SGRs in the annuli at greater than or equal to 2 m are found to be 1.1-2.7 times higher than that at 0.15 m radial distance during the first three months. This can be attributed to growth competition between grass and tree roots (Hipondoka et al., 2003; Messier et al., 2009). Unlike the GD, relatively large increase in SGR is found during May. Average SGRs in the annuli at greater than or equal to 2 m are observed to be 1.8 – 4.6 times higher than that at 0.15 m radial distance from center during May to October. Whereas, any trend in SGR with respect to radial distance is not observed during November and December. Any relation between SGR and time is not found. However, the variation of SGR is consistent with the trend of rainfall depth. SGR is found to be high during heavy rainfall period.

4. Conclusions

The present study investigated the spatial and temporal dynamics of GD and SGR in urban green space. Field monitoring was conducted during the entire life period (i.e., around 1 year) of deciduous species in the selected urban green space. Considerable spatial variation of GD occurs during the first six months. GD away from the trunk of the tree is 1.02-56.3 times higher than that near the tree trunk when shredded leaves are absent during the first six months. This may be due to tree shade and growth competition between grass and tree roots. GD near the tree trunk is higher than that away from tree trunk when shredded leaves and wilted grass are present during the first six months. GD becomes 1 m^2/m^2 after first six months and remains constant until the wilting point. GD variation would depend on rainfall depth.

SGR would not vary spatially during January and February. Thereafter, SGR varies spatially during the remaining life period of grass (i.e., up to October). This is found from the SGR ranges occur in the test site. SGR away from the trunk of the tree is 1.1-4.6

times higher than that near the tree trunk during the entire monitoring period. This can be due to tree shade and growth competition. The trend of variation of SGR is consistent with that of rainfall depth. Whereas, SGR would not vary consistently with time. In addition, spatial heterogeneity of SGR is also consistent with rainfall depth. More number of SGR ranges exist when rainfall is heavy.

The obtained spatial and temporal variation of GD and SGR can be adapted to interpret groundwater recharge and runoff in the sites vegetated with selected species. In addition, the obtained results also help to devise drainage schemes. It should be noted that grass regrows in the selected site. The decomposition of existing wilted grass affects the regrowth. Therefore, future studies are required to explore the regrowth dynamics of grass after wilting. The UAVs can be distantly connected to grass trimmers. This helps to establish economical unmanned grass mowing systems.

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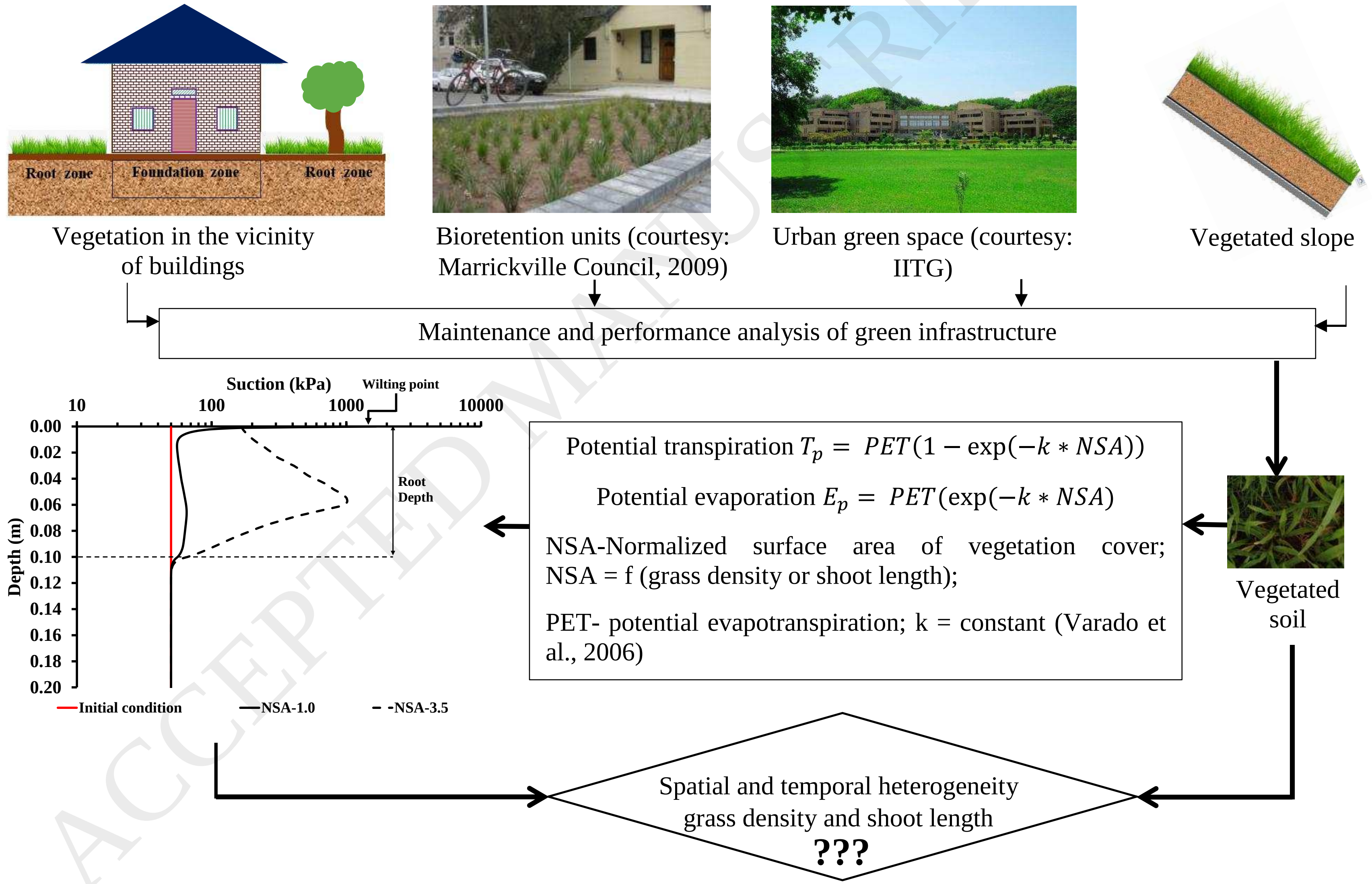


