The effects of blue, green, and neutral density photoselective gels on the spectral quality of sunlight

Dominic P. Petrella and Eric Watkins

Dept. of Horticultural Science, Univ. of Minnesota, 1970 Folwell Ave., St. Paul, MN 55108.

Introduction

Many researchers use neutral density black shade cloth to apply shade treatments that allow for the separation of confounding effects brought on by foliar shade (i.e. tree shade), such as water deficit due to competing vegetation, from plant responses to alterations in light quantity/quality. However, this black shade cloth does not alter spectral quality of sunlight like foliage does (Arthurs, Stamps, & Giglia, 2013; Kotilainen, Robson, & Hernández, 2018; Petrella & Watkins, 2020). Therefore, black shade cloths are not suitable for researchers looking to examine the effects altered spectral quality caused by foliar shade. Materials that selectively filter sunlight, like leaves, do exist and have been used to simulate foliar shade.

Photoselective gels (photoselective filters) are thin plastic sheets that are dyed with pigments that can selectively filter wavelengths of light, rendering them effective to simulate foliar shade (Jackman, 2010). These materials have been used in previous research (Griffith & Sultan, 2005; Hurdzan & Klein, 1975; Linkosalo & Lechowicz, 2006; Rajapakse, Pollock, McMahon, Kelly, & Young, 1992; Runkle & Heins, 2001; Skálová & Krahulec, 1992; Studzinska et al., 2012), but these types of gels could be used by more researchers if there were more details available on their spectral characteristics. There are also hundreds of options to choose from when looking for a potential gel to use, making it more difficult for researchers to pursue gel-based experiments. Therefore, our objective was to better characterize the spectral effects of a large sample of photoselective gels that researchers may use in shade research.

Materials and Methods

The effects of photoselective gels on the spectral quality of natural sunlight were evaluated in an unobstructed area at the University of Minnesota Turfgrass Research, Outreach, and Education center (44˚59'42.31"N, 93˚11'10.25"W) using a spectroradiometer (Apogee Instruments SS-110) on 15 May, 19 May, and 27 May 2020 (clear sky to mostly sunny days only). We evaluated a total of 85 blue, green, or neutral density gels from LEE Filters (LEE; https://www.leefilters.com/lighting/colour-list.html) and multiple brands from Rosco including e-colour+, Cinegel, and CalColor (https://us.rosco.com/en/products/family/filters-and-diffusions). Gels were chosen based on low resolution spectral energy distribution (SED) data provided by the manufacturers (the light source used to acquire these data was not provided). We specifically chose gels that either had or did not have an SED that was visually similar to a foliar shade SEDs (Petrella, 2019), gels that researchers may use based on previous research, or gels that researchers may use simply based on the name of the gel.

To acquire spectral data, sections of photoselective gel (7.62 x 3.81 cm) were placed over the spectroradiometer sensor in order for it to only be exposed to filtered sunlight, and data were acquired using an average of three scans in Apogee SpectroVision software. Spectral data for each gel were acquired in a random order on each day, and full sun spectra were acquired between taking data on every fifth gel. We evaluated the overall spectral energy distribution (SED), and then calculated the ratio of red to far-red light (R:FR; 655-665 / 725-735 nm), ratio of blue to green light [B:G (Sellaro et al., 2010); 420-490 / 500-570 nm], and the reduction in photosynthetic photon flux (PPF) compared to full sun. All SED data were normalized to 800 nm to factor out the effects of photon flux, and all data are presented as the mean ± the standard deviation to evaluate differences between the gels.

Results and discussion

Blue gels: All light blue gels produced alterations in spectral quality that were relatively similar to what has been shown to occur under moderate foliar shade (Petrella, 2019), i.e. greater photon flux between 400-500 nm relative to other wavelengths of photosynthetically active radiation (PAR). Gels that led to the most "natural" changes in the SED included the ⅛, ¼, and ½ CTB gels (Figure 1), in particular the Rosco Cinegel CTB gels, Mist blue, Pale blue, Booster blue, and Clearwater (Figure 2). These gels resulted in reductions in the R:FR ratio that were also consistent with published data from foliar shade (Table 1; de Castro, 2000; Lee, 1985; Leuchner, Menzel, & Werner, 2007; Messier & Bellefleur, 1988; Nangle, Gardner, Metzger, J.R., & Danneberger, 2012; Wherley, Gardner, & Metzger, 2005). While dark blue gels such as Cabana blue and No color blue (Figure 3) led to realistic reductions in the R:FR ratio (Table 1), the way in which these gels altered spectral quality was not consistent with any type of foliar shade (Figure 3). Peacock blue has been used by previous researchers, but based on our data, it is not an appropriate gel to use due to an SED that does not accurately represent foliar shade and being that the R:FR ratio was much lower than what would occur in most circumstances (Table 1; Runkle & Heins, 2001). Old steel blue was the only darker blue gel that led to alterations in the SED that were somewhat similar to that of moderate foliar shade (Figure 3). Blue CalColor gels were similar to CTB gels in regard to SED data and R:FR ratio data, but only the 15 and 30 strength blue CalColor gels exhibited an acceptably accurate SED (Figure 4, Table 1). Cyan CalColor gels altered the R:FR ratio similar to blue Calcolor gels, but the SED of the cyan gels was not similar to any type of foliar shade. We observed differences between the same model gel from different brands, something previously noted to occur (Jackman, 2010), and in many cases

LEE and Rosco Cinegel gels had the largest differences in spectral quality; however, the most extreme differences occurred between LEE and Rosco e-colour+ No color blue gels (Table 1).

Green gels: Dirty ice (Figure 5) and fluorescent green gels (Figure 5) led to a modest simulation of moderate foliar shade, and were more similar to the blue gels, especially in regards to the SED. Green CalColor gels (Figure 4) were quite similar to plus green (PG) gels, but neither altered spectral quality in a fashion similar to foliar shade, and R:FR ratio data produced by these gels were also much too high to simulate any type of foliar shade (Table 2). Dark green gels have been used in previous publications, and similar to Peacock blue gels, Dark green gels do not simulate the SED of foliar shade, nor do they lead to R:FR ratios similar to realistic scenarios (Table 1, Gautier, Varlet-Grancher, & Hazard, 1999).

