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RESEARCH ARTICLE

A meta-analysis of the canopy light extinction coefficient in terrestrial ecosystems

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Abstract The canopy light extinction coefficient (*K*) is a key factor in affecting ecosystem carbon, water, and energy processes. However, *K* is assumed as a constant in most biogeochemical models owing to lack of in-site measurements at diverse terrestrial ecosystems. In this study, by compiling data of *K* measured at 88 terrestrial ecosystems, we investigated the spatiotemporal variations of this index across main ecosystem types, including grassland, cropland, shrubland, broadleaf forest, and needleleaf forest. Our results indicated that the average *K* of all biome types during whole growing season was 0.56. However, this value in the peak growing season was 0.49, indicating a certain degree of seasonal variation. In addition, large variations in *K* exist within and among the plant functional types. Cropland had the highest value of *K* (0.62), followed by broadleaf forest (0.59), shrubland (0.56), grassland (0.50), and needleleaf forest (0.45). No significant spatial correlation was found between *K* and the major environmental factors, i.e., mean annual precipitation, mean annual temperature , and leaf area index (LAI). Intra-annually, significant negative correlations between *K* and seasonal changes in LAI were found in the natural ecosystems. In cropland, however, the temporal relationship was site-specific. The ecosystem type specific values of *K* and its temporal relationship with LAI observed in this study may contribute to improved modeling of global biogeochemical cycles.

Keywords canopy light extinction coefficient, ecological modeling, biogeochemical model, forest, grassland, cropland, leaf area index

1 Introduction

The canopy light extinction coefficient (*K*) is a parameter that describes the efficiency of light interception for the canopy of a terrestrial ecosystem. A low *K* indicates that much radiation can reach the bottom of the canopy. Conversely, a high *K* indicates that only a little radiation can penetrate into the understory of the canopy. Theoretically, *K* is determined by leaf inclined angle (α) and solar zenith angle (θ) (Monsi and Saeki, 1953; Campbell, 1986), i.e.,

$$\begin{cases} K = \cos\alpha\cos\theta,\ \alpha + \theta \leqslant \pi/2 \\ K = \dfrac{2}{\pi}\left[\cos\alpha\cos\theta\sin^{-1}(\tan\theta\tan\alpha) + \left(1 + \cos^2\alpha - \cos^2\theta\right)^{1/2}\right],\ \alpha + \theta\ > \pi/2 \end{cases}. \tag{1}$$

K is usually calculated with the Beer Lambert Law (Monsi and Sakei, 1953):

$$K = -\ln(I_i/I_o)\cos\theta/(\mathrm{LAI}\Omega), \tag{2}$$

where I_i is solar radiation under the canopy, I_o is solar radiation above the canopy, θ is solar zenith angle, LAI is leaf area index, and Ω is clumping index. In many cases, the Beer Lambert law is simply expressed as (Runyon et al., 1994; Liu et al., 1997; Sampson and Allen, 1998):

$$K = -\ln(I_i/I_o)/\mathrm{LAI}. \tag{3}$$

In this case, both solar zenith angle and clumping index

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are implicitly included in K, which implies that K may vary both temporally and spatially more than expected. However, owing to the lack of in-site measurements at diverse terrestrial ecosystems, K (expressed in the form of Eq. (3)) is assumed as a constant in many biogeochemical models and remote sensing models of evapotranspiration and gross primary productivity (GPP). For example, it is fixed as 0.5 in the CEVSA (Carbon Exchange in the Vegetation-Soil-Atmosphere) model (Cao and Woodward, 1998; Gao et al., 2013), LPJ (The Lund-Potsdam-Jena Dynamic Global Vegetation Model) (Sitch et al., 2003), and 3-Pg (Physiological Principles in Predicting Growth) model (Esprey et al., 2004), and as 0.65 in some crop growth models, such as CERES-Maize (Jones and Kiniry, 1986). In addition, a constant value of K is given in terms of estimating regional or global evapotranspiration and GPP, e.g., the MODIS GPP and evapotranspiration algorithm (Zhao and Running, 2010; Mu et al., 2011), VPM (Vegetation Photosynthesis Model) (Xiao et al., 2004), etc. Some models used plant functional type-specific values of K. For example, Thornton and Rosenbloom (2005) used 0.6 and 0.5 for the grass and evergreen needleleaf forest, respectively, in the Biome-BGC (BioGeochemical Cycles) model. Wang et al. (2011) used 0.58 and 0.50 for broadleaf forest and the other plant functional types in the GLOPEM-CEVSA (Global Production Efficiency Model with the Carbon Exchange in the Vegetation-Soil-Atmosphere) model. Kiniry et al. (1992) used different values among species for cropland in the ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria) model, e.g., 0.90 for cocklebur, 0.65 for maize and wheat, and 0.45 for soybean.