Fig. 1. Importance of grass density and shoot length in maintenance and performance analysis of green infrastructure

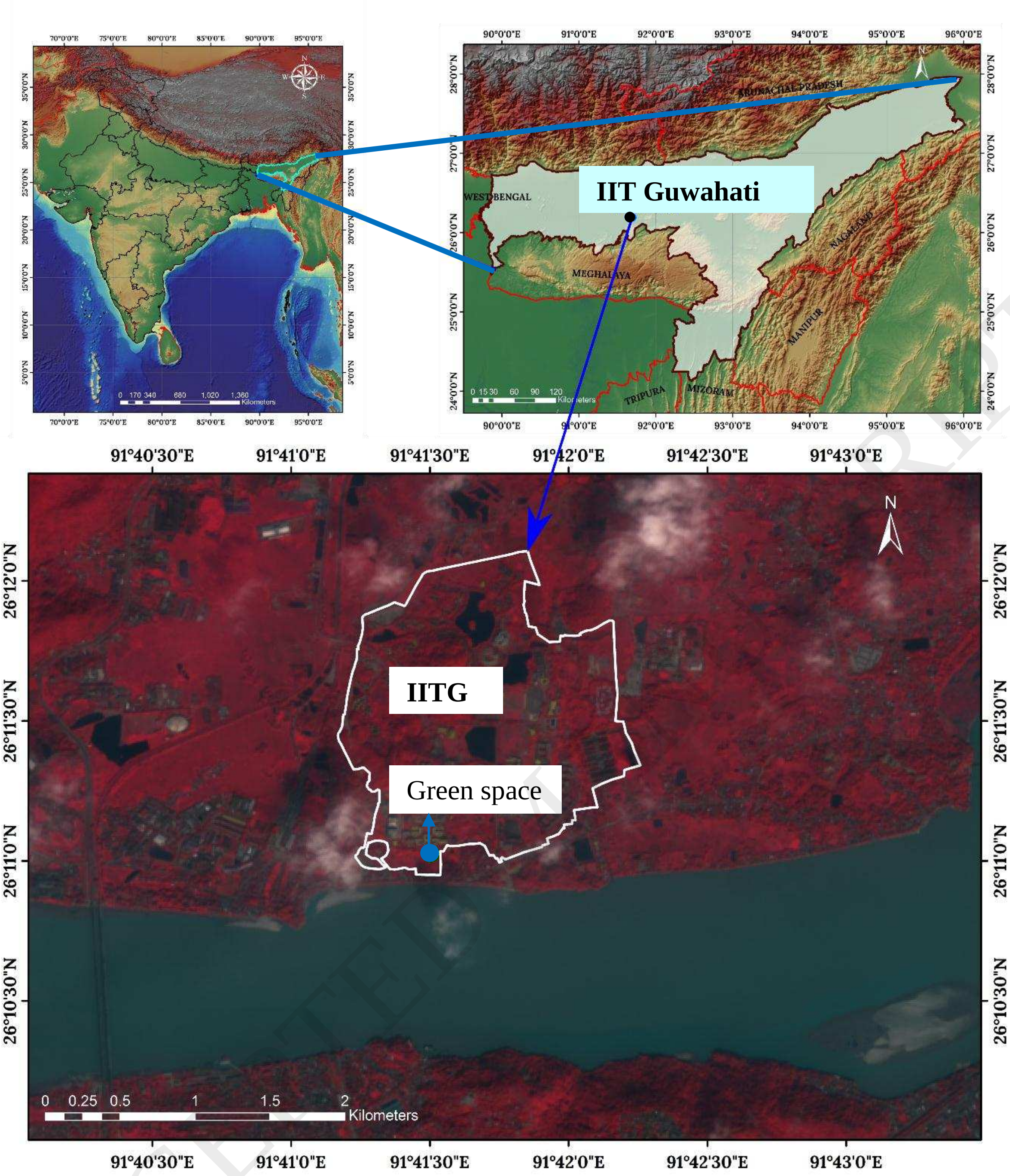


Fig. 2. Location of the selected green space in IITG, India


31-01-2016

(a)


28-02-2016

(b)


31-03-2016

(c)


30-04-2016

(d)


31-05-2016

(e)


30-06-2016

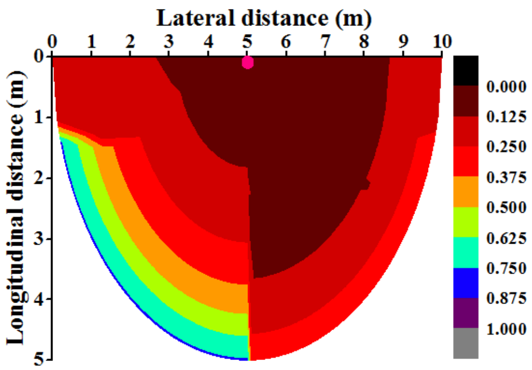
(f)

(g) (h)

(i) (j)

(k) (l)

Figure 3. changes in vegetation cover at the end of each month, i.e., (a) January' 2016; (b) February' 2016; (c) March' 2016; (d) April' 2016; (e) May' 2016; (f) June' 2016; (g) July' 2016; (h) August 2016; (i) September 2016; (j) October' 2016; (k) November' 2016; (l) December' 2016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10
Longitudinal distance (m)
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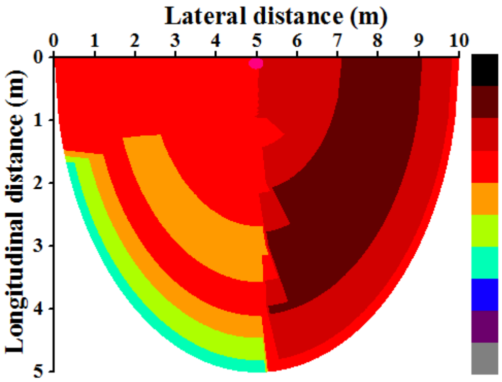
0.250
0.375
0.500
0.625
0.750
0.875
1.000