Neutral density: All of the ND gels that we evaluated led to alterations in spectral quality comparable to foliar shade in which wavelengths of PAR are reduced in a similar manner, and in particular 0.60 and 0.90 ND gels simulated what has been observed under deep foliar shade (Figure 7; Petrella, 2019). Except for 0.15 ND gels, R:FR ratio data were also in line with previous reports (Table 3). Rosco Cinegel ND gels, however, would not be the most suitable for shade simulations due to their lack of PAR neutrality (Figure 7). While these data show that ND gels are well suited to simulated foliar shade, to our knowledge, ND gels have not been used in for these purposes in published research.

Conclusions

There are many potential photoselective gel options for researchers to choose from when scanning webpages of the primary manufacturers, LEE Filters and Rosco, but only a select number of gels produce accurate representations of the changes in spectral quality that occur under foliar shade. Light blue gels, such as CTB and Booster blue gels, lead to more accurate simulations relative to dark blue gels, which lead to drastic changes in spectral quality that do not occur in nature. Most green gels do not simulate foliar shade well, but green gels that share characteristics with blue gels, such as 5700k fluorescent green, may be useful for some researchers. Neutral density gels may be the most interesting. These gels do not necessarily offer the best simulation of foliar shade, though in some instances they may, but they can reduce spectral ratios, like the R:FR ratio, to appropriate levels without leading to other unrealistic changes in spectral quality. Because of this, ND gels would be an excellent choice for many researchers looking to simulate foliar shade

Literature Cited

Arthurs, S. P., Stamps, R. H., & Giglia, F. F. (2013). Environmental Modification Inside Photoselective Shadehouses. *HortScience, 48*(8), 975-979. doi:10.21273/hortsci.48.8.975

de Castro, F. (2000). Light spectral composition in a tropical forest: Measurements and model. *Tree Physiol., 20*, 49-56.

Gautier, H., Varlet-Grancher, C., & Hazard, L. (1999). Tillering responses to the light envrionment and to defoliation in populations of perennial ryegrass (*Lolium perenne* L.) selected for contrasting leaf length. *Annals of Bot., 83*, 423-429.

Griffith, T. M., & Sultan, S. E. (2005). Shade tolerance plasticity in response to neutral vs green shade cues in Polygonum species of contrasting ecological breadth. *New Phytol., 166*(1), 141-147. doi:10.1111/j.1469-8137.2004.01277.x

Hurdzan, M. J., & Klein, R. M. (1975). Solar-simulating radiation systems for biological research. *Phytochem. and Photobiol., 21*, 383-385.

Jackman, J. (2010). Chapter 5: Lighting controls and uses. In J. Jackman (Ed.), *Lighting for digital video and television* (pp. 77-89). Burlington, MA, USA: Focal Press.

Kotilainen, T., Robson, T. M., & Hernández, R. (2018). Light quality characterization under climate screens and shade nets for controlled-environment agriculture. *PLoS One, 13*(6), e0199628. doi:10.1371/journal.pone.0199628

Lee, D. W. (1985). The spectral distribution of radiation in two neotropical rainforests. *Biotropica, 19*(2), 161-166.

Leuchner, M., Menzel, A., & Werner, H. (2007). Quantifying the relationship between light quality and light availability at different phenological stages within a mature mixed forest. *Ag. and Forest Meteorol., 142*(1), 35-44. doi:10.1016/j.agrformet.2006.10.014

Linkosalo, T., & Lechowicz, M. J. (2006). Twlight far-red treatment advances leaf bud burst of silver birch (*Betula pendula*). *Tree Physiol., 26*, 1249-1256.

Messier, C., & Bellefleur, P. (1988). Light quantity and quality on the forest floor of pioneer and climax stages in a birch-beech-sugar maple stand. *Canadian J. of Forest Res., 18*, 615-622.

Nangle, E. J., Gardner, D. S., Metzger, J. D., J.R., S., & Danneberger, T. K. (2012). Impact of nitrogen source and trinexapac-ethyl application on creeping bentgrass (*Agrostis stolonifera* L.) physiology under neutral shade, decidious tree shade, and full sunlight conditions. *HortScience, 47*(7), 936-942.

Petrella, D.P. 2019. Turfgrass breeding 101: Screening for stress tolerance. Holes Notes: The official publication of the MGCSA. 54(10) pg 22-31.

Petrella, D. P., & Watkins, E. (2020). Variation in fine fescue taxa response to simulated foliar shade. *Crop Sci., 60*(6), 3377-3394. doi.org/10.1002/csc2.20279.

Rajapakse, N. C., Pollock, R. K., McMahon, M. J., Kelly, J. W., & Young, R. E. (1992). Interpretation of light quality measurements and plant response in spectral filter research. *HortScience, 27*(11), 1208-1211.

Runkle, E. S., & Heins, R. D. (2001). Specific functions of red, far-red, and blue light in flowering and stem extension of long-day plants. *J. of Amer. Soc. of Hort. Sci., 126*(3), 275-282.

Sellaro, R., Crepy, M., Trupkin, S. A., Karayekov, E., Buchovsky, A. S., Rossi, C., & Casal, J. J. (2010). Cryptochrome as a sensor of the blue/green ratio of natural radiation in Arabidopsis. *Plant Physiol., 154*(1), 401-409. doi:10.1104/pp.110.160820

Skálová, H., & Krahulec, F. (1992). The response of three *Festuca rubra* clones to changes in light quality and plant density. *Functional Ecology, 6*, 282-290.

Studzinska, A., Gardner, D. S., Metzger, J. D., Shetlar, D., Harriman, R., & Danneberger, T. K. (2012). The effect of PcGA3ox overexpression on creeping bentgrass (Agrostis stolonifera L.): Performance under various light envrionments. *HortScience, 47*(2), 280-284.

Wherley, B. G., Gardner, D. S., & Metzger, J. D. (2005). Tall fescue photomorphogenesis as influenced by changes in the spectral composition and light intensity. *Crop Sci., 45*, 562-568.