K is a key factor determining ecological processes which may have significant impact on predicting ecosystem carbon and water processes in the biogeochemical models. For example, with the Biome-BGC model, White et al. (2000) found that increasing K from the mean minus 20% to the mean plus 20% would cause a 54% decrease of net primary production (NPP) at broadleaf forest areas in the USA. Domingo et al. (1999) illustrated that the evapotranspiration of shrubs increased by 4.8% on the average (by 12.2% maximally) in Spain from April to May in 1997 when K was reduced by 15% (Brenner and Incoll, 1997). Therefore, an accurate determination of K is important for modeling ecological processes.

Nevertheless, the fixed values of K in the models are mostly based on quite limited in-site measurements, and little is known about the representativeness of these values. Many studies documented significant variations in K within and across ecosystems (Kubota et al., 1994; Wheeler et al., 1995; White et al., 2000; Wang et al., 2001; Rouphael and Colla, 2005; Binkley et al., 2013). Therefore, in order to minimize the uncertainty of model prediction, it is imperative to make a comprehensive investigation of K across global terrestrial ecosystems.

In this study, we conducted a meta-analysis of the canopy light extinction coefficient by compiling data from 88 terrestrial plant communities selected from 59 published journal articles. Our objectives were (i) to establish a look-up table of the canopy light extinction coefficient for main plant functional types in global terrestrial ecosystems; and (ii) to explore the spatial and temporal variations in K in terms of climatic and biotic factors. In our study, both the mean K in the whole growing season in a year (K_{mean}) and the K in the peak growing season in the year (K_{pg}) were compiled to qualify the magnitude of seasonal variations in this parameter. We defined the peak growing season as the period when LAI reached its maximum in a year.

2 Materials and methods

Journal articles on K in terrestrial plant ecosystems published before April 2012 were compiled. In order to make K among various ecosystems comparable, K selected for this study followed a certain criteria: 1) K was calculated by the simplified Beer-Lambert law (Eq. (3)), which is used by most biogeochemical models. All of the variables in the equation were measured directly, and LAI was one half the total interception leaf area per unit ground surface area (Chen and Black, 1992; Jonckheere et al., 2004; Liu et al., 2013). The LAI was considered as 2 times and 1.28 times the projected leaf area for spruce needles and conifer needles, respectively (Chen and Black, 1992; Chen and Cihlar, 1996). 2) Only the data measured at noon were used in order to eliminate the influence of solar zenith angle (Flénet et al., 1996). 3) K of different plant communities measured at the same site, or the same plant community at different sites were considered as independent observations. Finally, data from 88 ecosystems from 59 published articles were extracted and analyzed for this study (details is available in Table A1).

In addition to K, LAI, mean annual temperature (MAT), and mean annual precipitation (MAP) were extracted from the journal articles where possible. In cases when MAP and MAT were not available, we used the data from the global climate database (WorldClim–Global Climate Data at http://www.worldclim.org/) according to the latitude and longitude provided. Due to the limited data for each plant functional type (PFT) based on IGBP (International Geosphere-Biosphere Programme) classification, we aggregated the ecosystems into five PFTs: grassland (grassland & savanna), shrubland (open shrubland & closed shrubland), cropland, broadleaf forest (evergreen & deciduous & mixed forest), and needleleaf forest (evergreen & deciduous).

3 Results and discussion

3.1 Variations in the canopy light extinction coefficient across plant functional types

The average (±sd) K in an entire growing season, K_{mean}, for all of the PFTs was 0.56±0.16 (Table 1), which was in between the two most frequently used values by most models (Jones and Kiniry, 1986; Cao and Woodward, 1998; Sitch et al., 2003; Esprey et al., 2004; Xiao et al., 2004) (i.e., 0.5 and 0.65). However, there were certain variations in K_{mean} across PFTs. It was highest for cropland (0.62±0.17), followed by broadleaf forest (0.59±0.12), shrubland (0.56±0.13), grassland (0.50±0.15), and needleleaf forest (0.45±0.11) (Table 1). When compared with the values used in PFT-specific fixed models, we found K_{mean} of broadleaf forest was close to that set by the GlOPEM-CEVSA model (0.58, Wang et al., 2011), and that of cropland was close to the 0.65 used in crop growth models (Jones and Kiniry, 1986). The K_{mean} for grassland (0.50) was the same as the commonly used value, i.e., 0.5 (e.g., CEVESA, VPM, LPJ, etc.), but smaller than that set in Biome-BGC (i.e., 0.6, Thornton and Rosenbloom, 2005). Notably, the calculated K_{mean} for needleleaf forest (0.45) is smaller than the constants set in most models.