(a)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Longitudinal distance (m)
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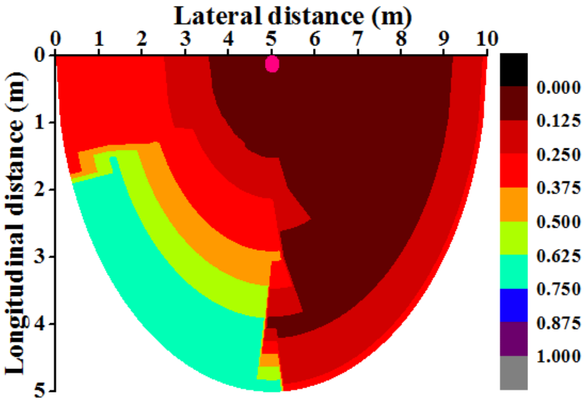
(b)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0.750
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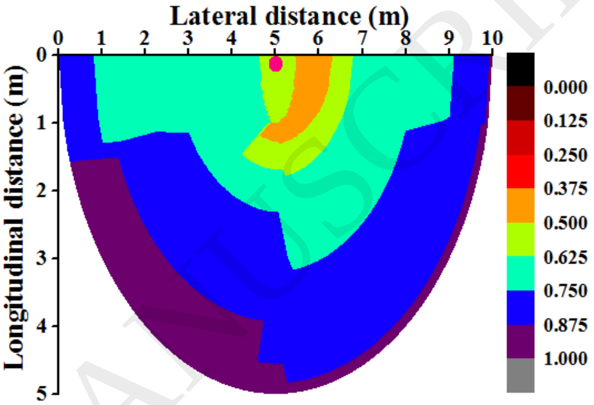
(c)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Longitudinal distance (m)