Figures and Tables

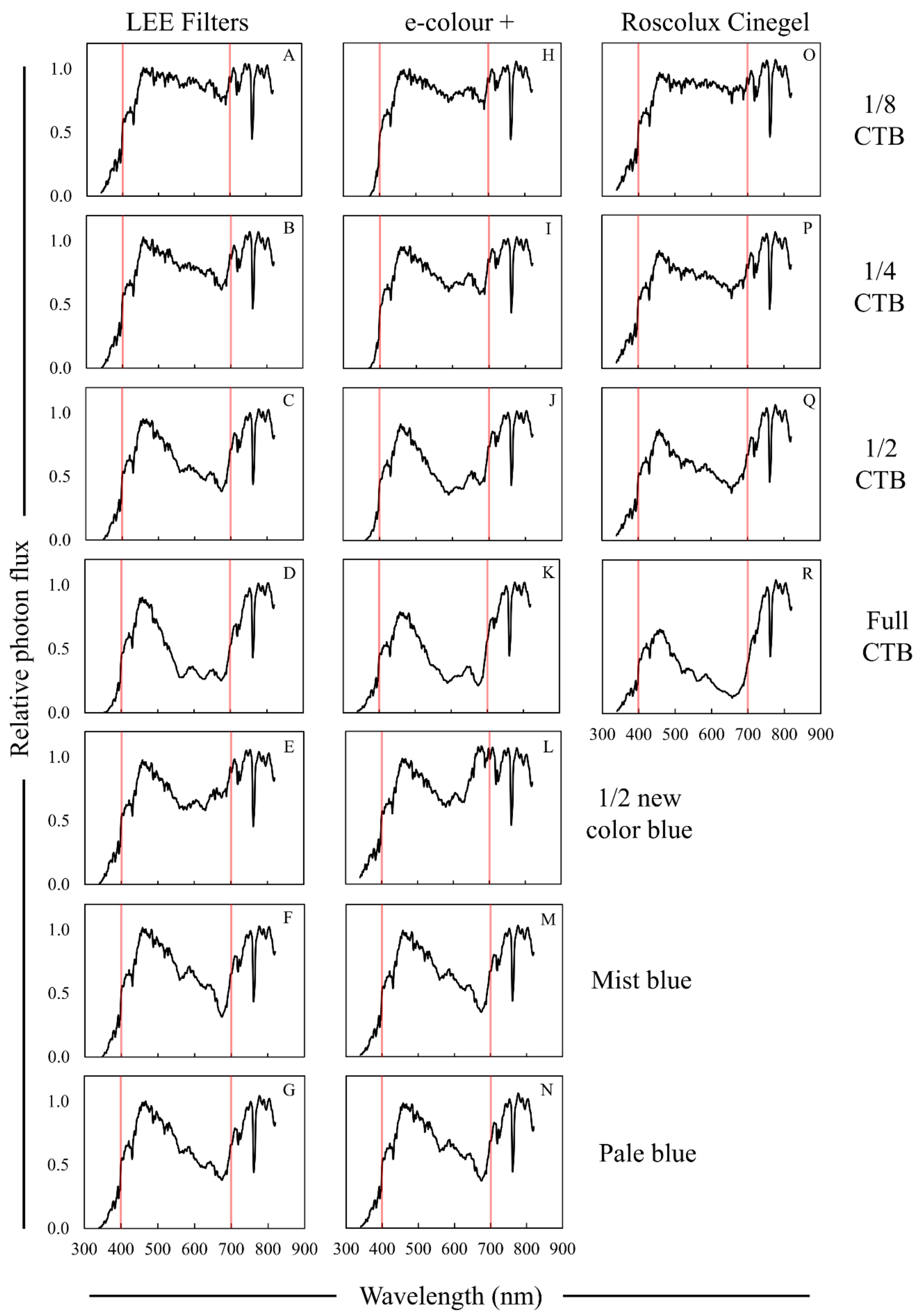

Figure 1: Relative spectral energy distributions (SEDs) of color temperature blue (CTB) and light blue color effects gels from LEE Filters, Rosco e-colour+, and Rosco Cinegel. **A, H, and O)** ⅛ CTB; **B, I, and P)** ¼ CTB; **C, J, and Q)** ½ CTB; **D, K, and R)** full CTB; **E and L)** ½ new color blue; **F and M)** Mist blue; **G and N)** Pale blue. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

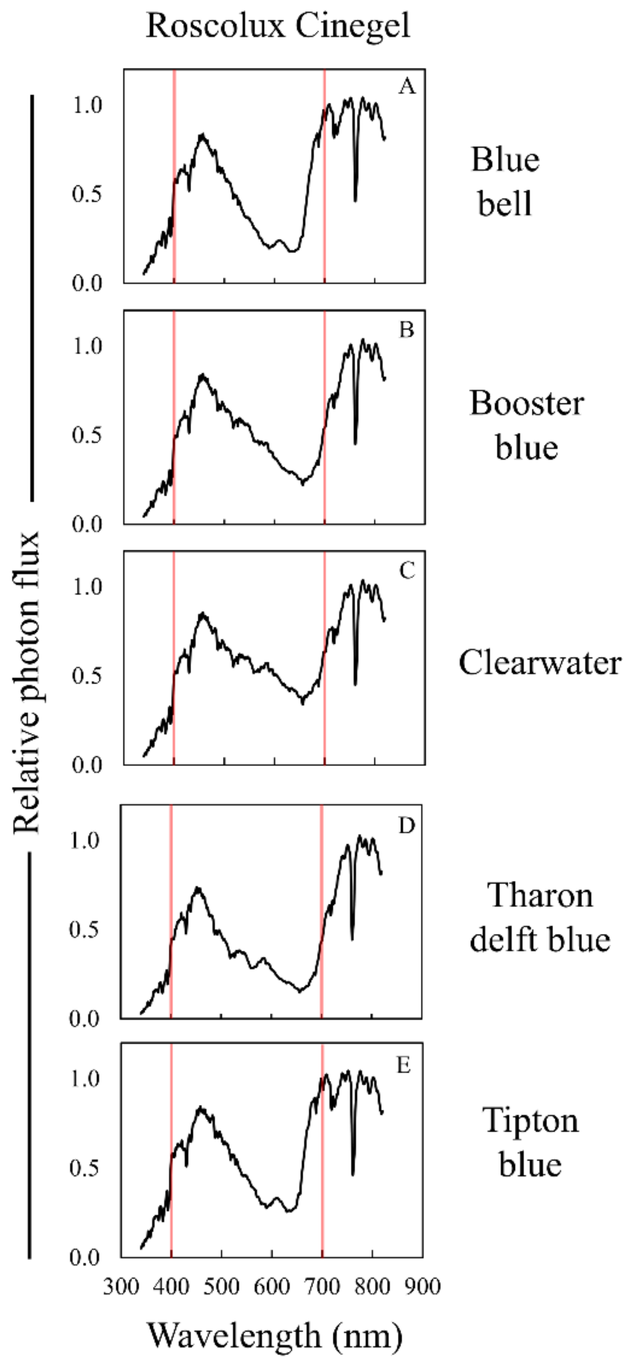

Figure 2: Relative spectral energy distributions (SEDs) of light blue color effects gels from Rosco Cinegel. **A)** Blue bell; **B)** Booster blue; **C)** Clearwater; **D)** Tharon delft blue; **E)** Tipton blue. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

