Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6930--20-10,071

Bioinspired Surface Treatments for Improved Decontamination: Deposition Variations

Brandy J. White

Laboratory for the Study of Molecular Interfacial Interactions
Center for Bio/Molecular Science & Engineering

Anthony P. Malanoski

Laboratory for Biosensors and Biomaterials
Center for Bio/Molecular Science & Engineering

Martin H. Moore

Laboratory for the Study of Molecular Interfacial Interactions
Center for Bio/Molecular Science & Engineering

Jordan D. Kushto

South River High School
Edgewater, MD

Gary P. Kushto

Optical Nanotechnology
Optical Sciences Division

August 10, 2020

UNCLASSIFIED//DISTRIBUTION A

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
10-08-2020

2. REPORT TYPE
NRL Memorandum Report

3. DATES COVERED *(From - To)*
01/10/2019 – 03/06/2020

4. TITLE AND SUBTITLE
Bioinspired Surface Treatments for Improved Decontamination: Deposition Variations

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brandy J. White, Anthony P. Malanoski, Martin H. Moore, Jordan D. Kushto*, and Gary P. Kushto

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
1C75

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/MR/6930--20-10,071

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Threat Reduction Agency
DTRA-Joint CBRN Center of Excellence
Bldg E-2800
APG-EA, MD 21010

10. SPONSOR / MONITOR'S ACRONYM(S)
DTRA - CB10125

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
* South River High School, 201 Central Ave E, Edgewater, MD 21037

14. ABSTRACT
This effort evaluates bioinspired coatings for use in a top-coat type application to identify those technologies that may improve decontamination capabilities for painted surfaces. This report details results for evaluation of a commercially available, transparent, surface treatment. Retention of the simulants paraoxon, methyl salicylate, dimethyl methylphosphate, and diisopropyl fluorophosphates following treatment of contaminated surfaces with a soapy water solution is reported. Reflectance characteristics, wetting behaviors, and target droplet diffusion on the surfaces are also discussed.

15. SUBJECT TERMS
Coatings Decontamination
Paint

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	Unclassified Unlimited	66	Brandy J. White
					19b. TELEPHONE NUMBER *(include area code)* (202) 404-6100

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

UNCLASSIFIED//DISTRIBUTION A

This page intentionally left blank.

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The Center for Bio/Molecular Science and Engineering at the Naval Research Laboratory (NRL) initiated a program in January 2015 for evaluation of bioinspired treatments suitable for use as a top coat on painted surfaces with the intention of achieving improved aqueous decontamination of these materials. Funding was provided by the Defense Threat Reduction Agency (DTRA, CB10125). As part of this effort engagement with scientists in academia and industry was used to identify technologies that offered potentially useful characteristics. A prior report detailed results for evaluation of four commercially available surface treatments, including Rust-Oleum® Wipe New. The current report looks at variations in performance based on methods used for deposition of a variation of the Wipe New product marketed as ReColor. Retention of the simulants paraoxon, methyl salicylate, dimethyl methylphosphate, and diisopropyl fluorophosphate following treatment of contaminated surfaces with a soapy water solution is reported along with droplet diffusion on the surfaces and wetting angles.

This page intentionally left blank.

BIOINSPIRED SURFACE TREATMENTS FOR IMPROVED DECONTAMINATION: DEPOSITION VARIATIONS

INTRODUCTION

The DoD Chemical and Biological Defense Program (CBDP) seeks to provide protection of forces in a contaminated environment including contamination avoidance, individual protection, collective protection, and decontamination. In January 2015, the Center for Bio/Molecular Science and Engineering at the Naval Research Laboratory (NRL) began an effort funded through the Defense Threat Reduction Agency (DTRA, CB10125) with a view toward evaluation and development of top-coat type treatments suitable for application to painted surfaces that would reduce retention of chemical threat agents following standard decontamination approaches. The effort sought to survey relevant and related areas of research and evaluate identified technologies under appropriate methods to determine efficacy, scalability, and durability.

Commercially available treatments offer potential advantages over the less mature technologies otherwise evaluated by this effort. Hazards, deposition approaches, and production scaling have been thoroughly addressed. The materials are suitable for immediate evaluation and movement into use as appropriate and may offer reduced development costs. A prior report documented results for evaluation of four commercially available surface treatments: NANOskin Hydro Express, Rust-Oleum® NeverWet®, Eagle One Superior NanoWax™, and Rust-Oleum® Wipe New (Figure 1).[1] The surface treatments were identified through interaction with academic and industrial scientists familiar with the technologies and with the goals of this ongoing effort. Treated coupons were subjected to standard evaluations including measurement of sessile, sliding, and shedding contact angles and quantification of retention for the simulant compounds.

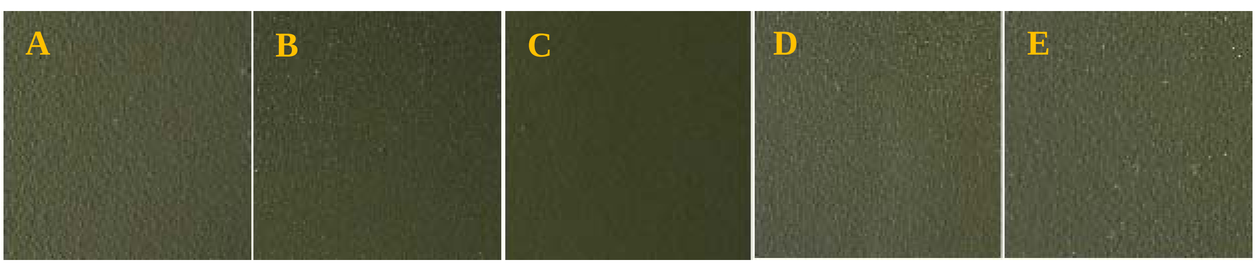


Fig. 1 — Images of a painted coupon (A), a Nanoskin treated coupon (B), a Wipe New treated coupon (C), a NeverWet treated coupon (D), and a NanoWax treated coupon (E). [1]

The Wipe New product provided reduced retention of paraoxon, methyl salicylate, dimethyl methylphosphate, and diisopropyl fluorophosphate as compared to paint only surfaces.[1] This product is available in several packaging variants: Trim Restore, Headlight Restore, ReColor, Wheels, and Tires. The Trim Restore, Headlight Restore, and ReColor packages contain 1-chloro-4-(trifluoromethyl)benzene and benzaldehyde according to the safety data sheets. The Wheels and Tires packages vary slightly from the other products and contain tert-butyl acetate in addition to the other components. The packaging variations are also supplied with slightly varying application guidance. In the original study, the Headlight Restore package was utilized. That material is supplied on a preloaded microfiber cloth to be wiped onto the surface.

Manuscript approved August 5, 2020.

Here, the ReColor product has been used; this product is supplied as a liquid with microfiber application cloths and sponges.

METHODS

Aluminum coupons were painted with a polyurethane based system following the directions for those products. Deposition of the surface treatments used single and multiple applications as well as application with and without polishing. All drying and curing steps were completed under laboratory ambient temperature and humidity. Rust-Oleum® ReColor is provided in a kit as a liquid with microfiber cloths and sponges.

Sessile contact angles for samples evaluated under this effort used three 3 μL droplets per surface with each droplet measured independently three times for each of three targets, water, ethylene glycol, and n-heptane. Geometric surface energy was calculated based on the water and ethylene glycol interactions using software designed for the DROPimage goniometer package. Sliding angles were determined using 5 μL droplets. The droplet was applied at 0° after which the supporting platform angle was gradually increased up to 60°. Sliding angles for each of the liquids were identified as the angle for which movement of the droplet was identified. Shedding angles for each liquid were determined using 12 μL droplets initiated 2.5 cm above the coupon surface. Changes in base angle of 10° were utilized to identify the range of droplet shedding angle based on a complete lack of droplet retention by the surface (not sliding). The angle was then reduced in steps of 1° to identify the minimum required angle. Droplet diameters were determined using tools provided by Adobe Photoshop CS3. Droplets of 5 μL were applied to the surfaces and images were collected at 30 s intervals for 5 min followed by images at 5 min intervals for a total of 30 min. DFP samples were kept covered for the duration of the experiment to minimize evaporation. In some cases, reflections from the glass cover can be seen in the images.

Simulant exposure and evaluation methods were based on the tests developed by Edgewood Chemical Biological Center referred to as Chemical Agent Resistance Method (CARM).[2] Standard target exposures utilized a challenge level of 10 g/m^2. Here, the coupons were 0.00101 m^2; a 10 g/m^2 target challenge was applied to the surfaces as two equally sized neat droplets. Following application of the target, coupons were aged 1 h. Decontamination used a gentle stream of air to expel target from the surface prior to rising with soapy water (0.59 g/L Alconox in deionized water). The coupons were then soaked in isopropanol for 30 min to extract remaining target; this isopropanol extract was analyzed by the appropriate chromatography method to determine target retention on the surface.

For target analysis, gas chromatography-mass spectrometry (GC-MS) was accomplished using a Shimadzu GCMS-QP2010 with AOC-20 auto-injector equipped with a Restex Rtx-5 (30 m x 0.25 mm ID x 0.25 μm df) cross bond 5% diphenyl 95% dimethyl polysiloxane column. A GC injection temperature of 200°C was used with a 1:1 split ratio at a flow rate of 3.6 mL/min at 69.4 kPa. The oven gradient ramped from 50°C (1 min hold time) to 180°C at 15°C/min and then to 300°C at 20°C/min where it was held for 5 min.

The spectral properties of the painted coupons and the coupons following deposition of the surface treatments were evaluated using a Perkin-Elmer Lambda 1050 UV/Vis/NIR spectrophotometer. The diffuse optical reflectance of each sample was collected in the 0.4 - 2.5 μm spectral region using the snap-in 150 mm integrating sphere accessory with PMT and InGaAs detection. All spectral data is referenced to a Spectralon® diffuse reflectance standard. Reference spectra were collected with the reflectance standard mounted on a port tangent to the surface of the integrating sphere. Sample spectra were collected by removing the reflectance reference and replacing it with the sample coupons, ensuring identical measurement geometries.

RESULTS

The products were applied to painted aluminum coupons. Table 1 provides contact angles for the resulting surfaces compared to that of the painted surface alone and a Fomblin Y oiled version of the painted surface. In the original study, all of the commercial products increased wetting angles for water and ethylene glycol with an associated reduction in geometric surface energy. The coatings did not yield oleophobic characteristics; all surfaces were fully wetted by heptane.[1] As shown in Table 1, the ReColor deposition variants yielded similar results. The original treatments also did not produce improved sliding or shedding characteristics for the painted surfaces. Here, while depositions without polishing did not produce sliding or shedding behaviors, shedding behaviors were noted for polished depositions (S1, S2, S3).

The tendency of droplets to spread across the surfaces was also evaluated (Figure 2; Appendices). For these studies, droplets of the simulants, DMMP, paraoxon, and MES (5 μL), were utilized. The spread of the droplets was quantified by measuring the diameter of the droplets in the images over time (Figures 3, 4, and 5). For the paint only samples, MES and paraoxon spread quickly reaching the edges of the coupon at 10 min. DMMP does not spread during the course of the 30 min incubation for any surface. DMMP and MES do not spread on the Wipe New treatments, though droplet diameters vary slightly from surface to surface (Figures 3, 4, and 5).

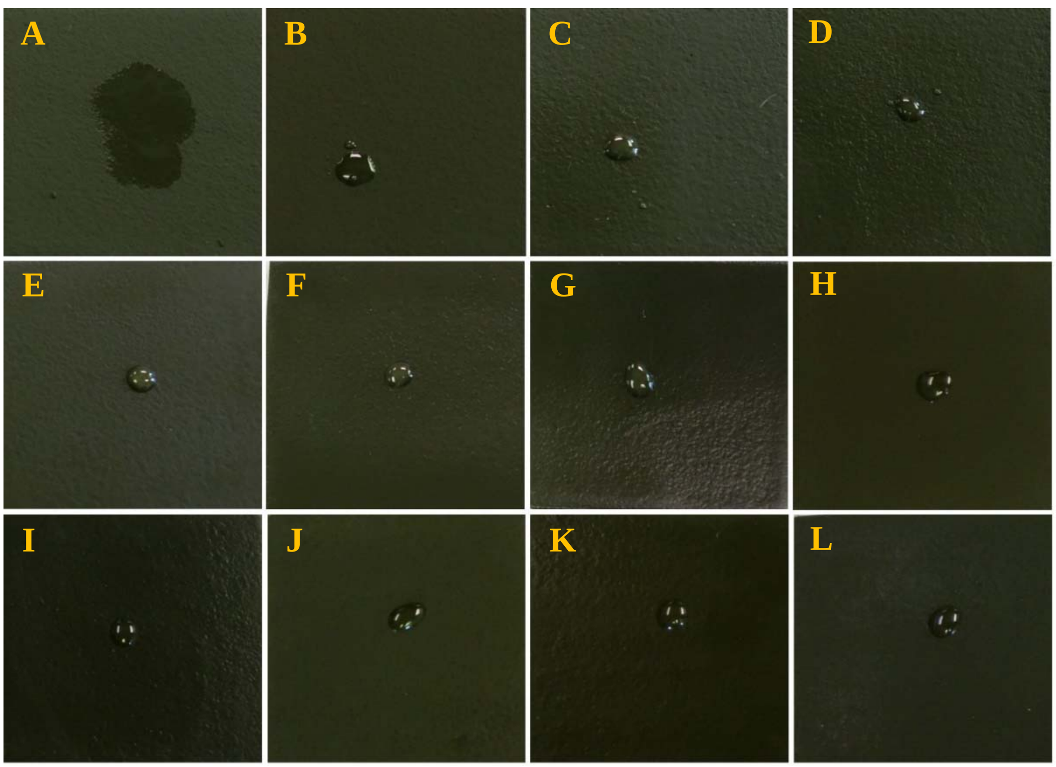


Fig. 2 — Images of a painted coupon (A) and painted coupons treated with the ReColor deposition variants showing standing droplets of MES immediately following exposure: (B) single ReColor application (1); (C) two coat ReColor application (2); (D) three coat ReColor application (3); (E) polished with single ReColor application (S1); (F) polished with two coat ReColor application (S2); (G) polished with three coat ReColor application (S3); (H) polished with single ReColor application followed by polishing (SC1P); (I) two cycle polished ReColor application (SC2); (J) two cycle polished ReColor application followed by polishing (SC2P); (K) three cycle polished ReColor application (SC3); (L) three cycle polished ReColor application followed by polishing (SC3P).