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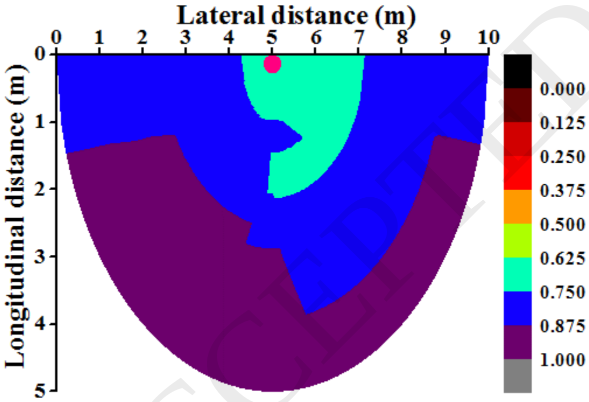
(d)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Longitudinal distance (m)
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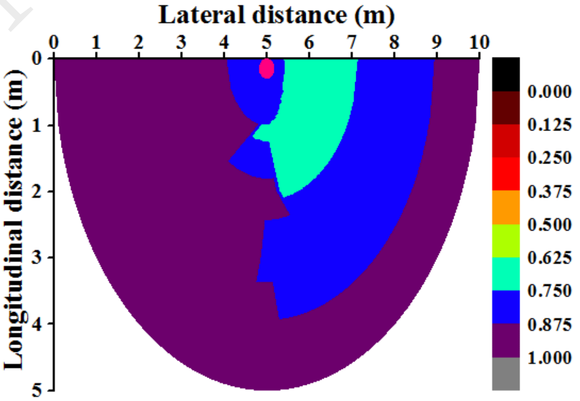
(e)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Longitudinal distance (m)
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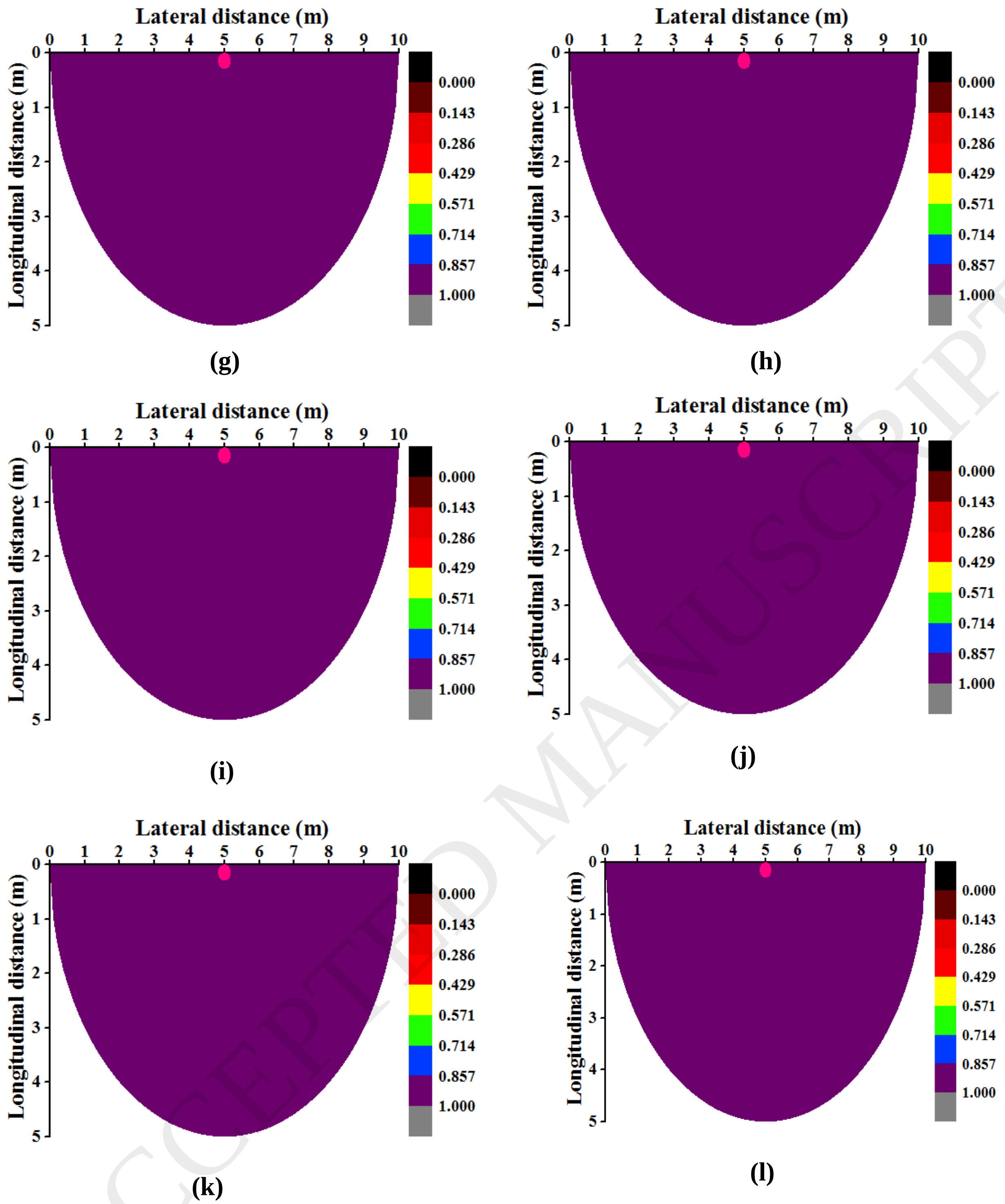
1.000