The average canopy light extinction coefficient of all the PFTs in the peak growing season, i.e., K_{pg}, was 0.49 (±0.22), which was 12.5% lower than K_{mean} ($p < 0.05$). This indicates that there were seasonal variations in K to a certain degree in these ecosystems. Among PFTs, there were also certain variations in K_{pg}. The cropland had the largest value (0.65), followed by grassland (0.40), needleleaf forest (0.39), and shrubland (0.38). The largest difference between K_{pg} and K_{mean} occurred in shrubland (32.14%, $p = 0.08$), followed by grassland (20.00%, $p < 0.05$), and needleleaf forest (13.33%, $p < 0.05$). However, no difference was found between these two values in cropland ($p = 1.00$).

The variations in K across PFTs are mostly related to the changes in canopy structure, such as leaf angle distribution and spatial arrangement (Monsi and Saeki, 1953; Chen et al., 2005; Awal et al., 2006; Wang et al., 2007). From Eq. (3), we can see that K contains the effects of clumping. Therefore, K in this study reflects the influence of leaf angle distribution and clumping. K is expected to be small when the leaves are vertical and clumped, which would allow more solar radiation to penetrate through the canopy than otherwise (Monsi and Saeki, 1953; Chen et al., 2005; Tesfaye et al., 2006). Our meta-analysis results are consistent with this expectation. For example, values for K in the cropland and broadleaf forest were high, but the values for K of the needleleaf forest were low. In general, the clumping effects of plant leaves in cropland are lower (Chen et al., 2005), which is the likely reason causing the largest K in cropland. Similarly, the overall distribution of leaf-inclination angles in broadleaf forest tends to be horizontal (Hutchison et al., 1986), leading to a relatively high K. Values for K in needleleaf forest were smallest, which may be due to the clumped arrangement of needle leaves (Chapin et al., 2002; Chen et al., 2005). Our results also indicated that values for K in grassland and shrubland were quite variable. This may be due to the fact that these two PFTs are widely distributed in diverse environments, in which the leaf size and arrangement would be quite variable. Further classification of K for shrubland and grassland according to the climate might be necessary once sufficient data are available.

3.2 Spatiotemporal relationships between the canopy light extinction coefficient and environmental factors

Spatially, no significant correlation between K_{mean} (or K_{pg}) and the two major climatic factors (i.e., MAP and MAT) was found within and across PFTs (Fig. 1). Further, no significant correlation was found between K and LAI across space for both within and across PFTs (Fig. 2). In contrast, the significant difference between K in the peak growing season, K_{pg}, and the average of the entire growing season, K_{mean}, suggests that seasonal variations in K exist for most ecosystems. Our further investigation illustrated that K was negatively correlated with LAI for the natural ecosystems: grassland, shrubland, and needleleaf forest (Fig. 3, $p < 0.01$, no seasonal data available for broadleaf forest). The R^2 of the relationship differed among PFTs,

Table 1 Means±standard deviations of the canopy light extinction coefficient (K) during the whole growth season (K_{mean}) and at the peak growing season (K_{pg}) for each plant functional type (PFT). One-Way ANOVA was used to compare the difference among PFTs and a Paired-Sample T test was used to compare the difference between K_{mean} and K_{pg} at the 0.05 level.

Plant functional type	K_{mean}	K_{pg}
Grassland	$0.50 \pm 0.15^{\mathrm{adA}}$(17)*	$0.40 \pm 0.13^{\mathrm{eB}}$(8)
Cropland	$0.62 \pm 0.17^{\mathrm{bA}}$(35)	$0.65 \pm 0.25^{\mathrm{fA}}$(14)
Shrubland	$0.56 \pm 0.13^{\mathrm{abdA}}$(12)	$0.38 \pm 0.12^{\mathrm{eA}}$(6)
Broadleaf forest	$0.59 \pm 0.12^{\mathrm{ab}}$(9)	NA
Needleleaf forest	$0.45 \pm 0.11^{\mathrm{cdA}}$(15)	$0.39 \pm 0.09^{\mathrm{eB}}$(7)
Average	$0.56 \pm 0.16^{\mathrm{A}}$(88)	$0.49 \pm 0.22^{\mathrm{B}}$(35)

* The number in parentheses indicates the numbers of sites used to calculate K. NA, not available. Lower case letters, within columns, represent the comparison among K_{mean} and K_{pg}, and the upper case letters, within rows, represent the comparison between K_{mean} and K_{pg}.