Table 1 – Sessile, Sliding, and Shedding Contact Angles

Coupon	Liquid	Sessile Angle	Sliding Angle	Shedding Angle	Geometric Surface Energy (mJ/m^2)
Painted Coupon	water	47.5 ± 1.1	>60	>60	71.9 ± 5.1
	ethylene glycol	55.7 ± 2.1	>60	>60	
	n-heptane	--	--	--	
Fomblin Y Oiled Paint	water	73.1 ± 2.1	>60	46.7 ± 3.3	32.2 ± 1.6
	ethylene glycol	52.5 ± 0.61	>60	49.8 ± 4.9	
	n-heptane	40.1 ± 2.9	>60	36.6 ± 3.3	
Original Wipe New Results[1]	water	80.9 ± 0.89	>60	>60	27.2 ± 1.9
	ethylene glycol	77.9 ± 1.9	>60	>60	
	n-heptane	--	--	--	
Single ReColor Application	water	83.6 ± 2.2	>60	>60	28.2 ± 3.6
	ethylene glycol	79.5 ± 1.3	>60	>60	
	n-heptane	--	--	--	
Two Coat ReColor Application	water	81.4 ± 2.0	>60	>60	28.5 ± 3.3
	ethylene glycol	79.3 ± 0.86	>60	>60	
	n-heptane	--	--	--	
Three Coat ReColor Application	water	86.6 ± 1.6	>60	>60	22.6 ± 2.3
	ethylene glycol	75.6 ± 1.7	>60	>60	
	n-heptane	--	--	--	
Polished with Single ReColor Application (S1)	water	84.0 ± 1.4	>60	49.9 ± 4.3	24.8 ± 2.3
	ethylene glycol	80.2 ± 0.8	>60	50.7 ± 2.4	
	n-heptane	--	--	--	
Polished with Two Coat ReColor Application (S2)	water	89.2 ± 1.2	>60	52.5 ± 3.3	19.2 ± 1.2
	ethylene glycol	80.8 ± 1.7	>60	55.6 ± 1.2	
	n-heptane	--	--	--	
Polished with Three Coat ReColor Application (S3)	water	88.7 ± 0.6	>60	52.8 ± 1.7	19.9 ± 0.6
	ethylene glycol	79.5 ± 1.0	>60	56.5 ± 0.5	
	n-heptane	--	--	--	
Single Polished/ Polished ReColor Application (SC1P)	water	77.1 ± 2.3	>60	>60	31.1 ± 5.1
	ethylene glycol	75.0 ± 3.3	>60	>60	
	n-heptane	--	--	--	
Two Cycle Polished ReColor Application (SC2)	water	68.9 ± 3.3	>60	>60	56.3 ± 10.0
	ethylene glycol	80.0 ± 1.8	>60	>60	
	n-heptane	--	--	--	
Two Cycle Polished/ Polished ReColor Application (SC2P)	water	76.1 ± 1.5	>60	>60	48.9 ± 4.7
	ethylene glycol	87.1 ± 1.0	>60	>60	
	n-heptane	--	--	--	
Three Cycle Polished ReColor Application (SC3)	water	72.0 ± 3.2	>60	>60	38.9 ± 6.6
	ethylene glycol	73.1 ± 1.2	>60	>60	
	n-heptane	--	--	--	
Three Cycle Polished/ Polished ReColor Application (SC3P)	water	77.7 ± 1.9	>60	>60	29.4 ± 3.6
	ethylene glycol	73.1 ± 3.4	>60	>60	
	n-heptane	--	--	--	

The coupons were subjected to simulant exposure (10 g/m^2), aging, washing, and drying. No visible impact on the ReColor treatments was noted following handling and processing steps. For all depositions, painted coupons were washed with isopropanol and soapy water, rinsed with water, and dried prior to application. When exposure was followed by the air and soapy water treatment for painted surfaces (Table

2), target retention was reduced for all of the ReColor deposition variants over that noted for the paint only surface. Little difference was noted among the single, two, and three layer depositions completed with only the wash to prepare the surfaces (Figure 6). When the wash was followed by light polishing (S1, S2, S3), the three layer deposition did show slight improvements over the single and two layer applications (Figure 7). The polished surfaces also retained less target than those that were not polished first. In the prior report, no differences were noted between polished and unpolished applications.[1] The original product (Wipe New) also showed greater retention of paraoxon than noted here for the ReColor coatings. Polishing between applications and polishing following application (Figure 8) did not improve performance in the coating.

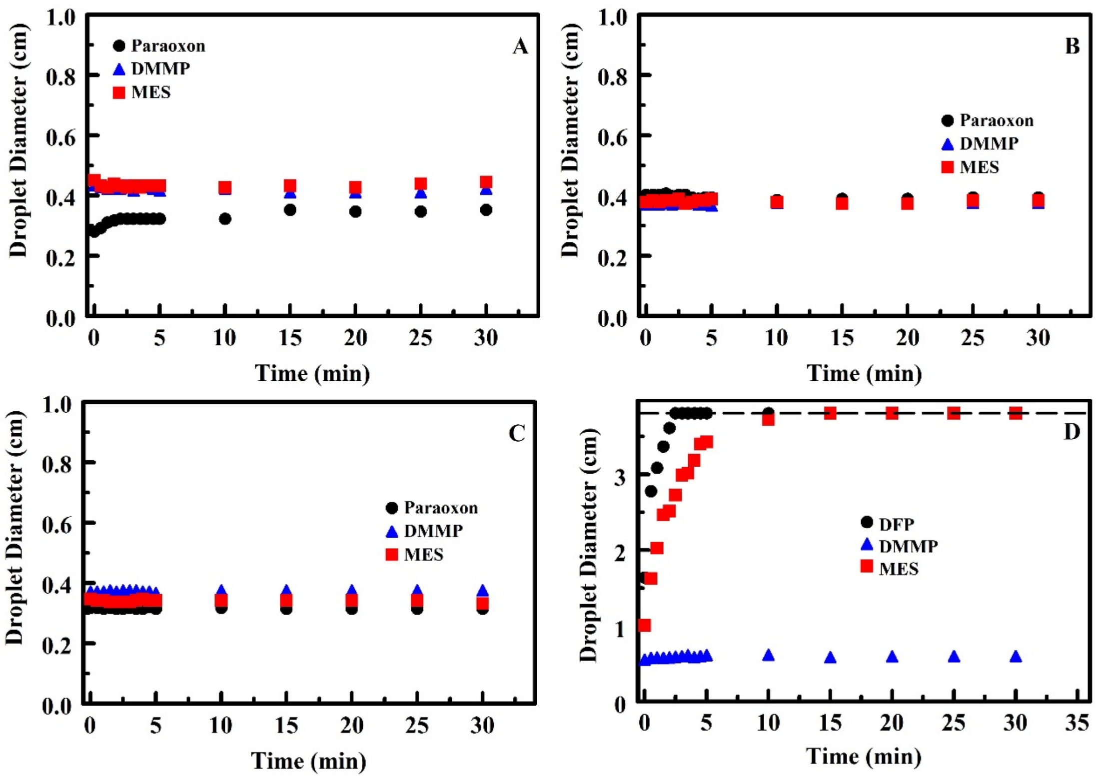


Fig. 3 — Progression of simulant droplet diameters during incubation on the surfaces for paraoxon (black), DMMP (blue), and MES (red): ReColor 1 (A), ReColor 2 (B), ReColor 3 (C), and paint only (D).

For comparison purposes, paint only coupons that were not rinsed prior to isopropanol extraction retained the following: paraoxon – 9.84 g/m^2, MES – 9.54 g/m^2, DMMP – 9.90 g/m^2, DFP - 7.39 g/m^2. Though the nominal target application was 10 g/m^2, recovery from surfaces was always less than this value. Losses due to evaporation would be expected, especially for DFP. Additional losses likely occur during the rinse steps due to agent interaction with the untreated region of the coupon; the back of these coupons is unpainted aluminum.

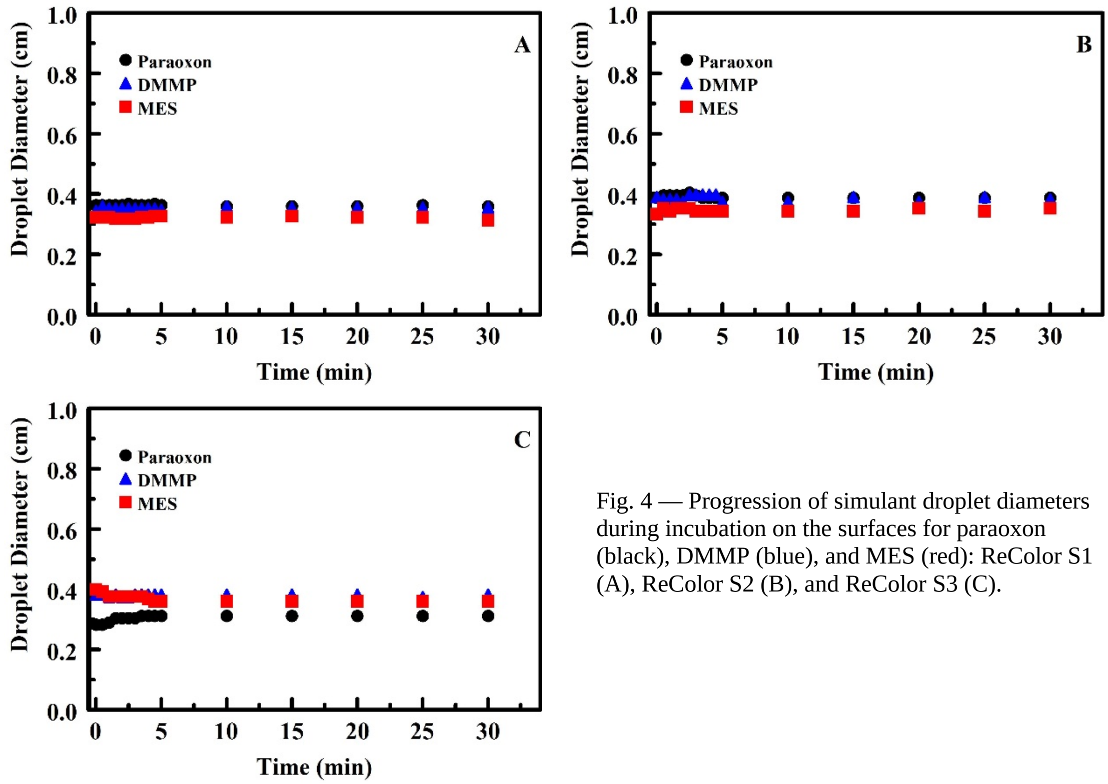


Fig. 4 — Progression of simulant droplet diameters during incubation on the surfaces for paraoxon (black), DMMP (blue), and MES (red): ReColor S1 (A), ReColor S2 (B), and ReColor S3 (C).

A comparison between the diffuse reflection spectra of an untreated paint sample and the ReColor 1, ReColor 2, and Recolor 3 coatings is provided in Figure 9. . It is immediately clear that the surface treatments have only minor effects on the spectral signature of the underlying paint suggesting that the surface treatment is largely optically inactive over this wavelength region. A minor decrease is observed in the sample reflectivity (< 3 %) in a narrow band centered at ~0.54 μm as well as much more broadband decrease over the 1-1.7 μm range. This decrease in diffuse reflectance can likely be attributed to thick film formation of the ReColor over the bare paint. The ReColor S1, ReColor S2, and ReColor S3 coatings (Figure 10) show a similar impact on the reflectance characteristics

Visual inspection of the samples shows that even after curing of the ReColor overcoat, the samples maintain a ‘wet’ look. This would be consistent with the topcoat filling pores in the bare paint surface and building up as a smooth, optically thick film leading to an increase in the specular reflectance of the sample. Since the ReColor film is optically thick, any optical absorption associated with it would manifest itself as a drop in the measured diffuse reflectivity with respect to the untreated sample. It should be noted, however, that the exact source of these spectral effects are difficult to assign unambiguously at this time, and these issues are under further investigation.

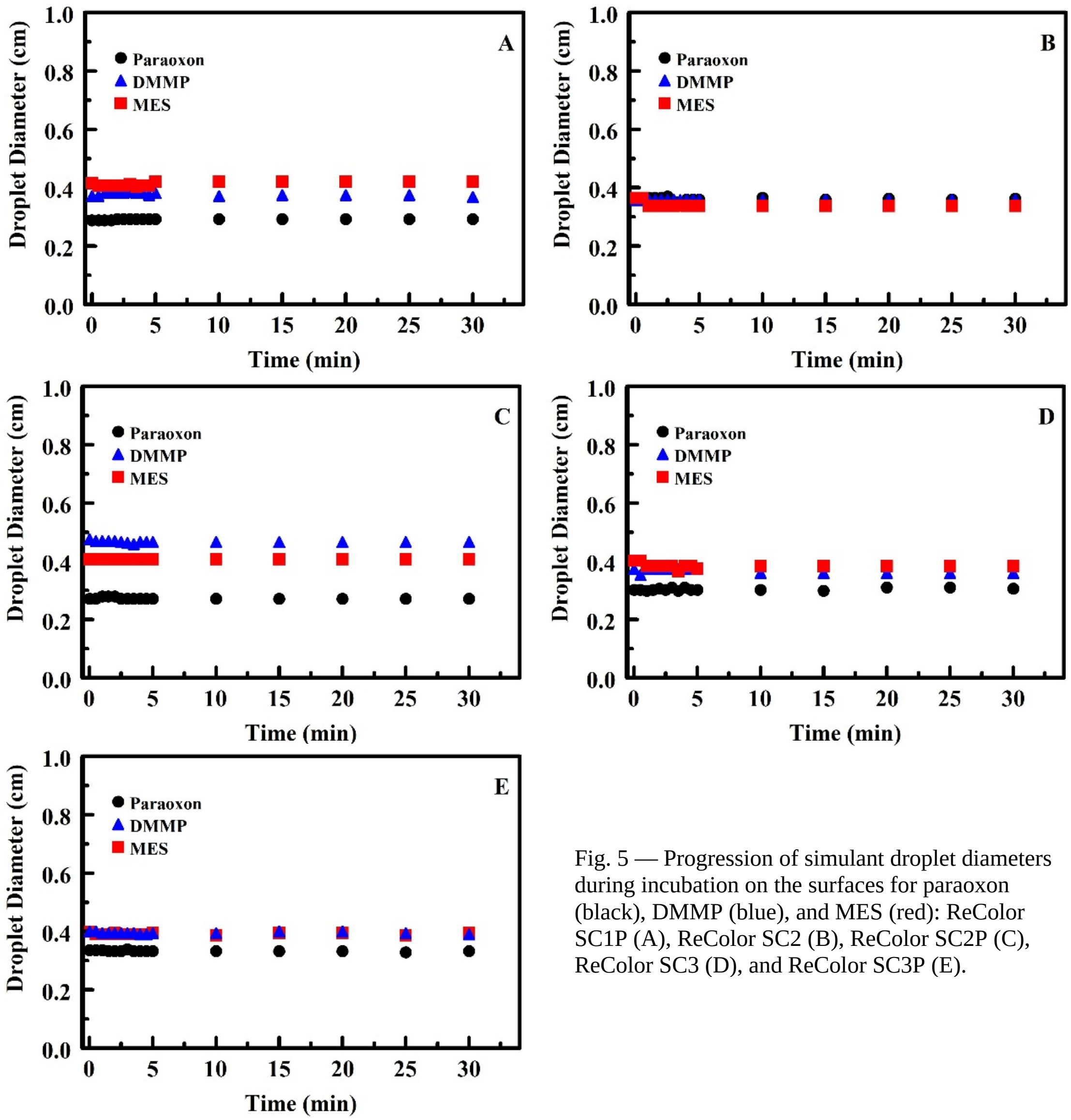


Fig. 5 — Progression of simulant droplet diameters during incubation on the surfaces for paraoxon (black), DMMP (blue), and MES (red): ReColor SC1P (A), ReColor SC2 (B), ReColor SC2P (C), ReColor SC3 (D), and ReColor SC3P (E).