(f)



(g) (h)

(i) (j)

(k) (l)

Fig. 4. Spatial heterogeneity of grass density at the end of: (a) January’ 2016; (b) February’ 2016; (c) March’ 2016; (d) April’ 2016; (e) May’ 2016; (f) June’ 2016; (g) July’ 2016; (h) August’ 2016; (i) September’ 2016; (j) October’ 2016; (k) November’ 2016; (l) December’ 2016

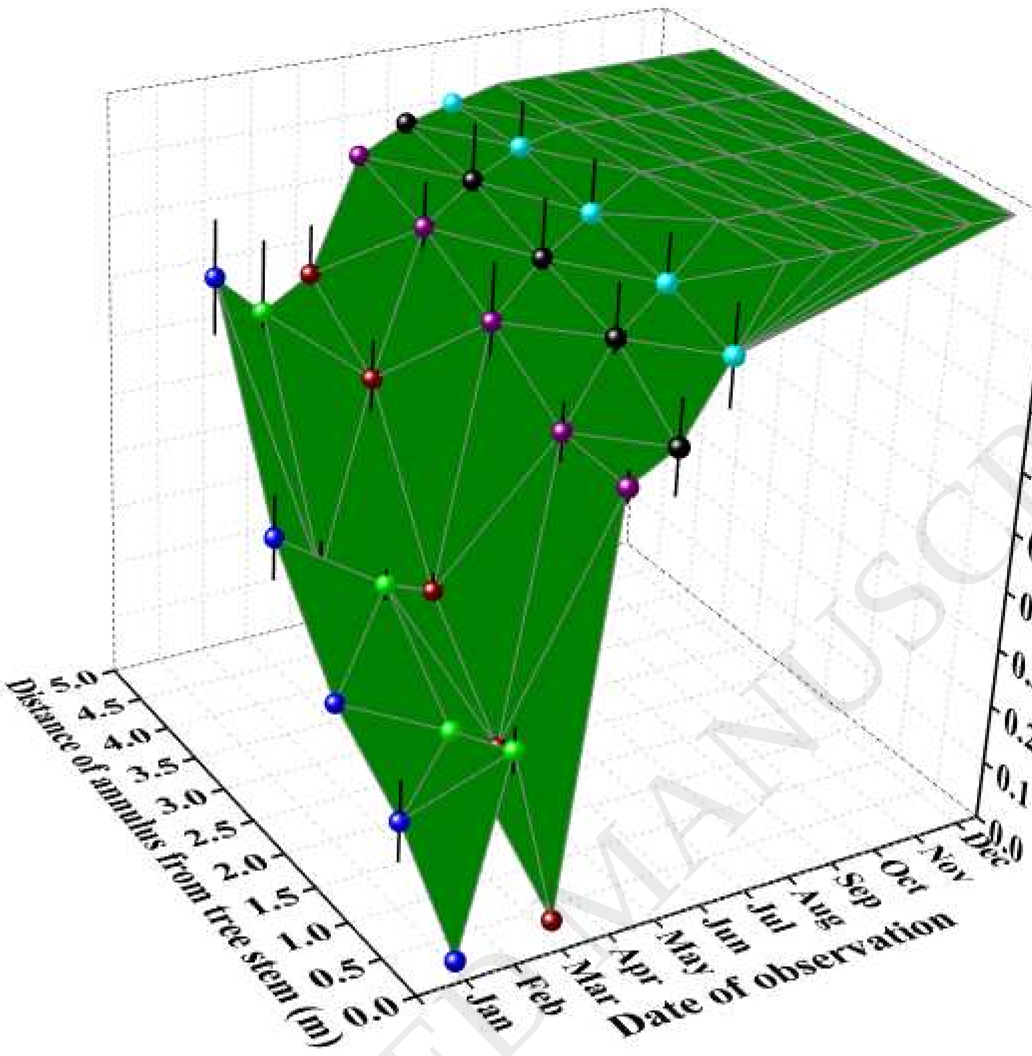
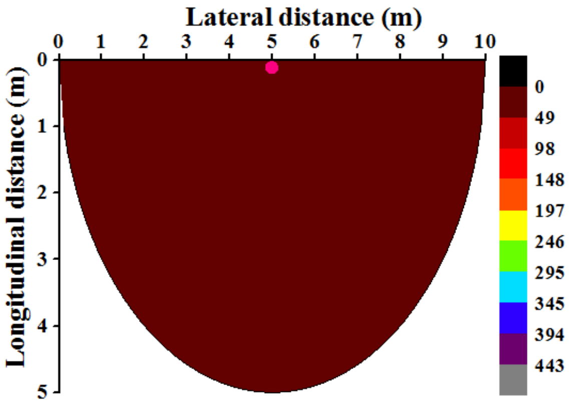