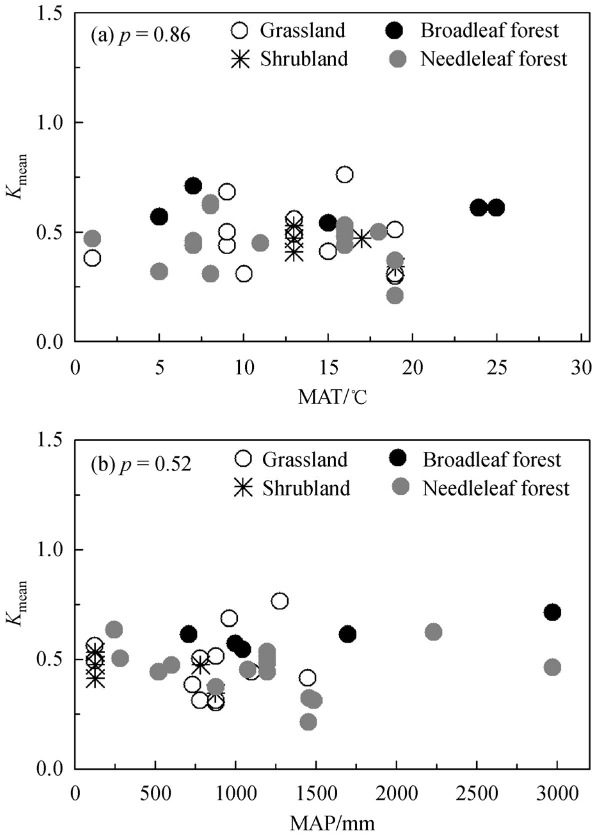

Fig. 1 Relationships between mean canopy light extinction coefficient in the growing season (K_{mean}) and (a) mean annual temperature (MAT), and (b) mean annual precipitation (MAP) for main plant functional types in terrestrial ecosystems. Each dot or circle in the figure indicates the value of one site. No significant correlation was found between K_{mean} and MAT or MAP.

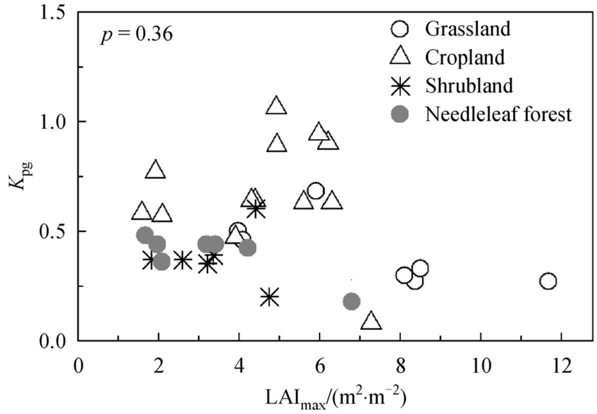

Fig. 2 Relationship between leaf area index at the peak growing season ($\mathrm{LAI}_{\mathrm{max}}$) and the canopy light extinction coefficient (K_{pg}) at the peak growing season for main plant functional type in terrestrial ecosystems. Each dot or circle in the figure indicates the value of one site. No significant correlation was found between K_{pg} and $\mathrm{LAI}_{\mathrm{max}}$.