Table 2 – Target Retention (g/m^2) Following 1 h Aging. ND indicates target concentrations below the threshold of detection for the method employed.

Coupon	Paraoxon	MES	DMMP	DFP
Painted Coupon	5.48	6.20	4.28	0.52
Fomblin Y Oiled Paint	1.24	2.85	0.59	0.34
Original Wipe New Result [1]	0.72	0.32	0.02	0.03
Single ReColor Application (1)	0.14	0.51	0.08	0.09
Two Coat ReColor Application (2)	0.20	0.62	0.04	0.10
Three Coat ReColor Application (3)	0.19	0.27	0.03	0.12
Polished with Single ReColor Application (S1)	0.06	0.42	0.03	0.12
Polished with Two Coat ReColor Application (S2)	0.04	0.31	0.09	0.11
Polished with Three Coat ReColor Application (S3)	0.07	0.16	ND	0.06
Single Polished/ Polished ReColor Application (SC1P)	0.05	0.37	0.01	0.11
Two Cycle Polished ReColor Application (SC2)	0.07	0.10	0.05	0.12
Two Cycle Polished/ Polished ReColor Application (SC2P)	0.11	0.21	0.09	0.14
Three Cycle Polished ReColor Application (SC3)	0.09	0.21	0.10	0.18
Three Cycle Polished/ Polished ReColor Application (SC3P)	0.10	0.30	0.10	0.17

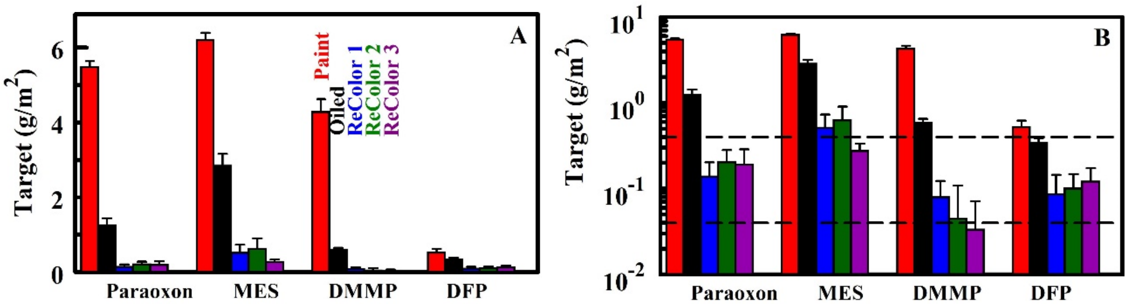


Fig. 6 — Target retention by coupons following treatment with an air stream and rinsing with soapy water: paint only (red) Fomblin Y oiled coupon (black); ReColor 1 (blue); ReColor 2 (green); and ReColor 3 (purple). Data is presented on both linear and logarithmic scales.

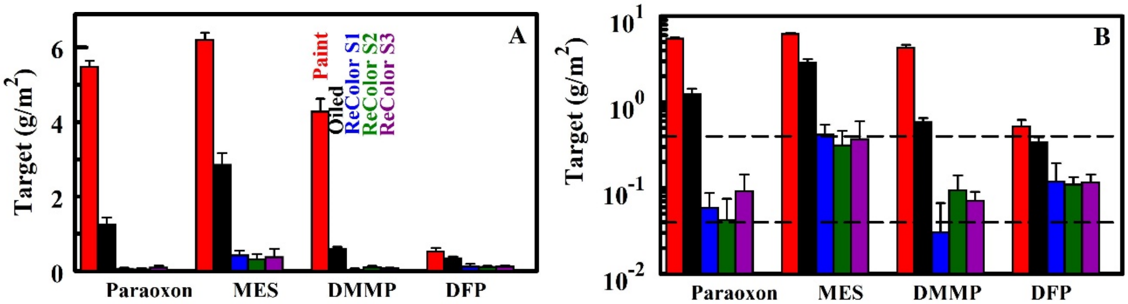


Fig. 7 — Target retention by coupons following treatment with an air stream and rinsing with soapy water: paint only (red) Fomblin Y oiled coupon (black); ReColor S1 (blue); ReColor S2 (green); and ReColor S3 (purple). Data is presented on both linear and logarithmic scales.

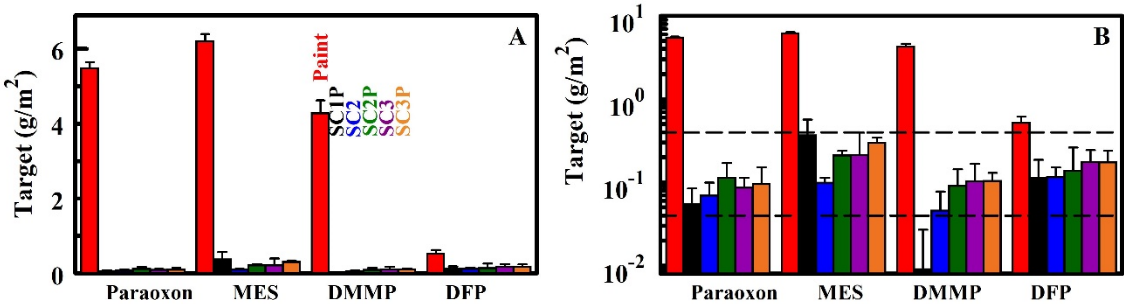


Fig. 8 — Target retention by coupons following treatment with an air stream and rinsing with soapy water: paint only (red) SC1P (black); SC2 (blue); SC2P (green); SC3 (purple); SC3P (orange). Data is presented on both linear and logarithmic scales.

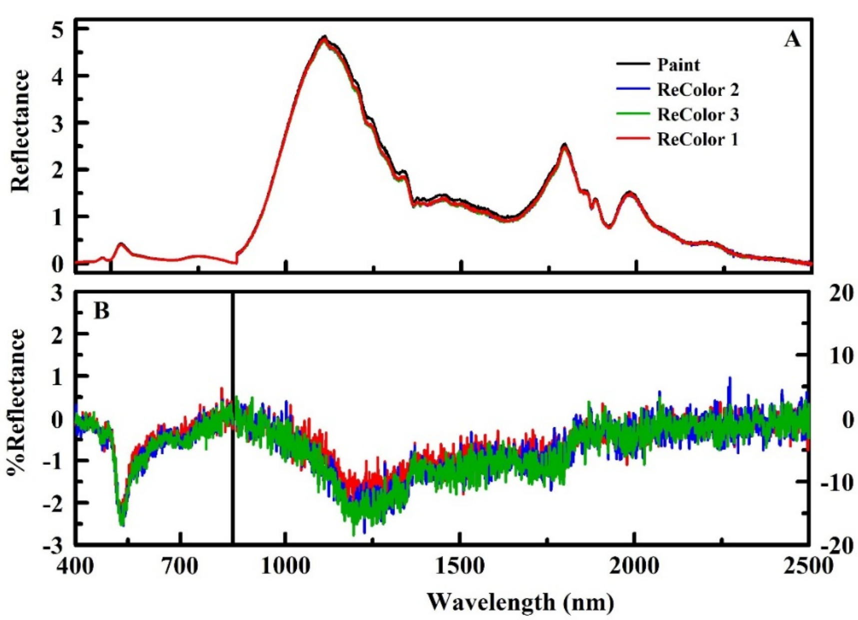


Fig. 9 — Reflectance spectra of the paint only coupon (black) compared to ReColor 1 (red); ReColor 2 (blue); and ReColor 3 (green). Data is presented in instrument units (A) and as a percentage of the paint only reflectance.

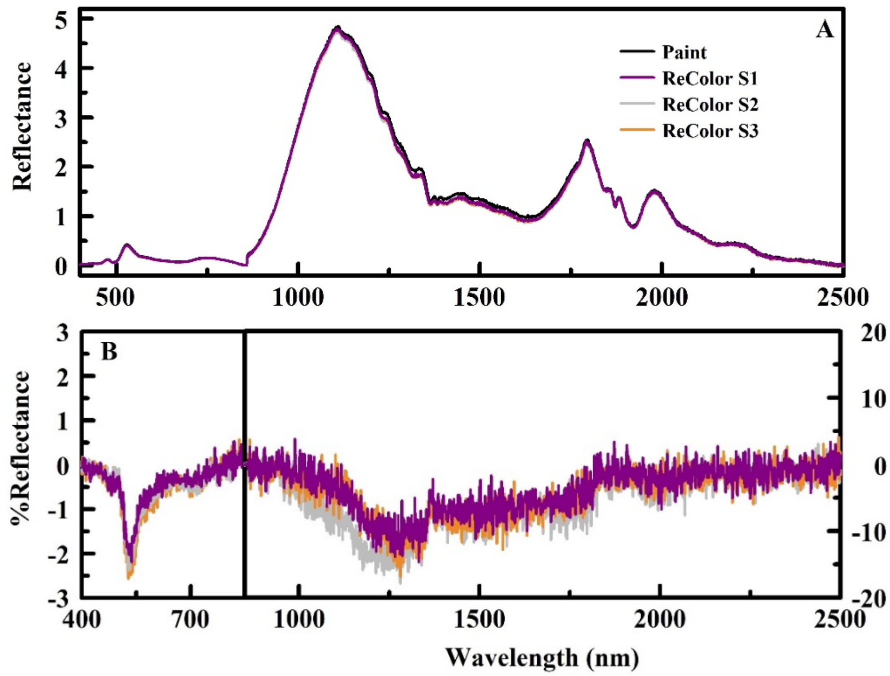


Fig. 10 — Reflectance spectra of the paint only coupon (black) compared to ReColor S1 (purple); ReColor S2 (gray); and ReColor S3 (orange). Data is presented in instrument units (A) and as a percentage of the paint only reflectance.

CONCLUSIONS

While the surface energy noted for the ReColor treatment is higher than some of the better performing treatments evaluated under this effort, target retention by this treatment was similar to the most effective materials evaluated. The commercial availability of this treatment offers the advantages of a COTS technology. These are generally cheaper due to large quantity production, are more flexible for different types of applications, offer a shorter development to production cycle, and wide spread use will identify design defects sooner. Spectrophotometric analysis is provided here to illustrate the potential changes in UV/vis and infrared reflectance. The ReColor coatings do produce a wet look on the painted surfaces (Figure 2 and Appendices). The long term stability of the coatings should be more thoroughly evaluated.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Haewon Uhm (Rust-Oleum®) for her comments on the potential of Rust-Oleum® products. This research was sponsored by the Defense Threat Reduction Agency (DTRA, CB10125). J.D. Kushto was supported through the NRL/ASEE Science and Engineering Apprentice Program (SEAP) during the summer of 2019.

REFERENCES

1. White, B., Moore, M., and Malanoski, A., "Bioinspired Surface Treatments for Improved Decontamination: Commercial Products," US Naval Research Laboratory, Washington, DC, **2017**; NRL/MR/6930-17,9736.
2. Lalain, T., Mantooth, B., Shue, M., Pusey, S., and Wylie, D., "Chemical Contaminant and Decontaminant Test Methodology Source Document," US Army RDEC, Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD, **2012**; ECBC-TR-980.

Appendix A

RECOLOR 1 IMAGES

Fig. A1 — Paraoxon on ReColor 1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