Fig. 5 Variation of average grass density in various annuli


Lateral distance (m)
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Longitudinal distance (m)
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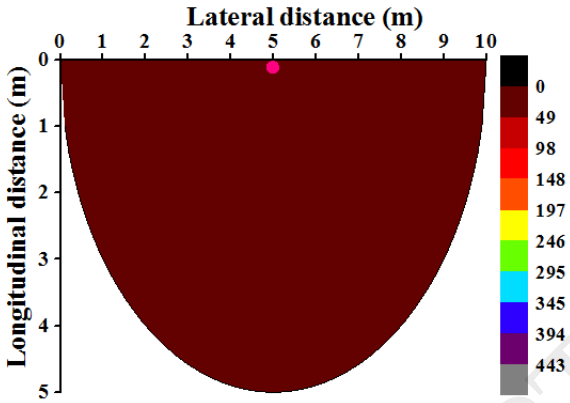
0
49
98
148
197
246
295
345
394
443

(a)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Longitudinal distance (m)
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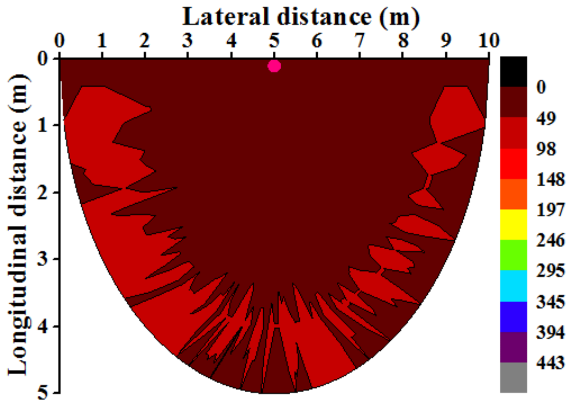
(b)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Longitudinal distance (m)
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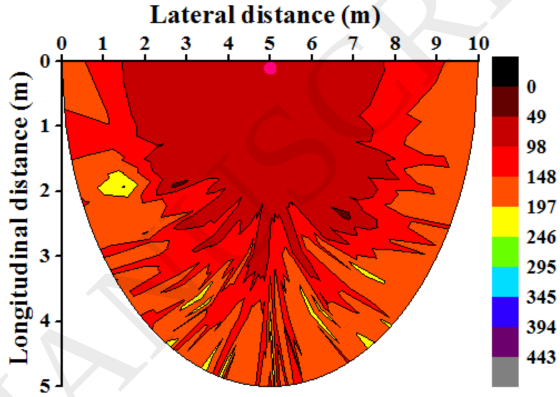
(c)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Longitudinal distance (m)
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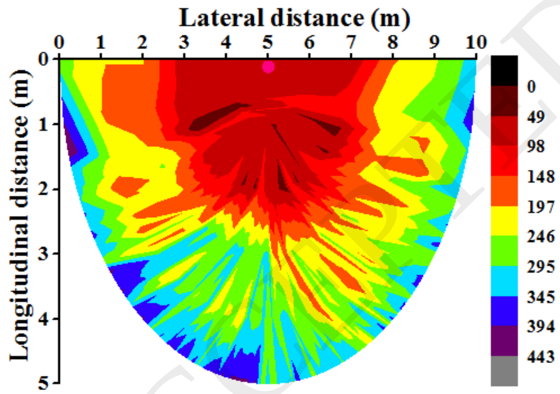
345
394
443