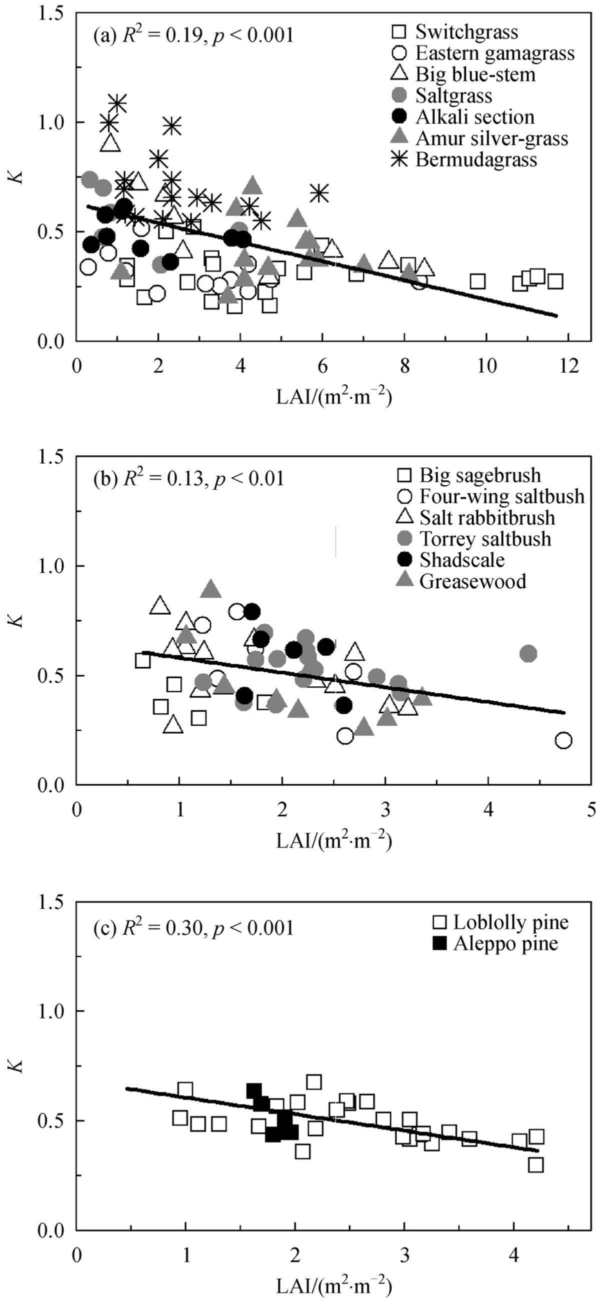

Fig. 3 Relationships between the canopy light extinction coefficient (K) and seasonal changes in leaf area indices (LAI) for three terrestrial plant functional types: (a) grassland, (b) shrubland, (c) needleleaf forest.

with the maximum at needleleaf forest (0.30), followed by grassland (0.19), and shrubland (0.13). For the cropland, however, the relationship between K and LAI varied with the crop species planted. For example, no significant relationship was found in the crops of cauliflower (*Brassica oleracea* L. *botrytis*) and mustard (*Brassica juncea* L.) (Fig. 4(a)). Positive relationships were found in other crop species, e.g., squash (*Cucurbita pepo* L.), tobacco (*Nicotiana tabacum* L.), peanut (*Araehis hypo-*

gaea L.), and chickpea (*Cicer arietinum* L.) (Fig. 4(b)). However, negative relationships were found in triticale (×*Triticosecale*), and wheat (*Triticumaestivum* L.) (Fig. 4 (c)).

The negative correlation between *K* and LAI for the natural PFTs may be the fact that the increase of LAI in the growing season is usually associated with the change in canopy architecture, such as foliage density, stem length, and clumping intensity (Brown and Parker, 1994; Kubota et al., 1994). For species in grasslands, the angle of inclination of leaves would become steeper with increasing LAI (Kubota et al., 1994), which allows for more light to penetrate into the sward and thus decreases *K*. For shrubland and needleleaf forest, light interception per unit of leaf area decreased as LAI increased due to the increasing clumpiness as gaps develop between trees (Assmann, 1970; Kellomaki et al., 1985). For broadleaf forest, Brown and Parker (1994), who adopted the method of spatial sequence instead of time successional sequence to study the temporal changes of *K* in broadleaf forests, suggested that *K* decreased as LAI increased ($p < 0.05$, $R^2 = 0.69$). Thus, we speculated that values for *K* in broadleaf forest are negatively correlated with LAI. Just as in shrubland and needleleaf forest, the reason is the increasing clumpiness as gaps develop between trees (Brown and Parker, 1994).