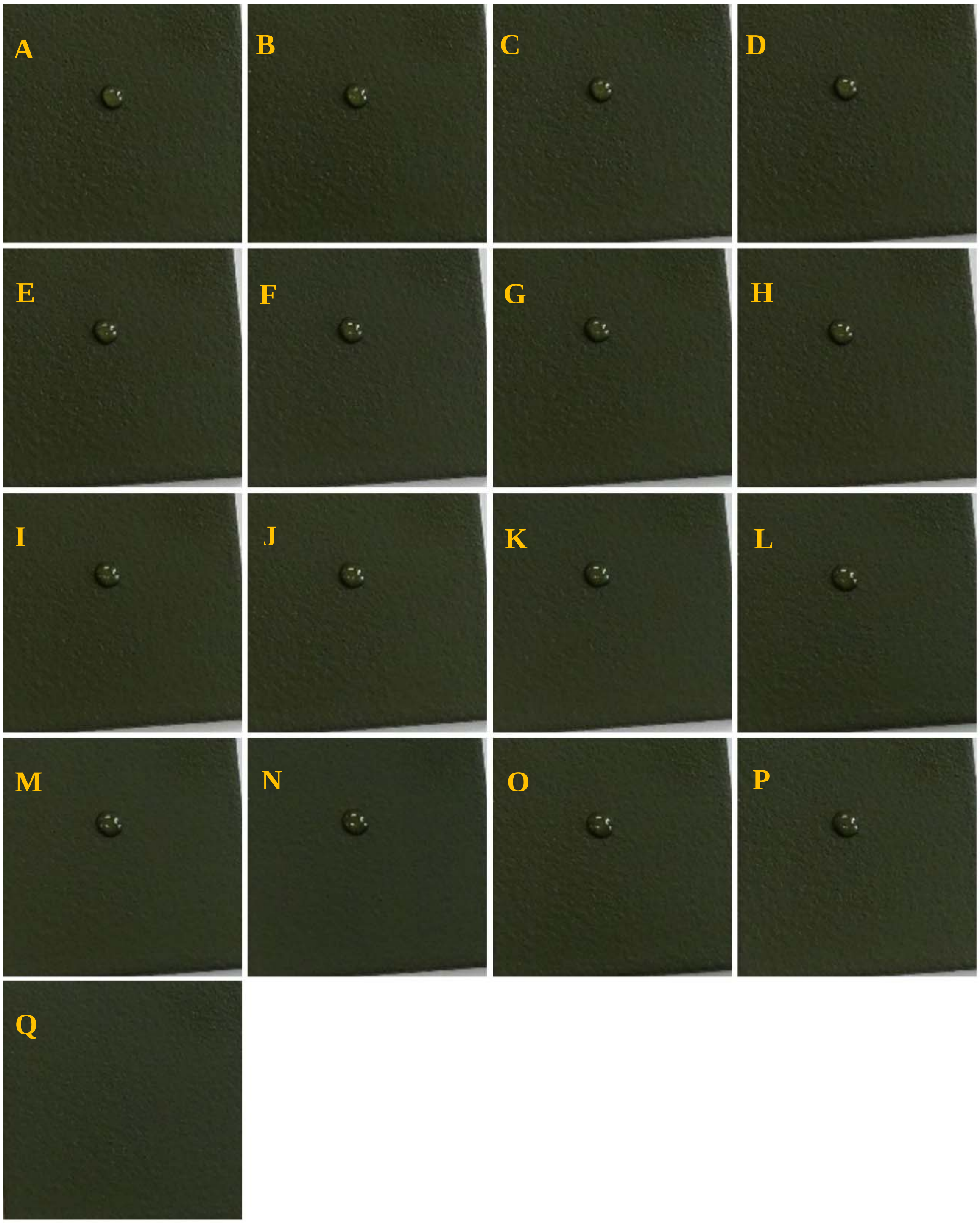


Fig. A2 — MES on ReColor 1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

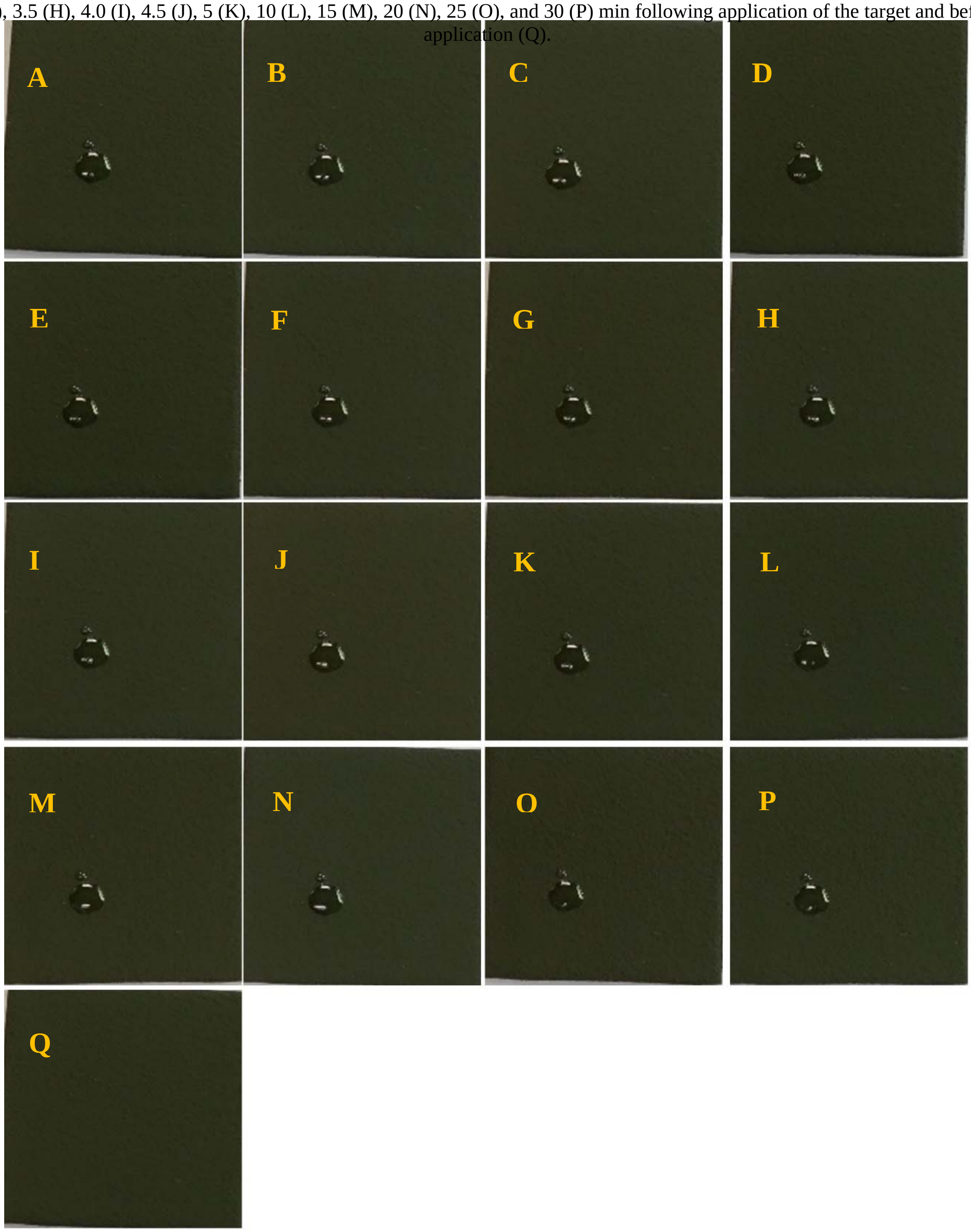
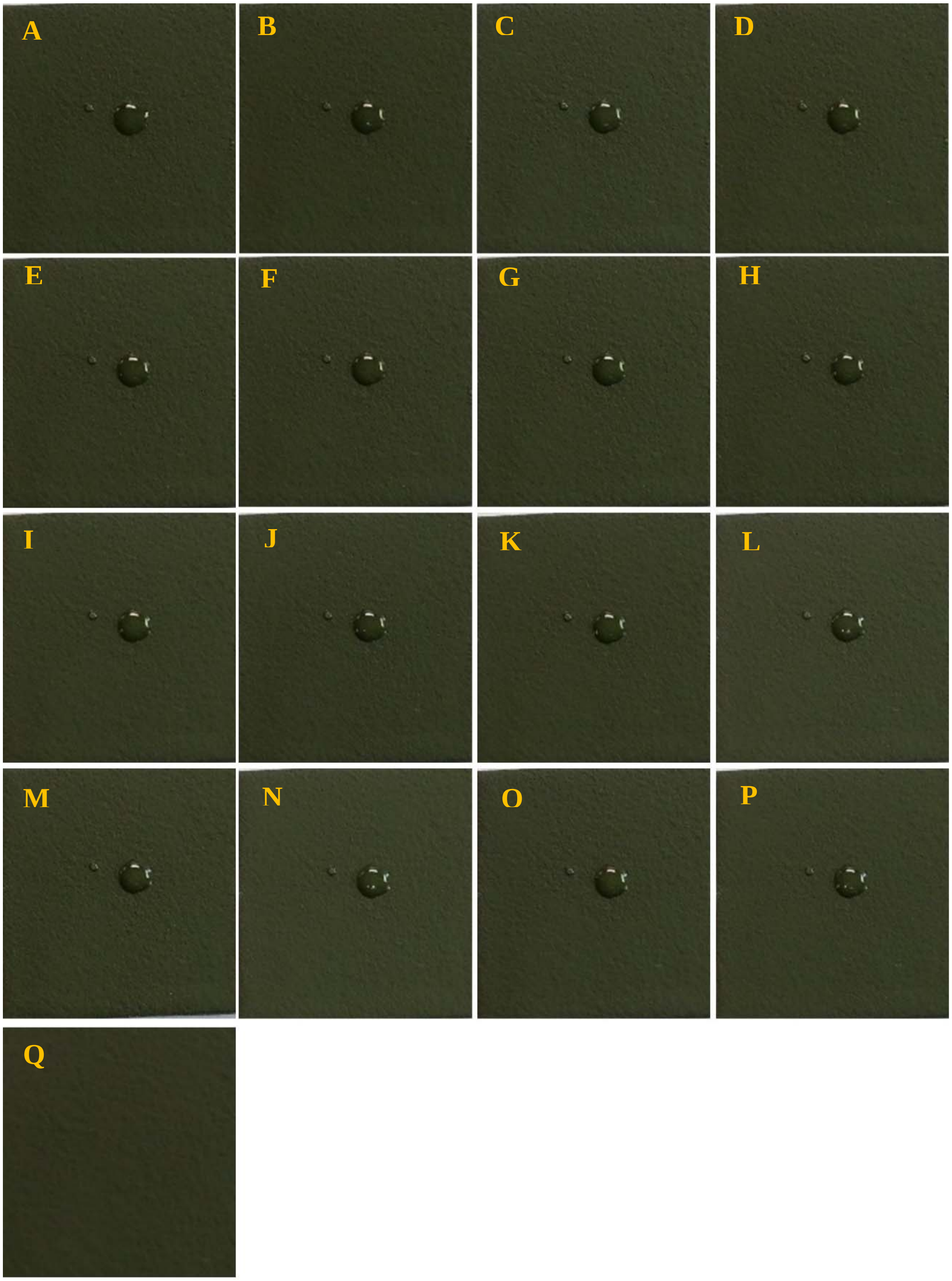


Fig. A3 — DMMP on ReColor 1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix B

RECOLOR 2 IMAGES

Fig. B1 — Paraoxon on ReColor 2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