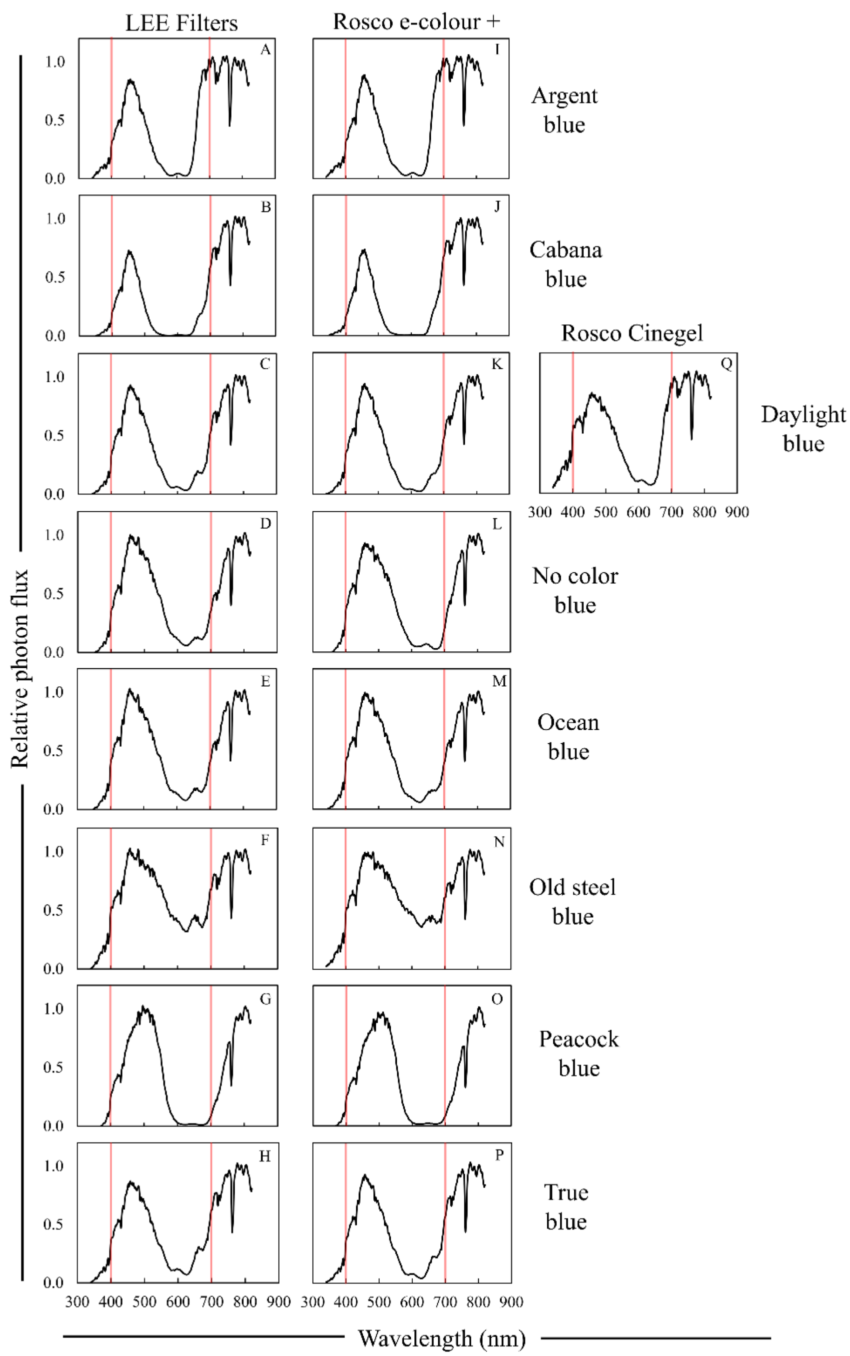

Figure 3: Relative spectral energy distributions (SEDs) of dark blue color effects gels from LEE Filters, Rosco e-colour+, and Rosco Cinegel (Daylight blue only). **A and I)** Argent blue; **B and J)** Cabana blue; **C, K, and Q)** Daylight blue; **D and L)** No color blue; **E and M)** Ocean blue; **F and N**) Old steel blue; **G and O)** Peacock blue; **H and P)** True blue. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active (PAR) radiation between the red bars.