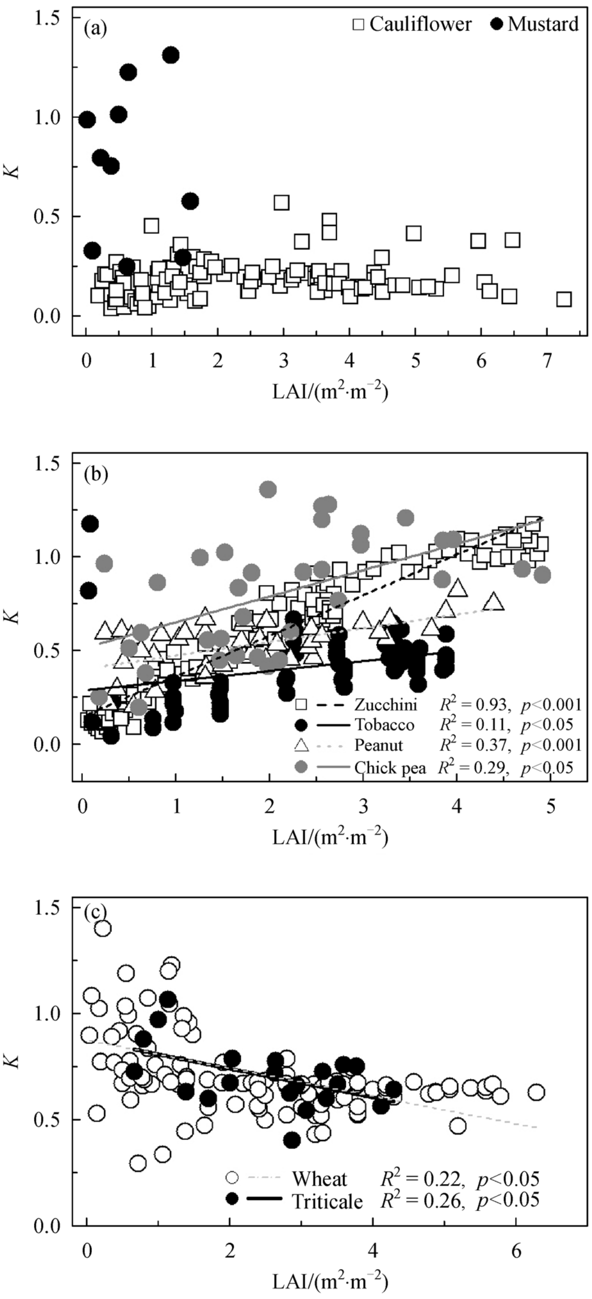

Fig. 4 Relationships between *K* and seasonal changes in LAI for different crops. (a) Uncorrelated, (b) positively correlated, (c) negatively correlated.

The relationship between *K* and seasonal LAI in cropland varied among ecosystems, which was different from the natural PFTs (i.e., grassland, shrubland, and needleleaf forest). Two reasons may cause such variability. First, it may be due to the contrast in leaf angular distribution among different crop species. For the crop species with planophile leaves (e.g., zucchini and tobacco), light interception per leaf area increased as LAI increased due to the decreased clumped effects as the distance between the plants decreased (Chen et al., 2005). In this case, increasing LAI will lead to an increase of *K*. By contrast, for the crop species with plagiophile leaves (e.g., wheat and triticale), the inclination angle of leaves would become steeper with increasing LAI (Kubota et al., 1994), which allows more light to penetrate into the canopy and thus decreases *K*. Second, many crop species experience continual management practices, such as thinning, irrigation, maturing, etc., which may substantially change the canopy structure and *K*-LAI relationship.

Theoretically, seasonal changes of the solar zenith angle may also cause the differences between *K* in the peak growing season and the growing season average. However, our investigation indicated that this factor is negligible. First, if this effect has significant impact, the difference (i.e., K_{mean}–K_{pg}) would be higher at high latitude ecosystems and lower at the low latitude ecosystems. However, the result indicated no significant relationship between the difference and latitude ($p > 0.05$, data not shown). Second, the effect of solar zenith angle (θ) on *K* (i.e., $1–\cos\theta$) in growing season would be 1%–12% in low latitudes (30°S–30°N), and 1%–26% in middle latitudes (30°S–60°S, 30°N–60°N). In our meta-analysis, most of the ecosystems were distributed in middle latitudes, implying that solar zenith angle is not an important factor causing the differences in *K* in different stages of a growing season.

4 Conclusions

This meta-analysis investigated the spatial and temporal variations in the canopy light extinction coefficient, *K*, in main terrestrial ecosystems. Our results showed that the average *K* of main PFTs in the whole growing season was 0.56. However, this value in the peak growing season was 0.49, indicating obvious seasonal variations in *K*. Large variations in *K* exist within and among PFTs. Cropland had the highest value of *K* (0.62), followed by broadleaf forest (0.59), shrubland (0.56), grassland (0.50), and needleleaf forest (0.45). No significant spatial correlation was found between *K* and the major environmental factors, i.e., MAP, MAT, and LAI. However, significant negative correlations between *K* and seasonal changes in LAI were found in the natural ecosystems. The PFT specific values of *K* and its temporal relationship with LAI observed in this study may contribute to improved modeling of global carbon and water processes.

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Appendix

Table A1 References and the extracted variables included in the compiled database for meta-analysis. PFT: plant functional type, BF: broadleaf forest, NF: needleleaf forest, K: canopy light extinction coefficient, K_{mean}: mean K in growing season, K_{pg}: K at the peak growing season, $\mathrm{LAI}_{\max}$: leaf area index at the peak growing season, MAP: mean annual precipitation, MAT: mean annual temperature.