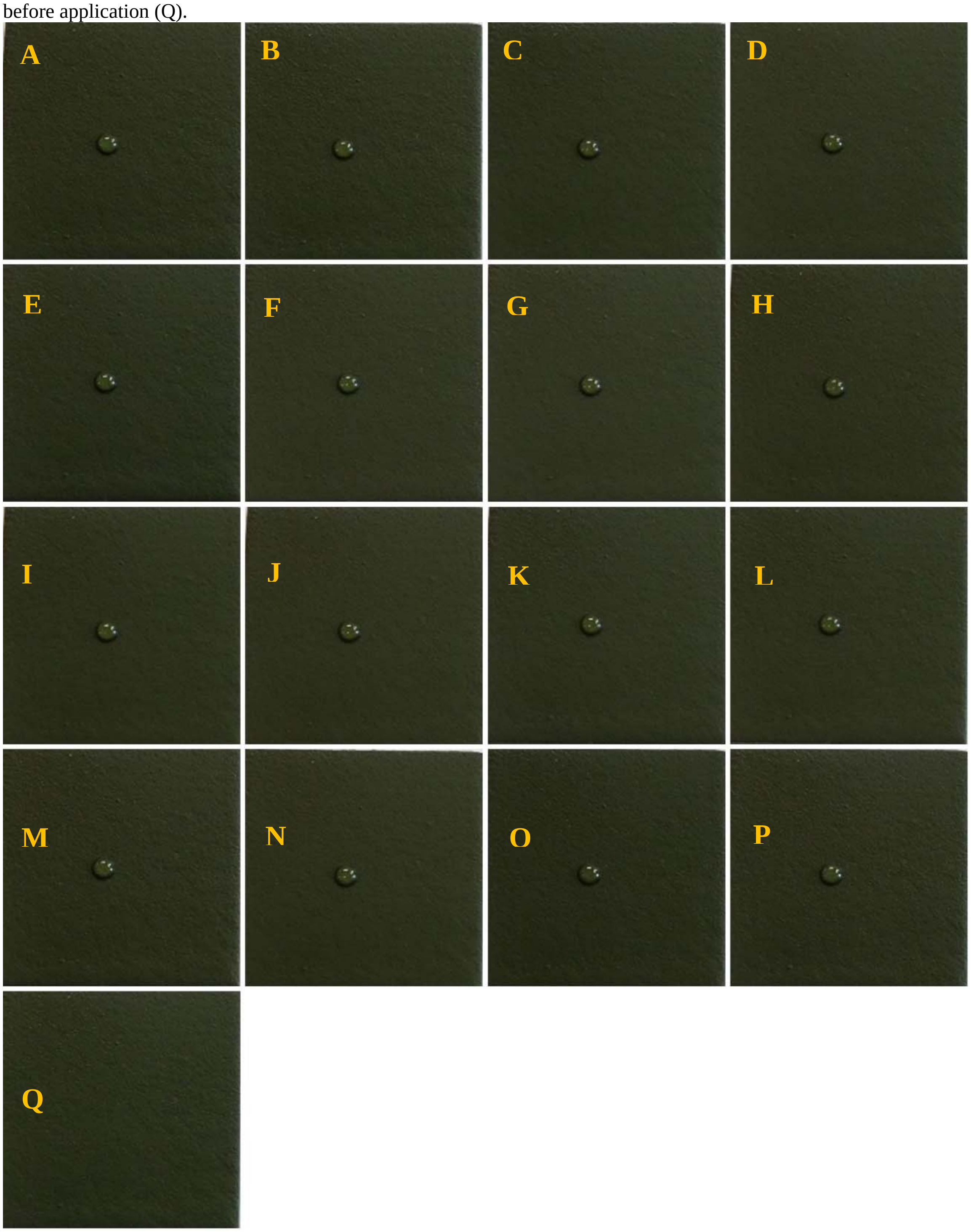


Fig. B2 — MES on ReColor 2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

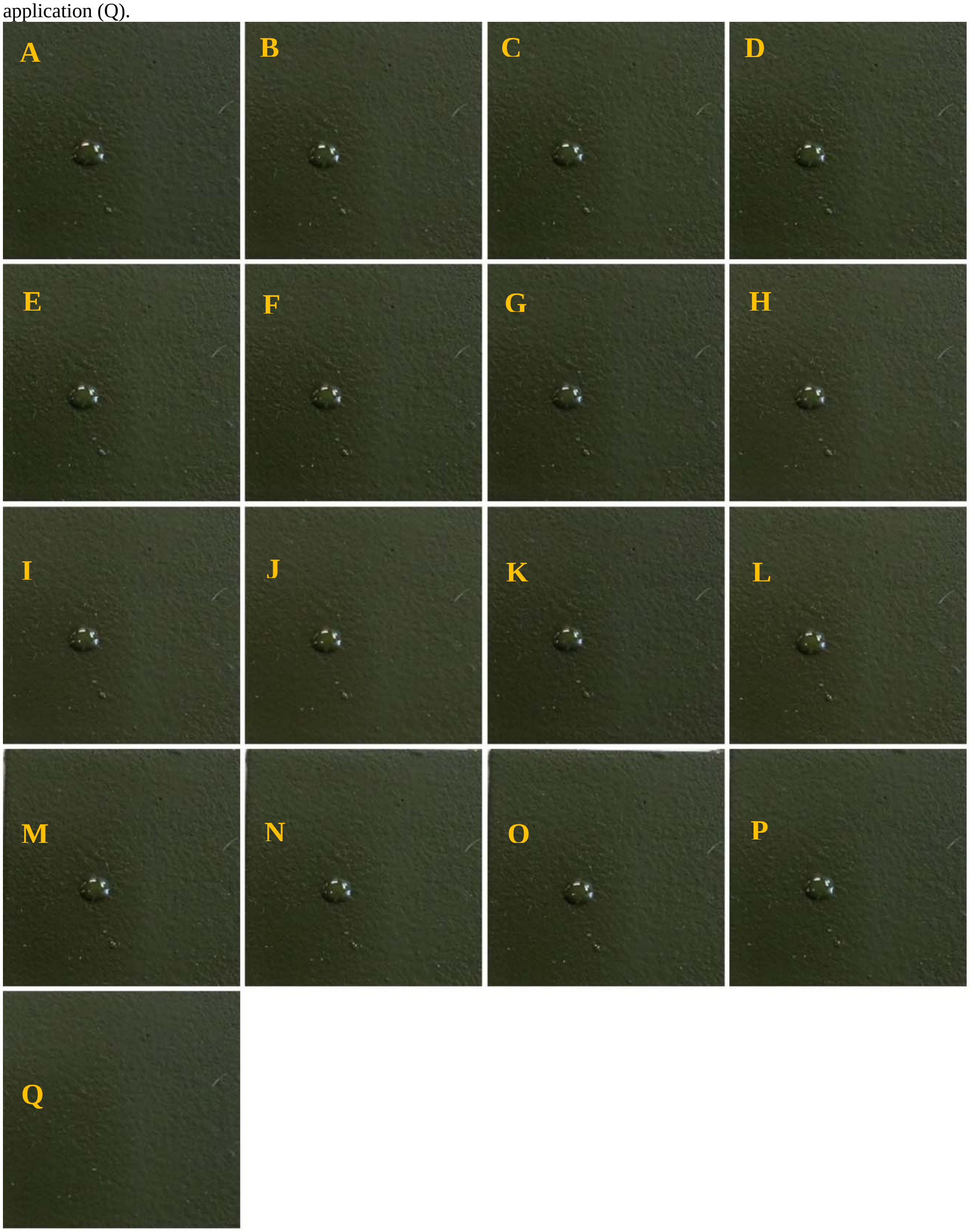
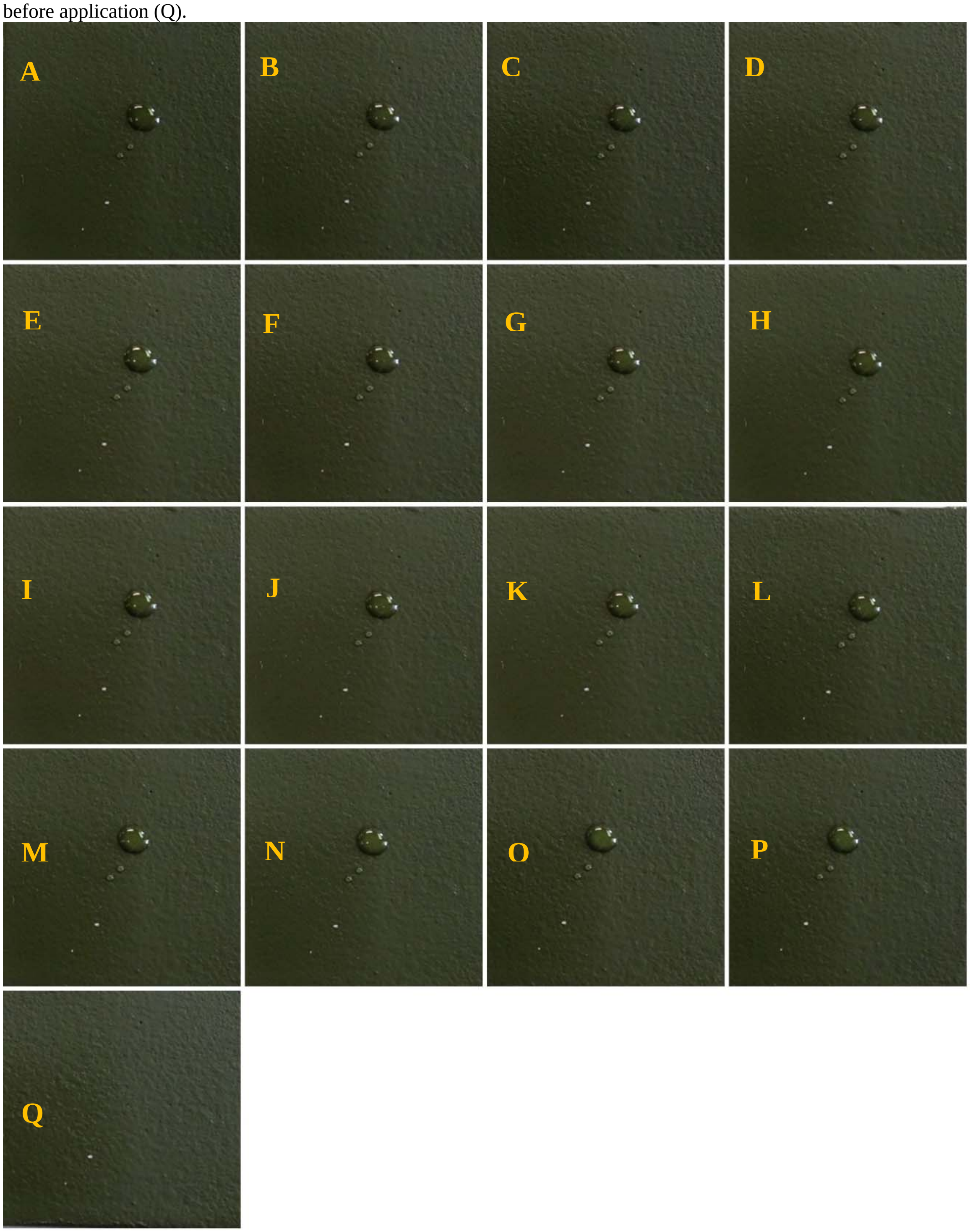


Fig. B3 — DMMP on ReColor 2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix C

RECOLOR 3 IMAGES

Fig. C1 — Paraoxon on ReColor 3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

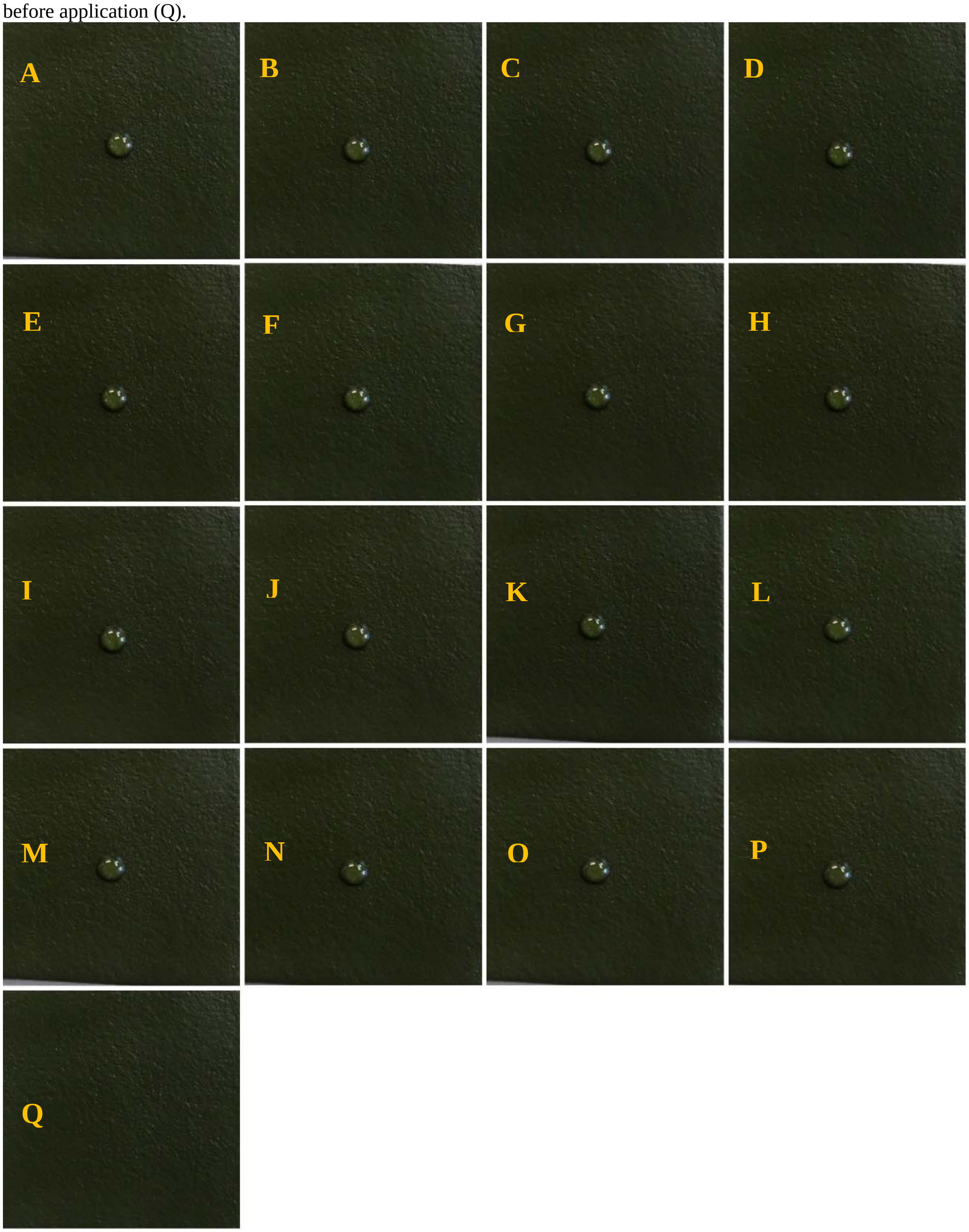


Fig. C2 — MES on ReColor 3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

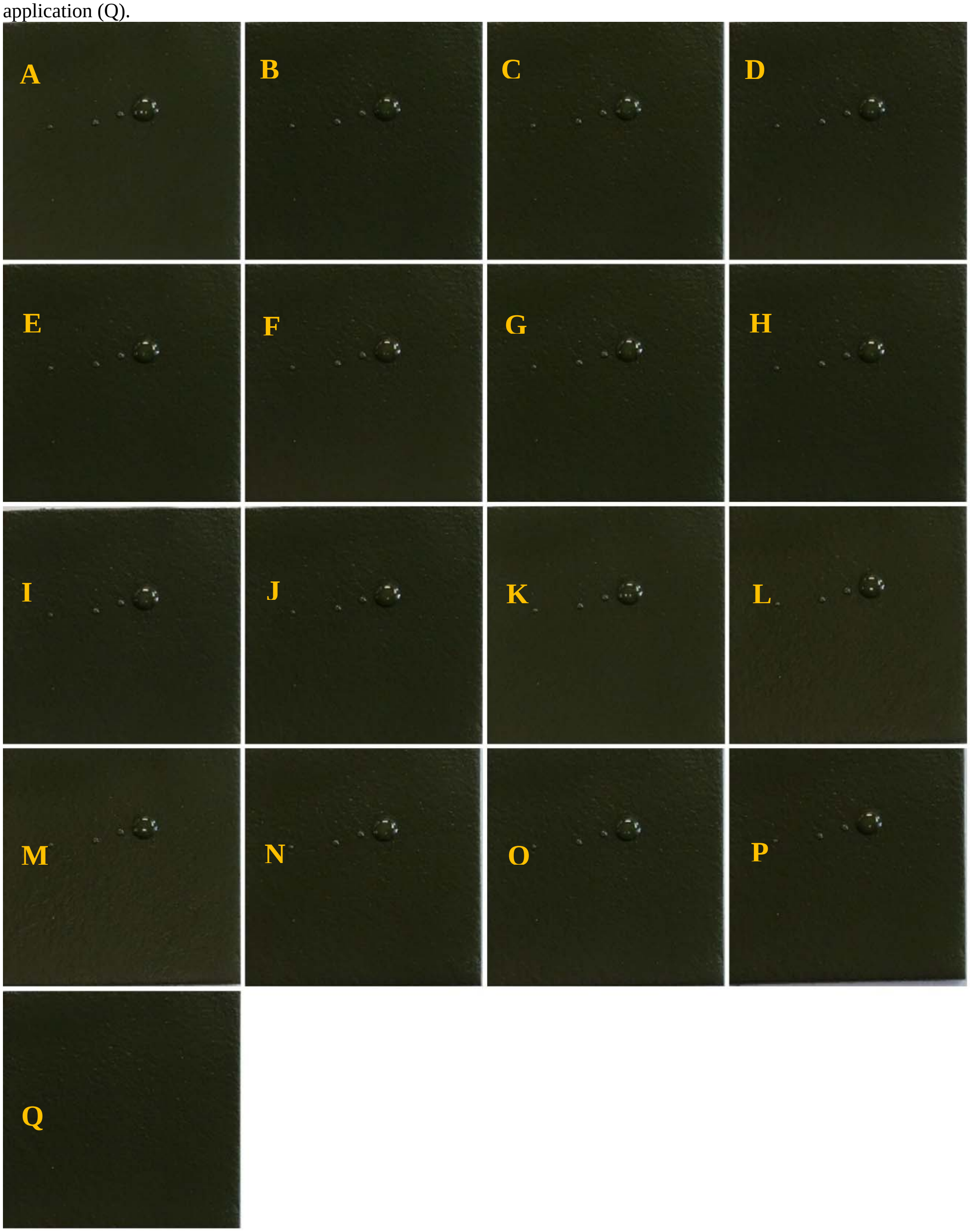
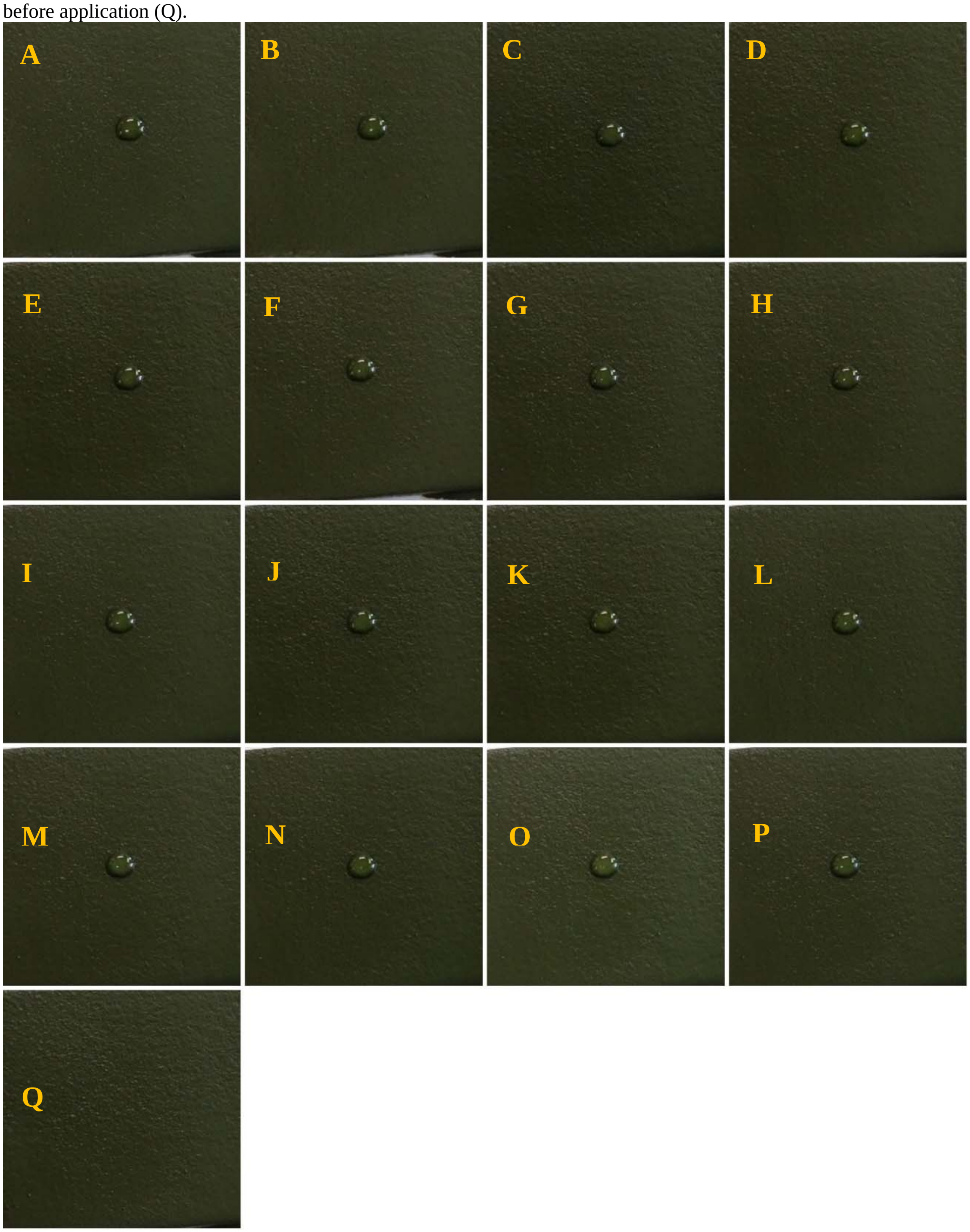