(d)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Longitudinal distance (m)
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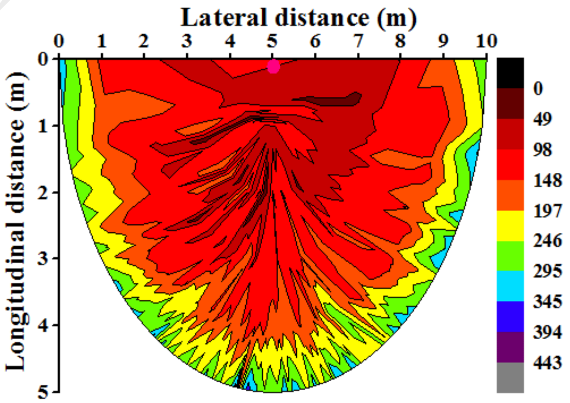
345
394
443

(e)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Longitudinal distance (m)
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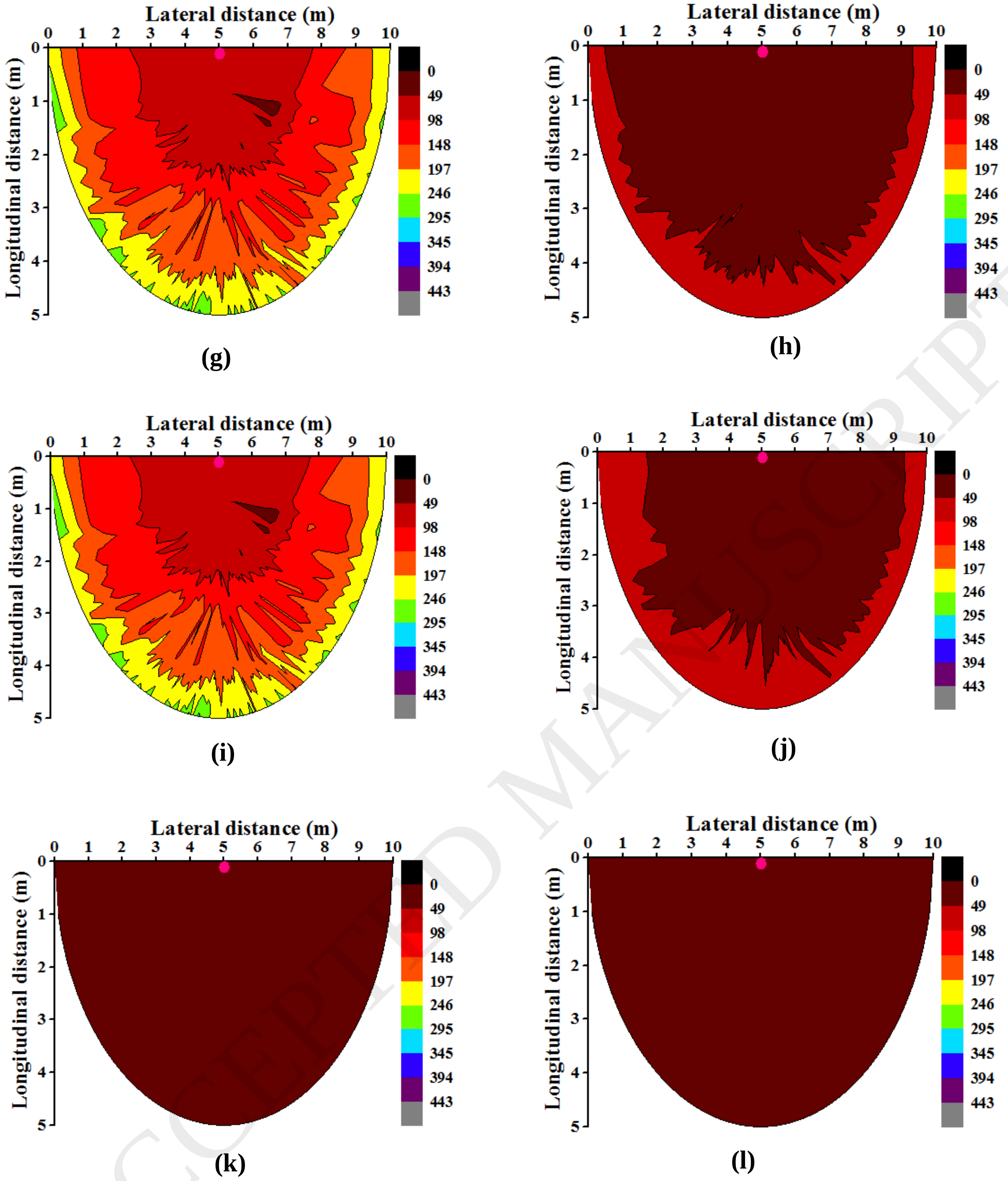
(f)