References	PFT	K_{mean}	K_{pg}	$\mathrm{LAI}_{\max}$ /($\mathrm{m}^2 \cdot \mathrm{m}^{-2}$)	MAP /mm	MAT /°C	Species	Location
Agata and Kamata, 1979 (from White et al., 2000)	Grassland	0.76					Sasa nipponica	Japan
Clifton-Brown et al., 2000	Grassland	0.68			960	9	Perennial grass	Ireland
Groeneveld, 1997††	Grassland	0.56	0.5	3.98			Saltgrass	USA
Groeneveld, 1997††	Grassland	0.49	0.46	4.08			Alkali section	USA
Jäggi et al., 2006	Grassland	0.44			1100	9	Meadow Foxtail	Swiss
Kiniry et al., 1999	Grassland	0.3	0.27	11.68	875	19	Switchgrass	USA
Kiniry et al., 1999	Grassland	0.31	0.27	8.36	875	19	Eastern gamagrass	USA
Kiniry et al., 1999	Grassland	0.51	0.33	8.49	875	19	Big blue-stem	USA
Kiniry et al., 2011	Grassland	0.37			875	19	Switchgrass	USA
Kiniry et al., 2011	Grassland	0.31			780	10	Switchgrass	USA
Kiniry et al., 2011	Grassland	0.38			732	1	Switchgrass	USA
Kubota et al., 1994	Grassland	0.74	0.38	15.4	1669	16	Napier grass	Japan
Lantinga et al., 1999	Grassland	0.5			780	9	Ryegrass and clover	The Netherlands
Matsuda et al., 1991(from White et al., 2000)	Grassland	0.4					Napier grass	Japan
Monsi and Saeki, 1953	Grassland	0.41	0.3	8.1	1452	15	Amur silver-grass	Japan
Montero et al., 2001**	Grassland	0.61					Geranium	Spain
Morgan and Brown, 1983	Grassland	0.76	0.68	5.92	1277	16	Bermudagrass	USA
Awal et al., 2006	Cropland	0.44			1848	10	Maize	Japan
Awal et al., 2006	Cropland	0.6			1848	10	Peanut	Japan
Bell et al., 1992**	Cropland	0.53					Peanut	Australia
Bell et al., 1993	Cropland	0.55	0.64	4.4	804	20.35	Peanut	Australia
Boonen et al., 2002**	Cropland	0.87					Tomato	Belgium
Calderini et al., 1997	Cropland	0.42			1164	18	Wheat	Argentina
Carretero et al., 2010	Cropland	0.4	0.29	11.86	1164	18	Wheat	Argentina
Ceotto and Castelli, 2002	Cropland	0.41	0.47	3.9	555	22	Tobacco	Italy
Chapman et al., 1993 (from Kiniry et al., 2005)	Cropland	0.37					Peanut	Australia
Collino et al., 2001	Cropland	0.74			936	18	Peanut	Argentina
Ferreira and Abreu, 2001	Cropland	0.58			128	19.01	Sunflower	Portugal
Gao et al., 2004	Cropland	0.56			600	14	Wheat	China
Gardner and Auma, 1989 (from Kiniry et al., 2005)	Cropland	0.8					Peanut	USA
Giunta and Montzo, 2004	Cropland	0.7	0.64	4.3	539	15	Spring triticale	Italy
Grantz et al., 1997	Cropland	0.7			192	16	Cotton	USA
Higashide, 2009**	Cropland	0.6					Tomato	Japan
Hu et al., 2011	Cropland	0.46			1020	23	Paddy	China

(*Continued*)