Fig. C3 — DMMP on ReColor 3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix D

RECOLOR S1 IMAGES

Fig. D1 — Paraoxon on ReColor S1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

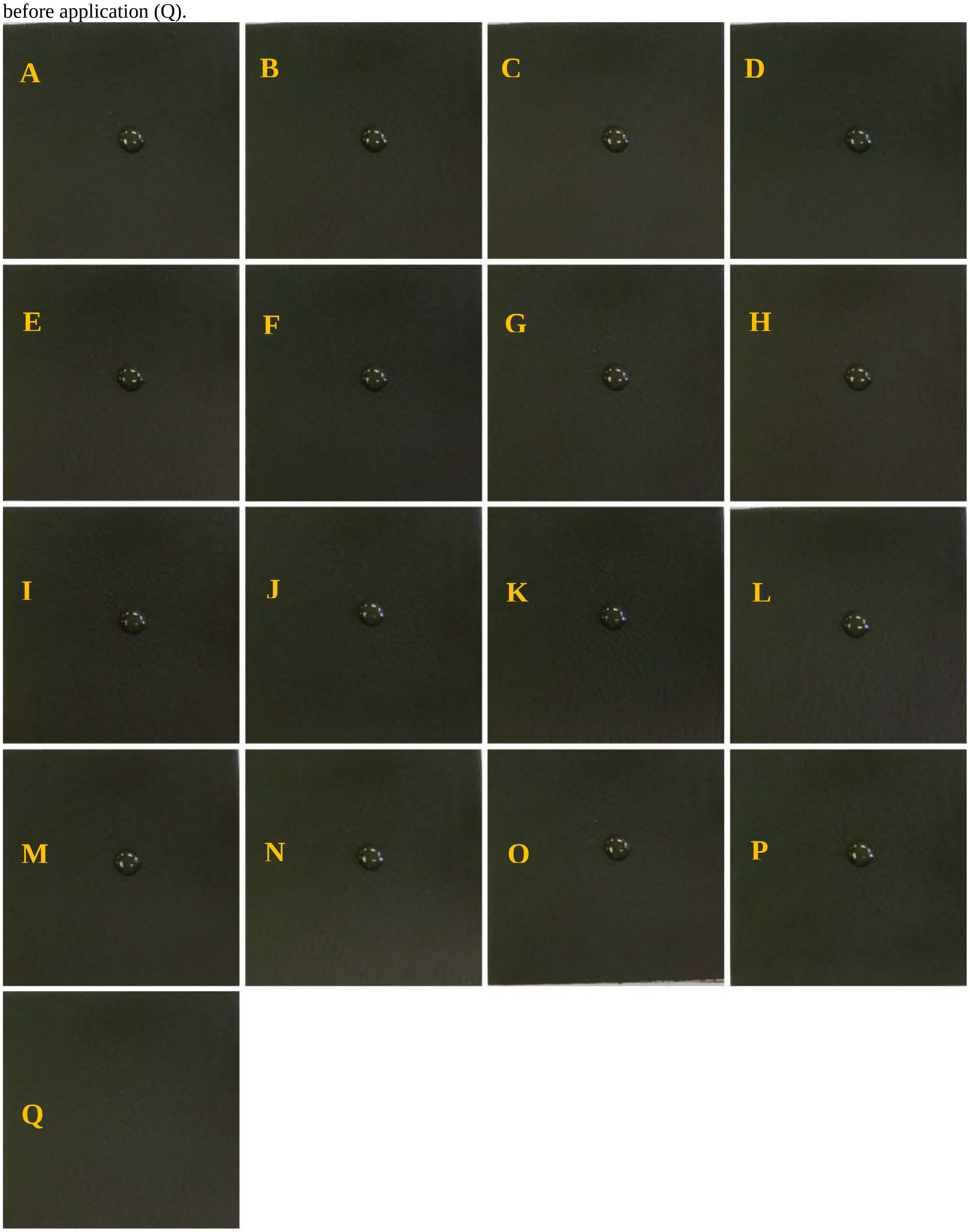


Fig. D2 — MES on ReColor S1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

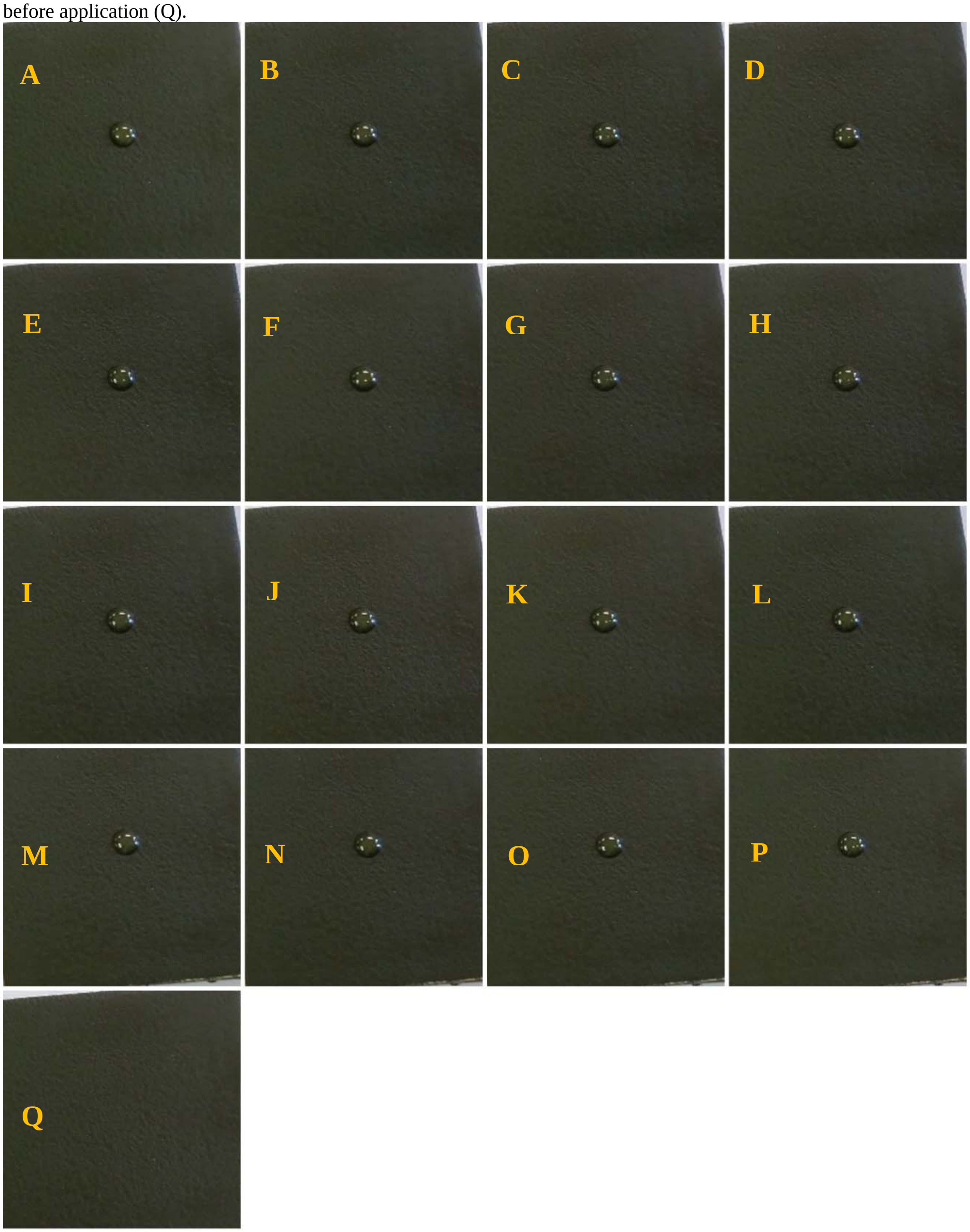
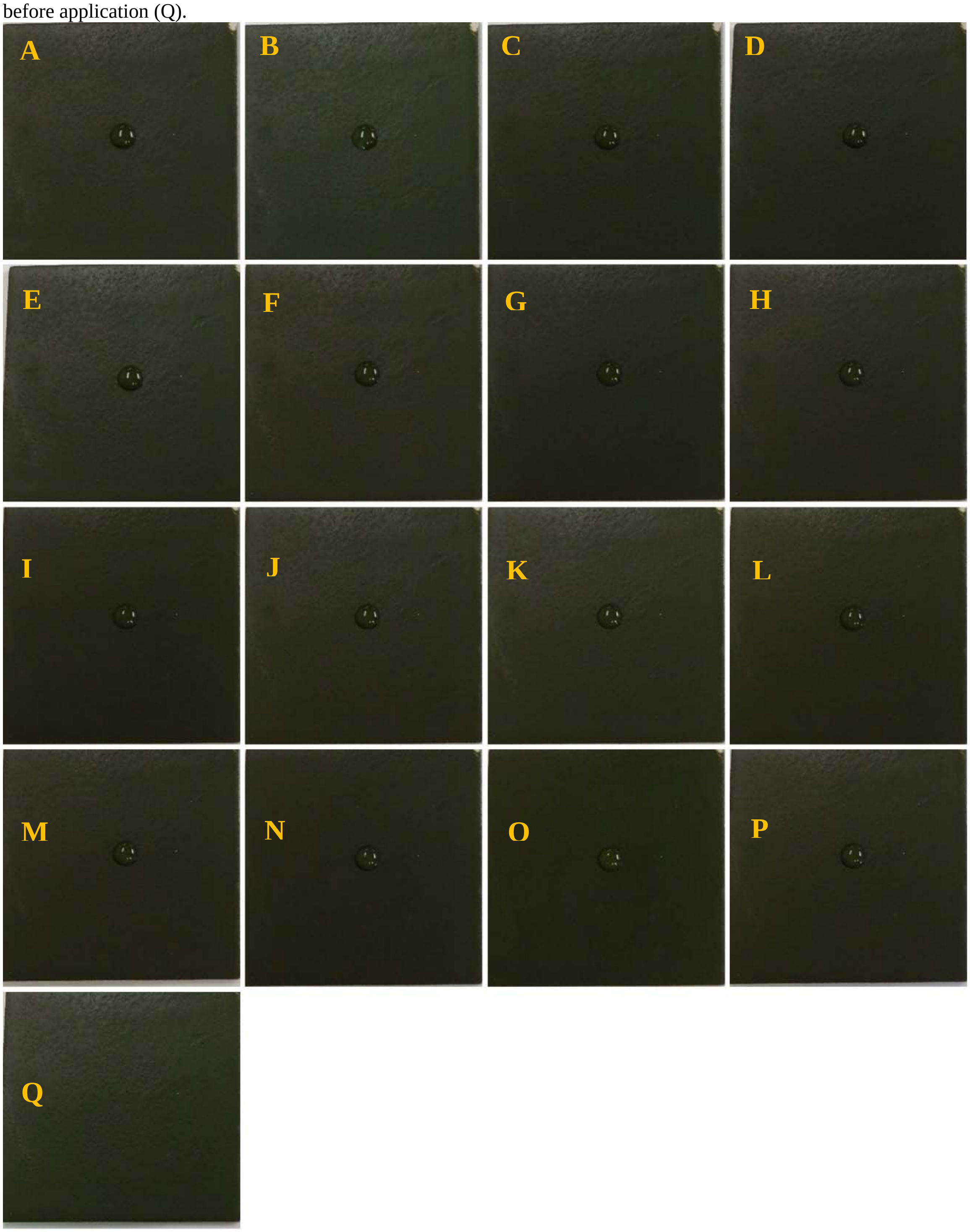


Fig. D3 — DMMP on ReColor S1. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix E

RECOLOR S2 IMAGES

Fig. E1 — Paraoxon on ReColor S2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