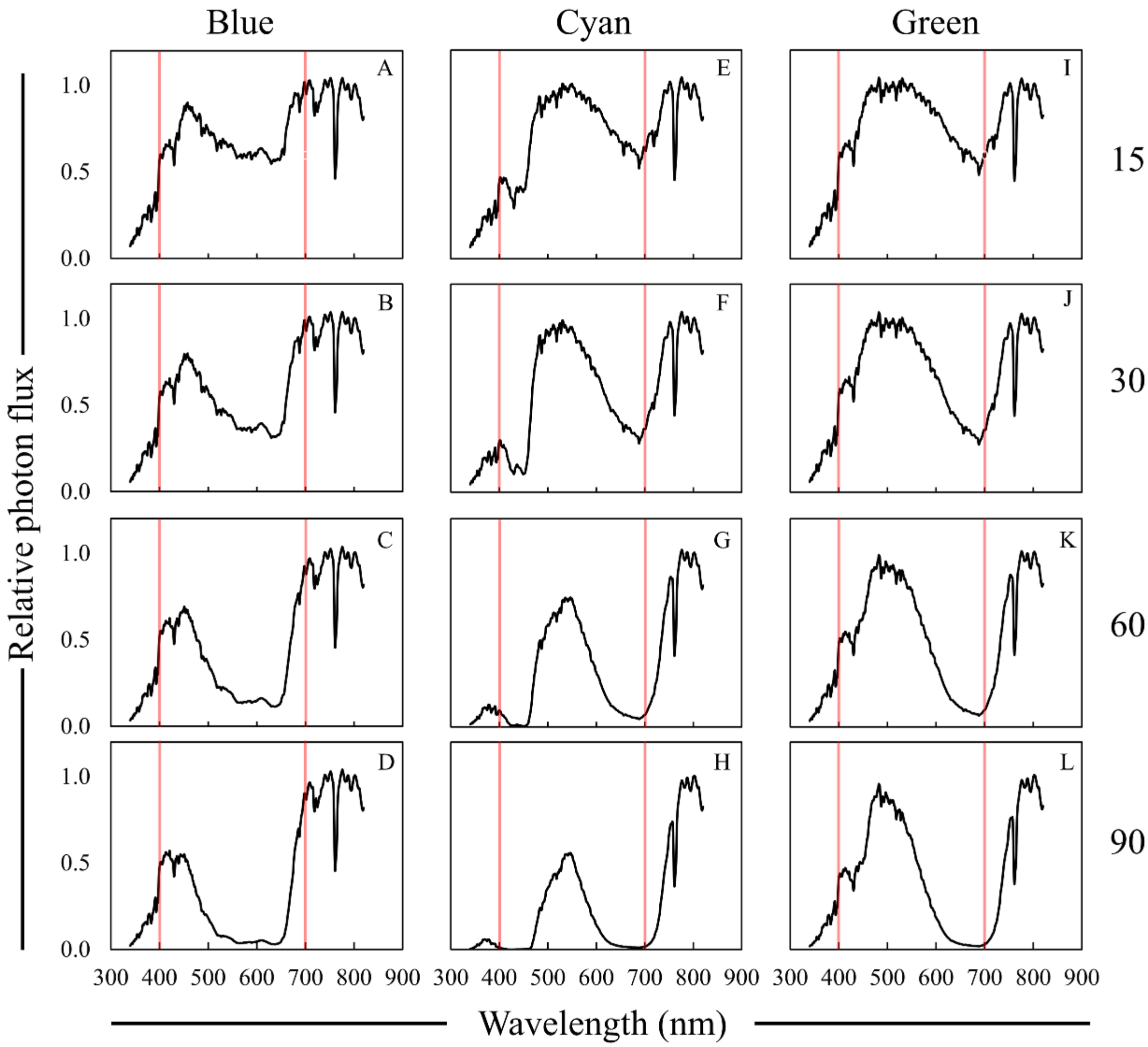

Figure 4: Relative spectral energy distributions (SEDs) of blue, cyan, and green Rosco CalColor gels ranging from 15-90 strength. **A-D)** Blue gels from 15 to 90 strength; **E-G)** Cyan gels from 15 to 90 strength; **I-L)** Green gels from 15 to 90 strength. Data were normalized to the photon flux at 800 nm, and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

Table 1: Average R:FR ratio, B:G ratio, and reduction in photosynthetic photon flux (PPF) under a range of color temperature blue (CTB) and blue color effects gels from brands including LEE Filters, Rosco e-colour+, Rosco Cinegel, and Rosco CalColor.

Gel	Brand	R:FR [a]	B:G [b]	PPF reduction [c]
1/8 CTB	LEE	0.91 ± 0.04 [d]	0.94 ± 0.01	20.7 ± 3.1
	e-colour+	0.90 ± 0.06	0.98 ± 0.01	24.7 ± 1.2
	Cinegel	0.92 ± 0.02	0.94 ± 0.01	24.3 ± 2.5
1/4 CTB	LEE	0.78 ± 0.04	1.01 ± 0.01	28.3 ± 1.5
	e-colour+	0.76 ± 0.05	1.06 ± 0.01	30.0 ± 2.7
	Cinegel	0.71 ± 0.02	1.05 ± 0.01	35.0 ± 2.7
1/2 CTB	LEE	0.57 ± 0.02	1.21 ± 0.01	44.0 ± 4.4
	e-colour+	0.60 ± 0.03	1.32 ± 0.01	45.7 ± 1.2
	Cinegel	0.51 ± 0.01	1.22 ± 0.01	45.7 ± 3.2
Full CTB	LEE	0.41 ± 0.02	1.66 ± 0.02	56.3 ± 0.6
	e-colour+	0.37 ± 0.03	1.49 ± 0.01	57.7 ± 0.6
	Cinegel	0.19 ± 0.01	1.71 ± 0.01	67.7 ± 2.1
1/2 new color blue	LEE	0.81 ± 0.04	1.15 ± 0.02	39.3 ± 3.8
	e-colour+	1.07 ± 0.02	1.11 ± 0.01	25.3 ± 1.5
Mist blue	LEE	0.55 ± 0.03	1.13 ± 0.03	40.7 ± 3.1
	e-colour+	0.54 ± 0.03	1.12 ± 0.01	37.7 ± 3.1
Pale blue	LEE	0.56 ± 0.02	1.15 ± 0.03	46.7 ± 5.9
	e-colour+	0.57 ± 0.01	1.12 ± 0.01	37.3 ± 3.1
Blue bell	Cinegel	0.40 ± 0.03	1.68 ± 0.01	52.7 ± 0.6
Booster blue	Cinegel	0.30 ± 0.02	1.29 ± 0.01	52.7 ± 0.6
Clearwater	Cinegel	0.46 ± 0.03	1.24 ± 0.01	46.7 ± 0.6
Tharon delft blue	Cinegel	0.22 ± 0.01	1.71 ± 0.01	63.7 ± 0.6
Tipton blue	Cinegel	0.52 ± 0.03	1.44 ± 0.01	47.7 ± 0.6
Argent blue	LEE	0.53 ± 0.02	3.12 ± 0.05	62.7 ± 0.6
	e-colour+	0.46 ± 0.04	3.31 ± 0.03	63.7 ± 2.9
Cabana blue	LEE	0.17 ± 0.01	8.43 ± 0.07	80.3 ± 0.6
	e-colour+	0.16 ± 0.01	8.16 ± 0.07	78.0 ± 0.0
Daylight blue	LEE	0.25 ± 0.01	2.28 ± 0.03	66.0 ± 0.0
	e-colour+	0.21 ± 0.01	2.46 ± 0.02	67.7 ± 1.2
	Cinegel	0.24 ± 0.01	1.64 ± 0.01	58.3 ± 2.3
No color blue	LEE	0.21 ± 0.01	1.47 ± 0.02	63.7 ± 0.6
	e-colour+	0.08 ± 0.01	1.46 ± 0.00	63.7 ± 2.3
Ocean blue	LEE	0.26 ± 0.01	1.56 ± 0.02	61.0 ± 1.7
	e-colour+	0.24 ± 0.01	1.62 ± 0.01	58.7 ± 2.3
Old steel blue	LEE	0.52 ± 0.02	1.15 ± 0.02	43.3 ± 1.5
	e-colour+	0.57 ± 0.03	1.16 ± 0.00	42.0 ± 2.7
Peacock blue	LEE	0.04 ± 0.01	0.96 ± 0.00	67.7 ± 1.5
	e-colour+	0.06 ± 0.00	0.93 ± 0.00	68.0 ± 1.7
True blue	LEE	0.37 ± 0.02	1.79 ± 0.03	62.7 ± 1.2