(g) (h) (i) (j) (k) (l)

Fig. 6. Spatial heterogeneity of shoot growth rate at the end of: (a) January’ 2016; (b) February’ 2016; (c) March’ 2016; (d) April’ 2016; (e) May’ 2016; (f) June’ 2016; (g) July’ 2016; (h) August’ 2016; (i) September’ 2016; (j) October’ 2016; (k) November’ 2016; (l) December’ 2016

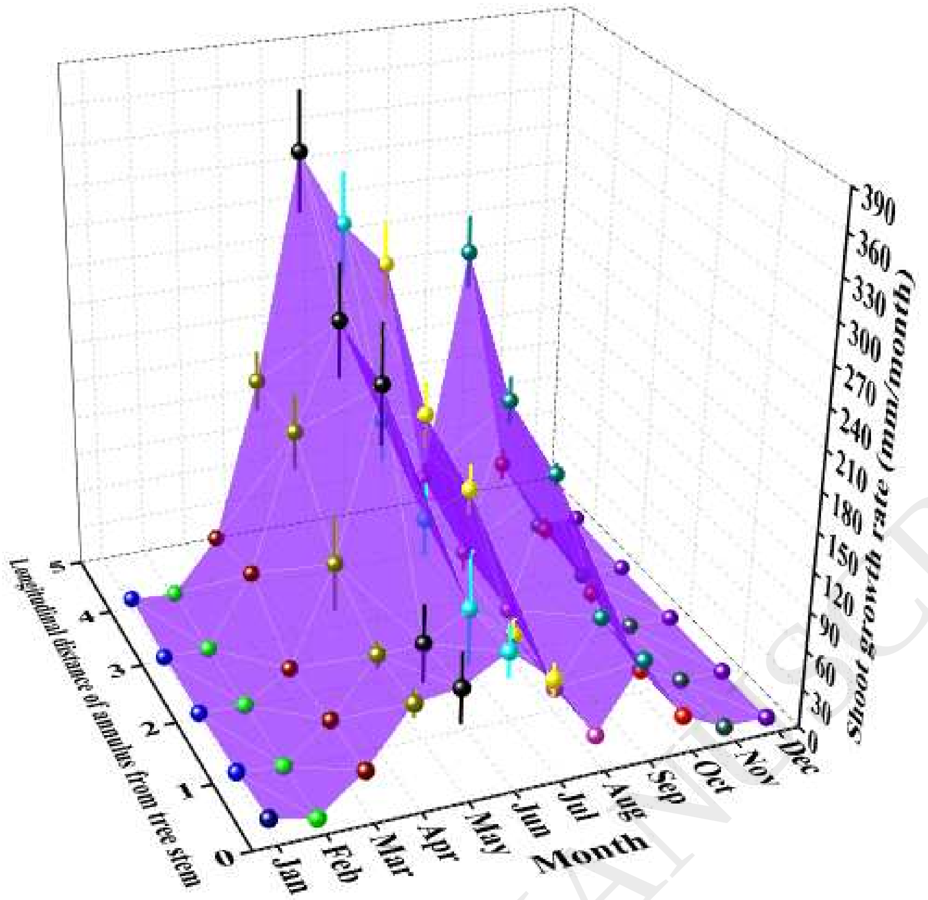


Fig. 7 Variation of average shoot growth rate in various annuli