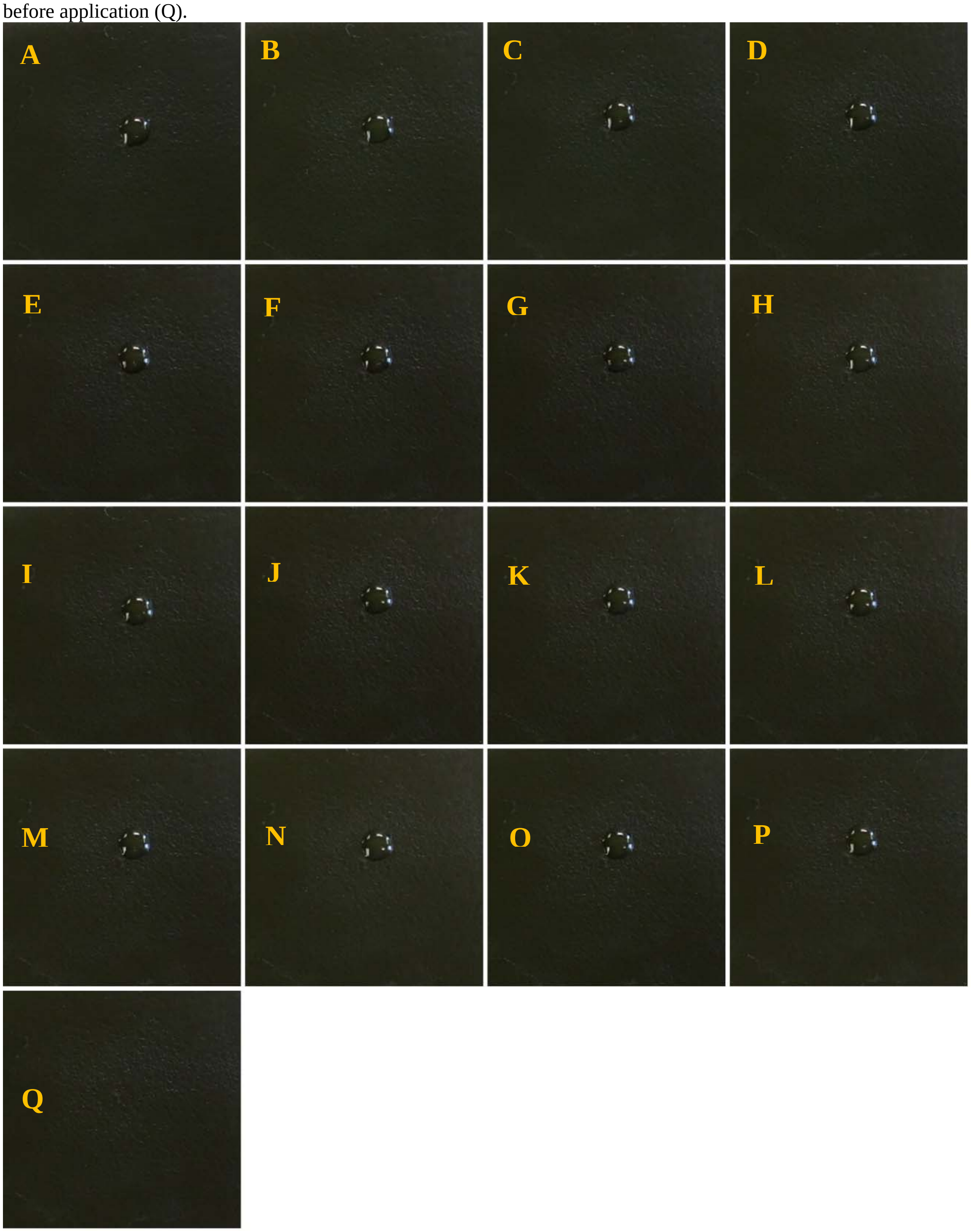


Fig. E2 — MES on ReColor S2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

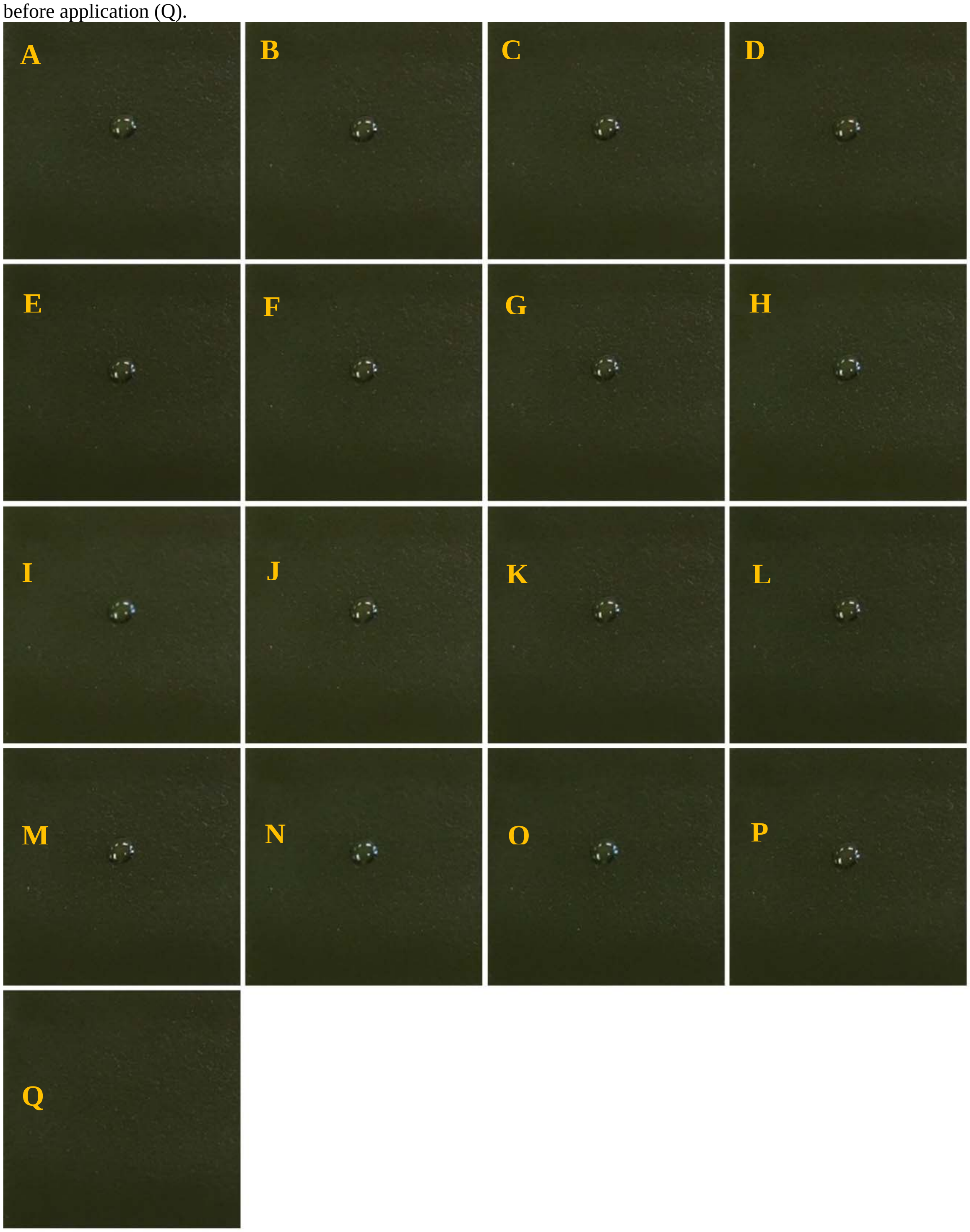
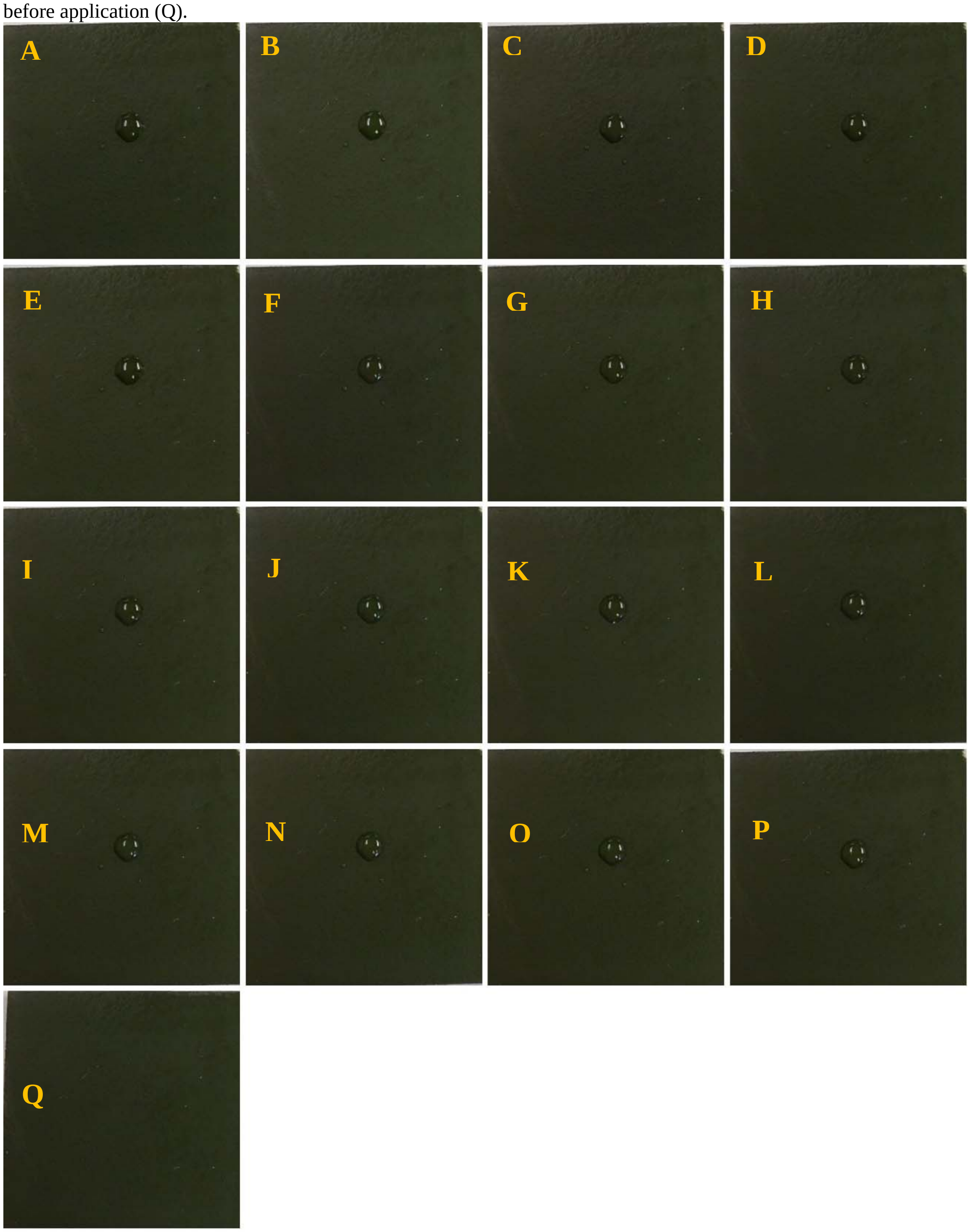


Fig. E3 — DMMP on ReColor S2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix F

RECOLOR S3 IMAGES

Fig. F1 — Paraoxon on ReColor S3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

Fig. F2 — MES on ReColor S3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

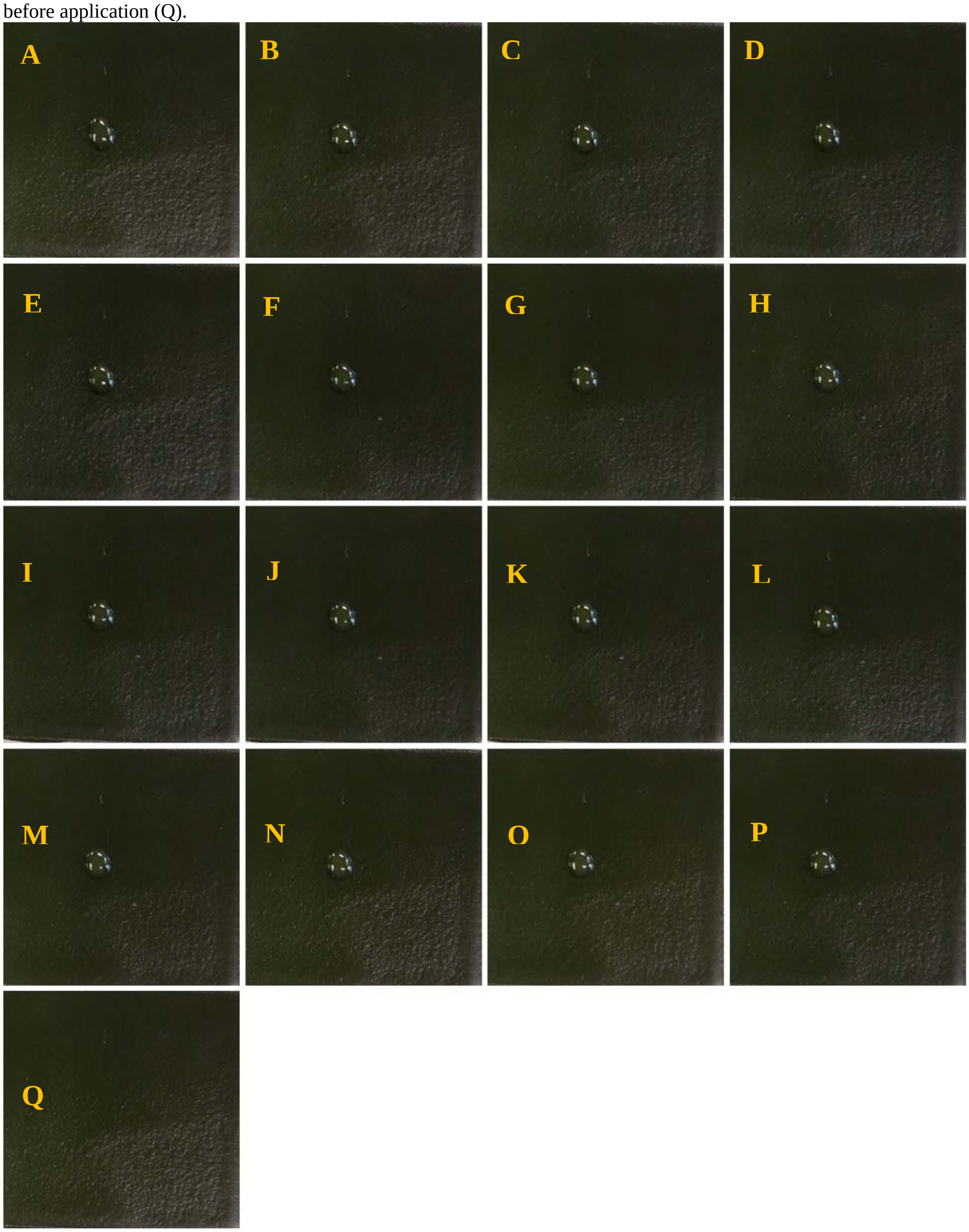
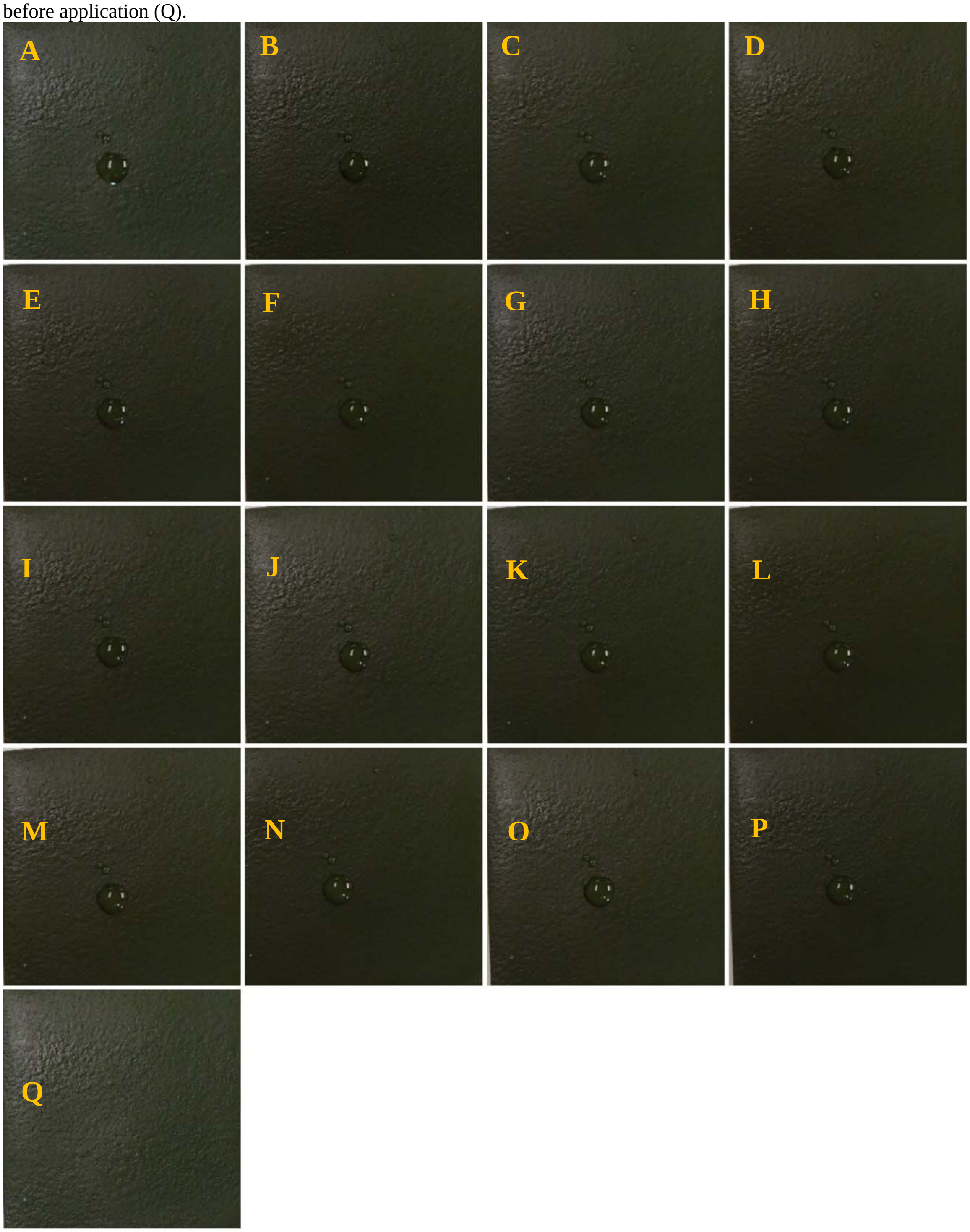