	e-colour+	0.26 ± 0.02	2.00 ± 0.02	64.3 ± 0.6
Blue 15	CalColor	0.78 ± 0.05	1.18 ± 0.00	31.7 ± 3.2
Blue 30		0.57 ± 0.03	1.52 ± 0.00	47.0 ± 2.0
Blue 60		0.31 ± 0.02	2.65 ± 0.01	65.3 ± 0.6
Blue 90		0.15 ± 0.01	5.47 ± 0.04	77.0 ± 1.0
Cyan 15	CalColor	0.78 ± 0.05	0.87 ± 0.02	25.3 ± 0.6
Cyan 30		0.54 ± 0.03	0.90 ± 0.02	34.0 ± 2.7
Cyan 60		0.22 ± 0.02	0.88 ± 0.02	53.7 ± 1.2
Cyan 90		0.10 ± 0.01	0.92 ± 0.01	61.3 ± 1.2

Note: Data are presented as averages acquired on three different clear sky or mostly sunny days between 13:00-14:00 h: 15 May, 19 May, and 27 May 2020.

[a] R:FR = 655-665 / 725-735

[b] B:G = 420-490 / 500-570

[c] PPF reduction = Percent reduction in PPF relative to full sun

[d] mean ± the standard deviation

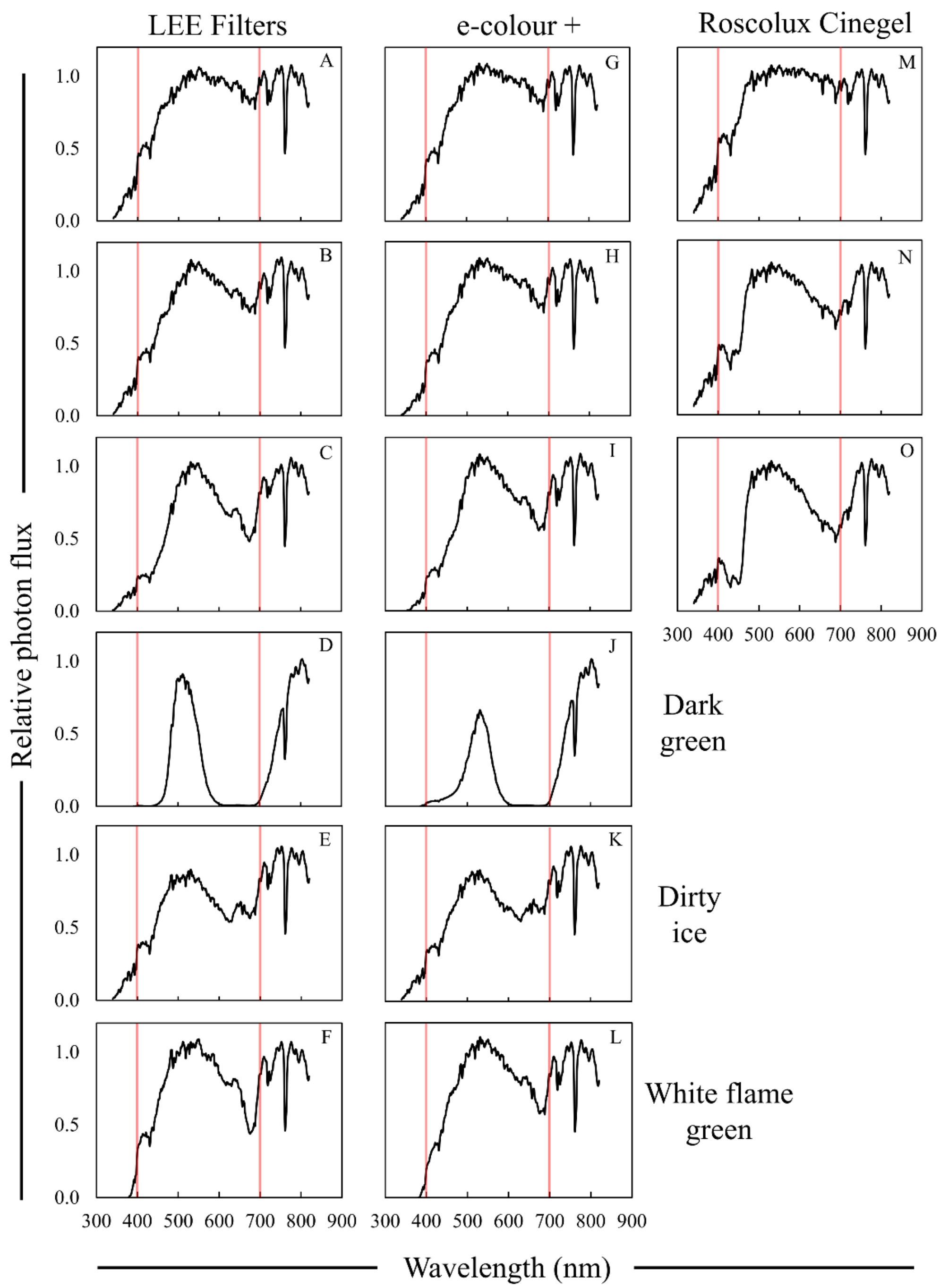

Figure 5: Relative spectral energy distributions (SEDs) of plus green (PG) and green color effects gels from LEE Filters, Rosco e-colour+, and Rosco Cinegel. **A, G, and M)** ¼ PG; **B, H, and N)** ½ PG; **C, I, and O)** full PG; **D and J)** Dark green; **E and K)** Dirty ice; **F and L)** White flame green. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