References	PFT	K_{mean}	K_{pg}	$\mathrm{LAI}_{\mathrm{max}}$ /$(\mathrm{m}^2 \cdot \mathrm{m}^{-2})$	MAP /mm	MAT /°C	Species	Location
Jaaffar and Gardner, 1988 (from Kiniry et al., 2005)	Cropland	0.65					Peanut	USA
Jones et al., 1982 (from Kiniry et al., 2005)	Cropland	0.57					Peanut	USA
Kiniry et al., 2004	Cropland	0.47			444	13	Maize	USA
Kiniry et al., 2005	Cropland	0.65			792	17	Peanut	USA
Lunagaria and Shekh, 2006	Cropland	0.64	0.63	6.3	892	27	Wheat	India
McCaughey and Davies, 1974	Cropland	0.44			948	7	Maize	Canada
O’Connell et al., 2004	Cropland	0.8	0.57	2.09	337	14.4	Pea	Australia
O’Connell et al., 2004	Cropland	0.75	0.58	1.59	337	14.4	Mustard	Australia
O’Connell et al., 2004	Cropland	0.93	0.77	1.92	337	14.4	Wheat	Australia
Olesen et al., 2004	Cropland	0.79			588	8	Wheat	Denmark
Rouphael and Colla, 2005**	Cropland	0.59	1.06	4.92			Zucchini	Italy
Sadras, 1996	Cropland	0.81			708	17	Cotton	Australia
Teixeira et al., 2011	Cropland	0.98	0.9	6.21	640	11.4	Lucerne	New Zealand
Tesfaye et al., 2006	Cropland	0.69	0.94	5.98	612	26	Beans	Ethiopia
Tesfaye et al., 2006	Cropland	0.8	0.89	4.93	612	26	Chickpea	Ethiopia
Tesfaye et al., 2006	Cropland	0.67	0.63	5.6	612	26	Cowpea	Ethiopia
Wang et al., 2001	Cropland	0.57			276	17	Soybean	USA
Wheeler et al., 1995**	Cropland	0.18	0.08	7.27			Cauliflower	UK
Baille et al., 2006**	Shrubland	0.63					Rose	Spain
Cohen et al., 1995	Shrubland	0.47			780	17	Apple	Israel
González-Real et al., 2007**	Shrubland	0.84					Rose	Spain
Groeneveld, 1997††	Shrubland	0.41	0.37	1.84			Big sagebrush	USA
Groeneveld, 1997††	Shrubland	0.53	0.2	4.74			Four-wing saltbush	USA
Groeneveld, 1997††	Shrubland	0.53	0.35	3.22			Salt rabbitbrush	USA
Groeneveld, 1997††	Shrubland	0.53	0.6	4.40			Torrey saltbush	USA
Groeneveld, 1997††	Shrubland	0.53	0.37	2.6			Shadscale	USA
Groeneveld, 1997††	Shrubland	0.47	0.39	3.36			Greasewood	USA
Hirose et al., 1988** (from White et al., 2000)	Shrubland	0.69					Yellow loosestrife	Netherlands
Hirose et al., 1988** (from White et al., 2000)	Shrubland	0.72					Yellow loosestrife	Netherlands
Kiniry, 1998	Shrubland	0.34			875	19	Honey mesquite	USA
Heilman and Xie, 1994	BF	0.57			1000	5	Populus	USA
Li et al., 1997	BF	0.54			1044	15	Cottonwood	China
Maass et al., 1995	BF	0.61			707	25	Tropical deciduous forest	Mexico
Miyaji et al., 1997	BF	0.61			1700	24	Cacao	Brazil
Reifsnyder et al., 1971	BF	0.89					Hardwood	USA
Waring and Schlesinger, 1985 (from White et al., 2000)	BF	0.5					Castanopsis	USA

(*Continued*)

References	PFT	K_{mean}	K_{pg}	LAI_{max} /($\text{m}^2 \cdot \text{m}^{-2}$)	MAP /mm	MAT /°C	Species	Location
Waring and Schlesinger, 1985 (from White et al., 2000)	BF	0.4					Fagus	USA
Waring and Schlesinger, 1985 (from White et al., 2000)	BF	0.6					Rain forest	USA
Runyon et al., 1994	BF	0.71			2973	7	Alder	USA
Hale, 2003	NF	0.31			1488	8	Spruce	USA
Kiniry, 1998	NF	0.37			875	19	Eastern red cedar	USA
McCrady and Jokela, 1998	NF	0.33	0.28	6.8	1453	19	Loblolly Pine	USA
Rotenberg and Yakir, 2011	NF	0.5	0.44	1.97	285	18	Aleppo Pine	Israel
Runyon et al., 1994	NF	0.46			2973	7	Sitka spruce	USA
Runyon et al., 1994	NF	0.45			1078	11	Douglas-fir	USA
Runyon et al., 1994	NF	0.62			2234	8	Douglas-fir	USA
Runyon et al., 1994	NF	0.32			1460	5	Mountain hemlock	USA
Runyon et al., 1994	NF	0.44			521	7	Ponderosa Pine	USA
Runyon et al., 1994	NF	0.63			248	8	Western Juniper	USA
Sampson and Allen, 1998	NF	0.51	0.48	1.67	1200	16	Loblolly Pine	USA
Sampson and Allen, 1998	NF	0.44	0.36	2.09	1200	16	Loblolly Pine	USA
Sampson and Allen, 1998	NF	0.53	0.44	3.19	1200	16	Loblolly Pine	USA
Sampson and Allen, 1998	NF	0.48	0.44	3.42	1200	16	Loblolly Pine	USA
Smith et al., 1991	NF	0.47	0.42	4.22	600	1	Loblolly Pine	USA

**, Studies were conducted in the greenhouse, the mean annual precipitation (MAP) and mean annual temperature (MAT) of which were not extracted. ††, Studies of which plants mainly used the groundwater, and the mean annual precipitation (MAP), and mean annual temperature (MAT) were not extracted.