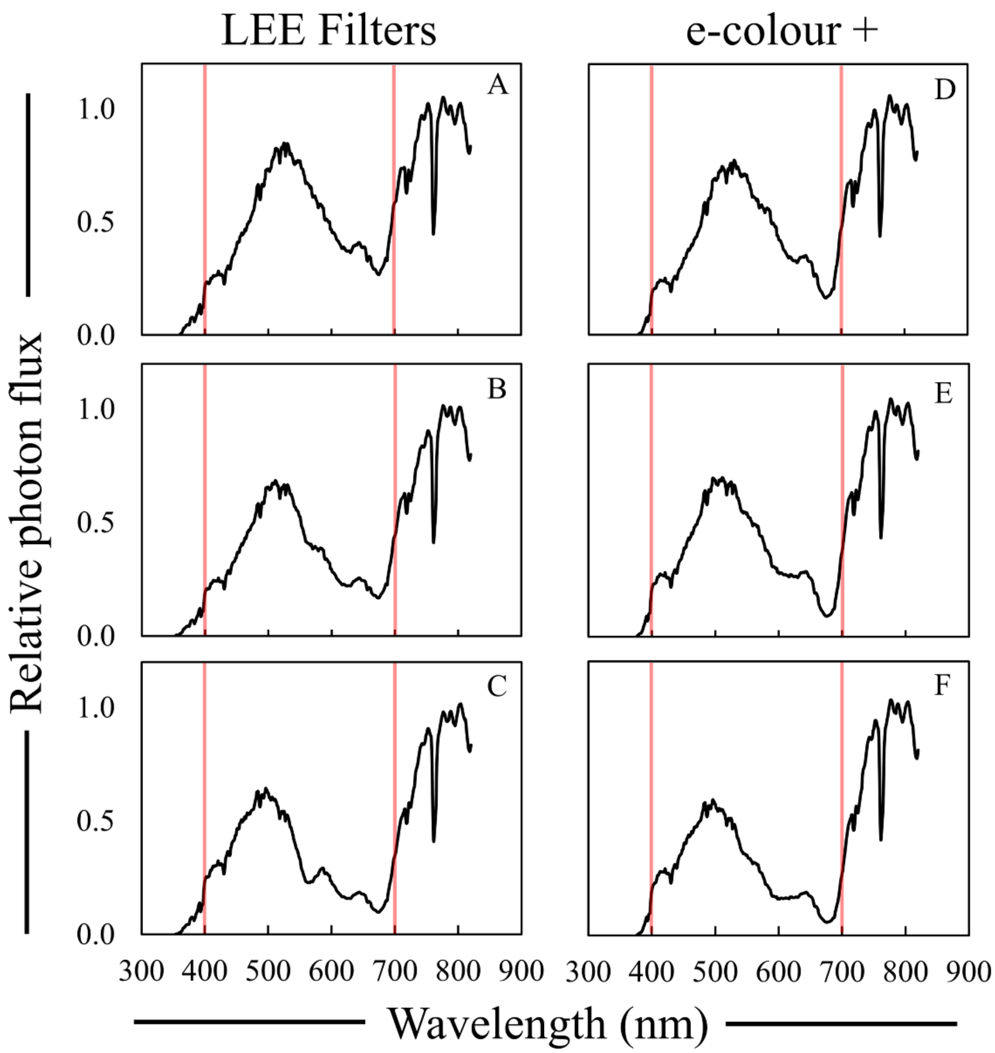

Figure 6: Relative spectral energy distributions (SEDs) of fluorescent green color effects gels from LEE Filters, and Rosco e-colour+. **A and D)** 3600k; **B and E)** 4300k; **C and F)** 5700k. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

Table 2: Average R:FR ratio, B:G ratio, and reduction in photosynthetic photon flux (PPF) under a range of plus green (PG) and green color effects gels from brands including LEE Filters, Rosco e-colour+, Rosco Cinegel, and Rosco CalColor.

Gel	Brand	R:FR [a]	B:G [b]	PPF reduction [c]
1/4 PG	Cinegel	0.97 ± 0.04 [d]	0.71 ± 0.01	20.0 ± 1.0
	e-colour+	1.00 ± 0.08	0.67 ± 0.07	19.0 ± 1.0
	Cinegel	1.06 ± 0.08	0.74 ± 0.01	17.3 ± 3.2
1/2 PG	LEE	0.86 ± 0.04	0.62 ± 0.01	25.7 ± 0.6
	e-colour+	0.96 ± 0.08	0.63 ± 0.06	24.7 ± 2.5
	Cinegel	0.87 ± 0.06	0.62 ± 0.01	27.3 ± 0.6
Full PG	LEE	0.65 ± 0.04	0.44 ± 0.04	39.3 ± 0.6
	e-colour+	0.78 ± 0.02	0.47 ± 0.01	36.0 ± 2.0
	Cinegel	0.75 ± 0.05	0.47 ± 0.01	34.7 ± 3.2
Dark green	LEE	0.02 ± 0.01	0.21 ± 0.01	83.0 ± 1.0
	e-colour+	0.01 ± 0.00	0.18 ± 0.01	88.3 ± 0.6
Dirty ice	LEE	0.71 ± 0.03	0.73 ± 0.00	39.3 ± 0.6
	e-colour+	0.78 ± 0.02	0.68 ± 0.01	42.0 ± 3.0
White flame green	LEE	0.71 ± 0.03	0.66 ± 0.01	28.0 ± 1.0
	e-colour+	0.83 ± 0.02	0.61 ± 0.01	31.0 ± 2.0
3600k	LEE	0.43 ± 0.02	0.56 ± 0.01	54.3 ± 0.6
	e-colour+	0.35 ± 0.01	0.53 ± 0.01	61.0 ± 3.6
4300k	LEE	0.30 ± 0.01	0.68 ± 0.01	66.0 ± 0.0
	e-colour+	0.25 ± 0.01	0.69 ± 0.01	65.3 ± 3.1
5700k	LEE	0.21 ± 0.01	1.05 ± 0.00	70.7 ± 0.6
	e-colour+	0.18 ± 0.01	0.94 ± 0.01	73.3 ± 2.1
Green 15	CalColor	0.81 ± 0.05	0.60 ± 0.00	28.3 ± 3.8
Green 30	CalColor	0.55 ± 0.03	0.41 ± 0.01	48.0 ± 2.0
Green 60	CalColor	0.17 ± 0.01	0.21 ± 0.00	72.7 ± 0.6
Green 90	CalColor	0.07 ± 0.01	0.12 ± 0.00	85.0 ± 0.0

Note: Data are presented as averages acquired on three different clear sky or mostly sunny days between 13:00-14:00 h: 15 May, 19 May, and 27 May 2020.

[a] R:FR = 655-665 / 725-735

[b] B:G = 420-490 / 500-570

[c] PPF reduction = Percent reduction in PPF relative to full sun

[d] mean ± the standard deviation

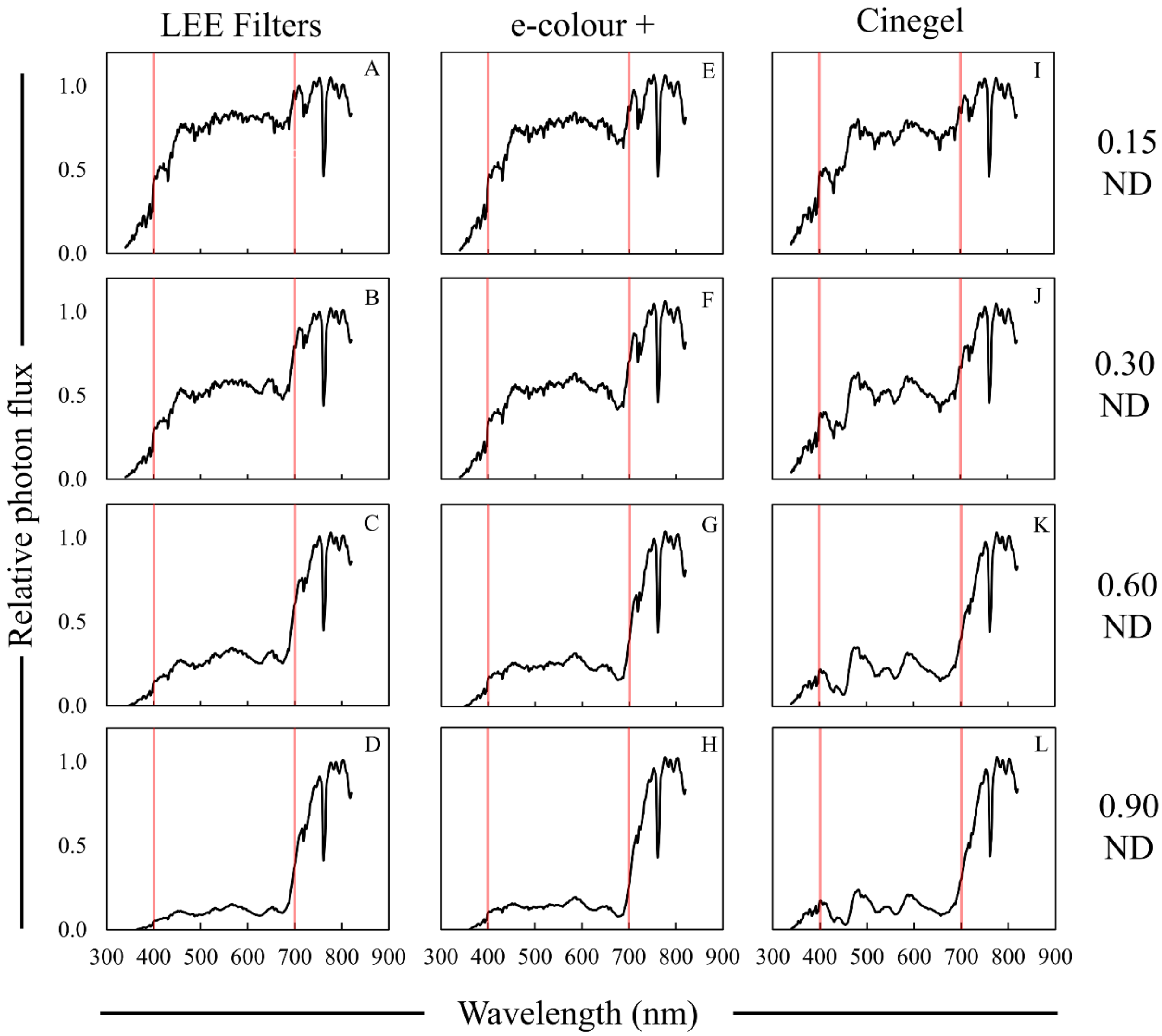

Figure 7: Relative spectral energy distributions (SEDs) of neutral density (ND) gels of increasing strength from LEE Filters, Rosco e-colour+, and Rosco Cinegel. **A, E, and I)** 0.15; **C, F, and J)** 0.30; **C, G, and K)** 0.60; **D, H, and L)** 0.90. Data were normalized to the photon flux at 800 nm and are presented as the average of relative SEDs acquired on 15 May, 19 May, and 27 May 2020 on clear sky or mostly sunny days between 13:00-14:00 h. Red bars indicate 400 and 700 nm respectively, designating photosynthetically active radiation (PAR) between the red bars.

Table 3: Average R:FR ratio, B:G ratio, and reduction in photosynthetic photon flux (PPF) under a range of neutral density (ND) from brands including LEE Filters, Rosco e-colour+, and Rosco Cinegel.

Gel	Brand	R:FR [a]	B:G [b]	PPF reduction [c]
0.15 ND	LEE	0.85 ± 0.05 [d]	0.84 ± 0.01	29.7 ± 0.6
	e-colour+	0.84 ± 0.04	0.86 ± 0.00	36.0 ± 1.7
	Cinegel	0.76 ± 0.05	0.86 ± 0.00	36.0 ± 1.7
0.30 ND	LEE	0.61 ± 0.04	0.83 ± 0.01	51.7 ± 0.6
	e-colour+	0.61 ± 0.01	0.88 ± 0.00	53.0 ± 1.0
	Cinegel	0.53 ± 0.03	0.86 ± 0.01	54.0 ± 1.0
0.60 ND	LEE	0.36 ± 0.02	0.78 ± 0.01	76.0 ± 1.7
	e-colour+	0.30 ± 0.01	0.91 ± 0.00	79.7 ± 0.6
	Cinegel	0.23 ± 0.01	0.90 ± 0.01	79.7 ± 0.6
0.90 ND	LEE	0.18 ± 0.01	0.77 ± 0.02	90.0 ± 0.0
	e-colour+	0.18 ± 0.01	0.95 ± 0.01	88.3 ± 0.6
	Cinegel	0.13 ± 0.01	0.89 ± 0.01	88.0 ± 0.0

Note: Data are presented as averages acquired on three different clear sky or mostly sunny days between 13:00-14:00 h: 15 May, 19 May, and 27 May 2020.

[a] R:FR = 655-665 / 725-735

[b] B:G = 420-490 / 500-570

[c] PPF reduction = Percent reduction in PPF relative to full sun

[d] mean ± the standard deviation