Fig. F3 — DMMP on ReColor S3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix G

RECOLOR SC1P IMAGES

Fig. G1 — Paraoxon on ReColor SC1P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

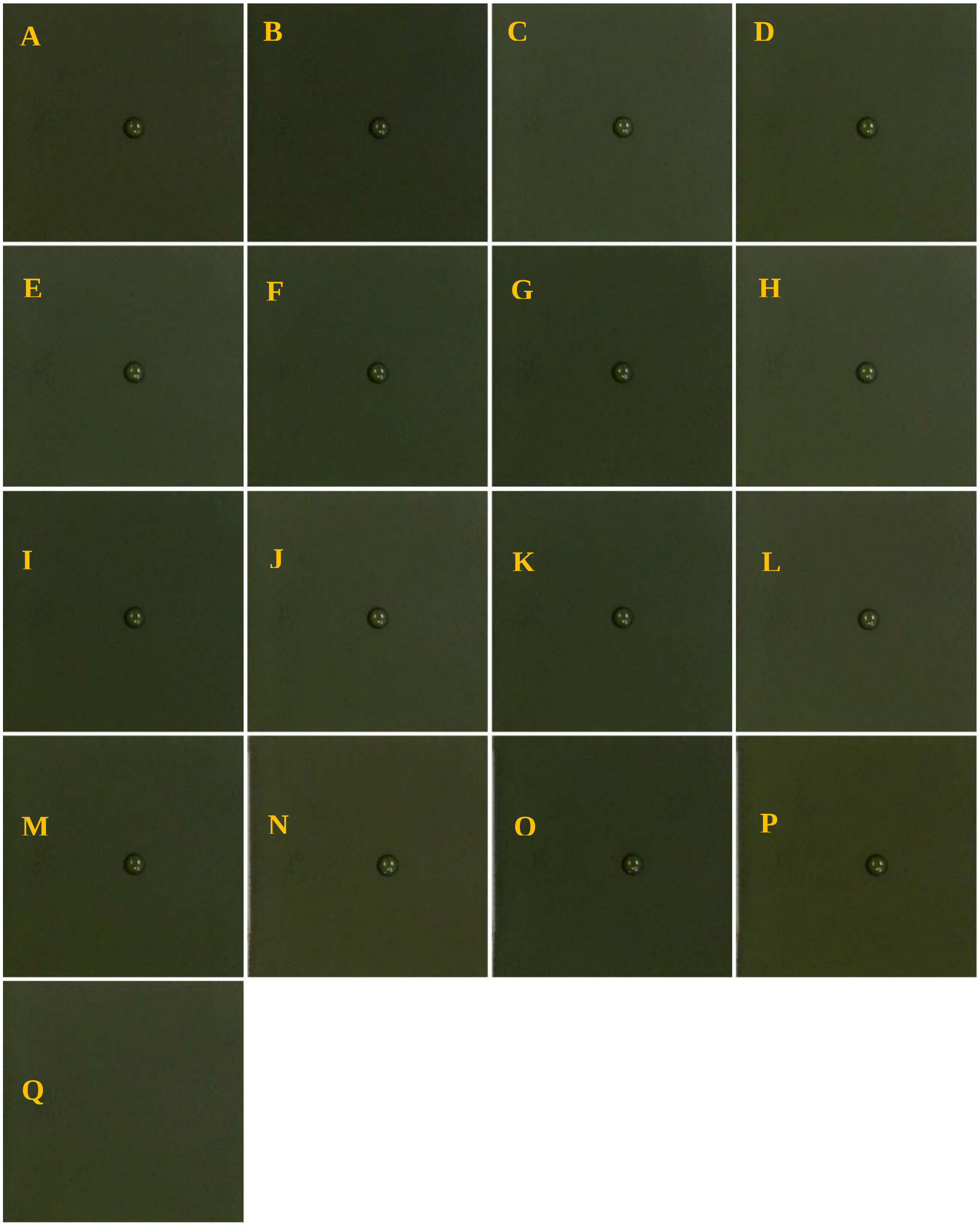


Fig. G2 — MES on ReColor SC1P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

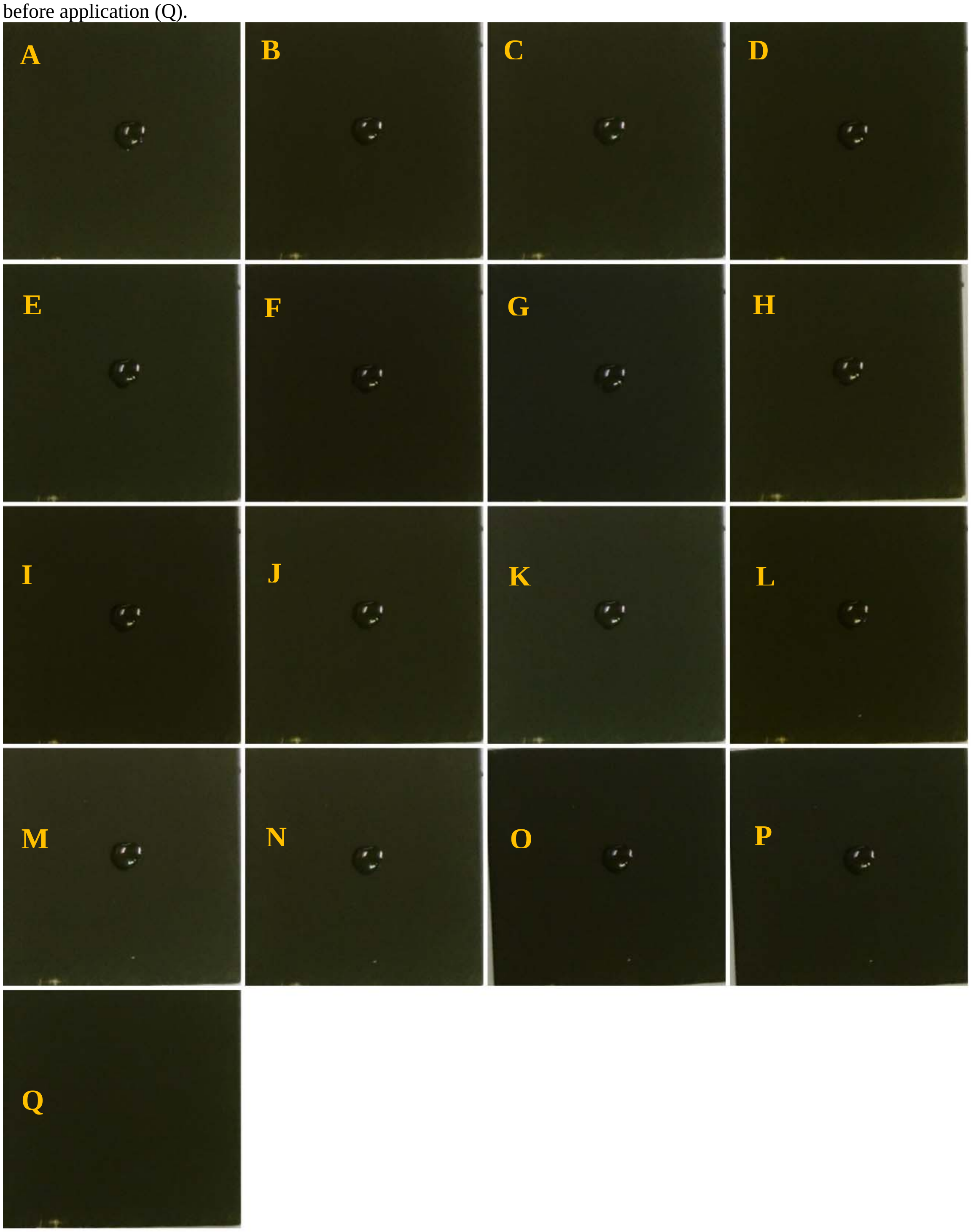
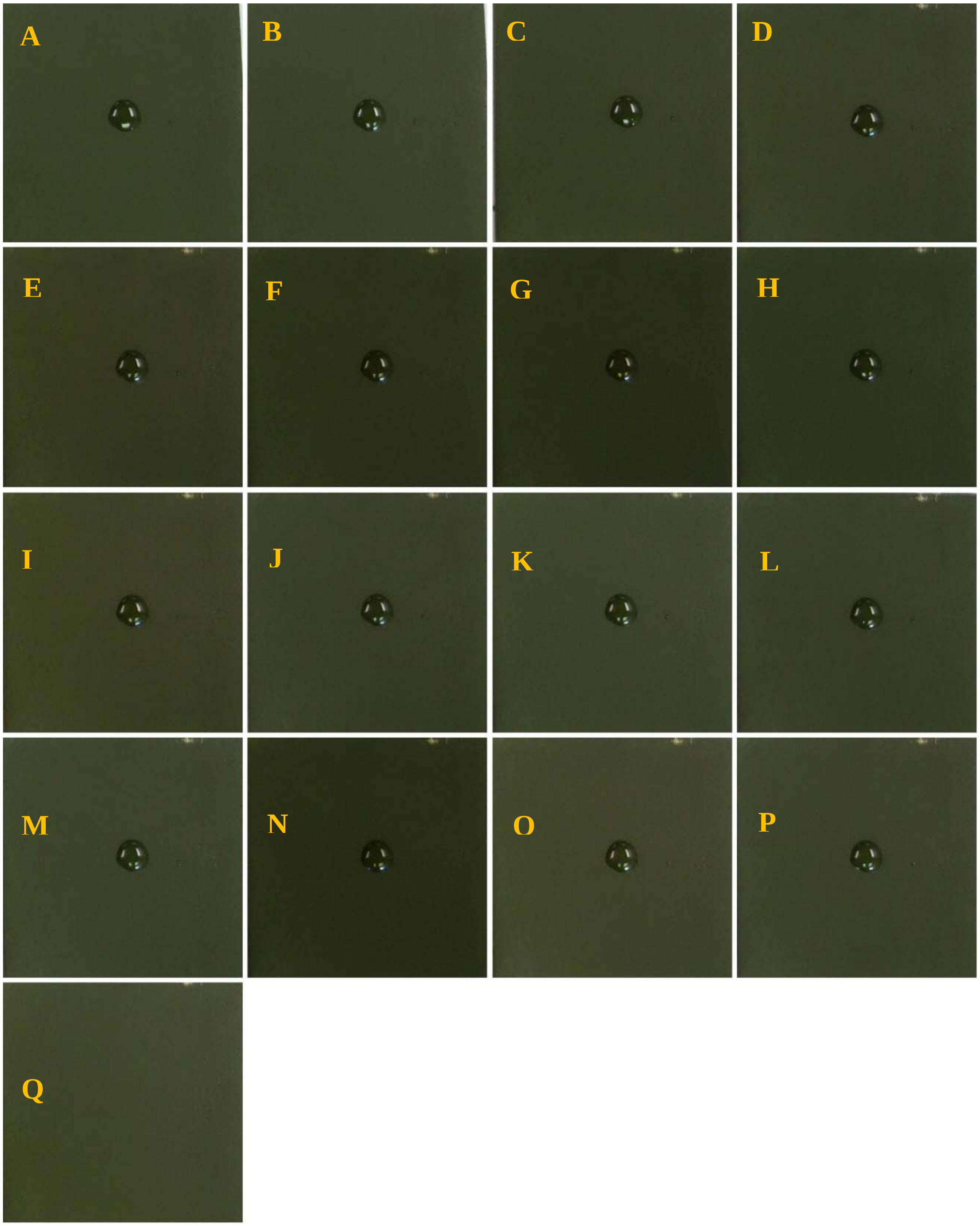


Fig. G3 — DMMP on ReColor SC1P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix H

RECOLOR SC2 IMAGES

Fig. H1 — Paraoxon on ReColor SC2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

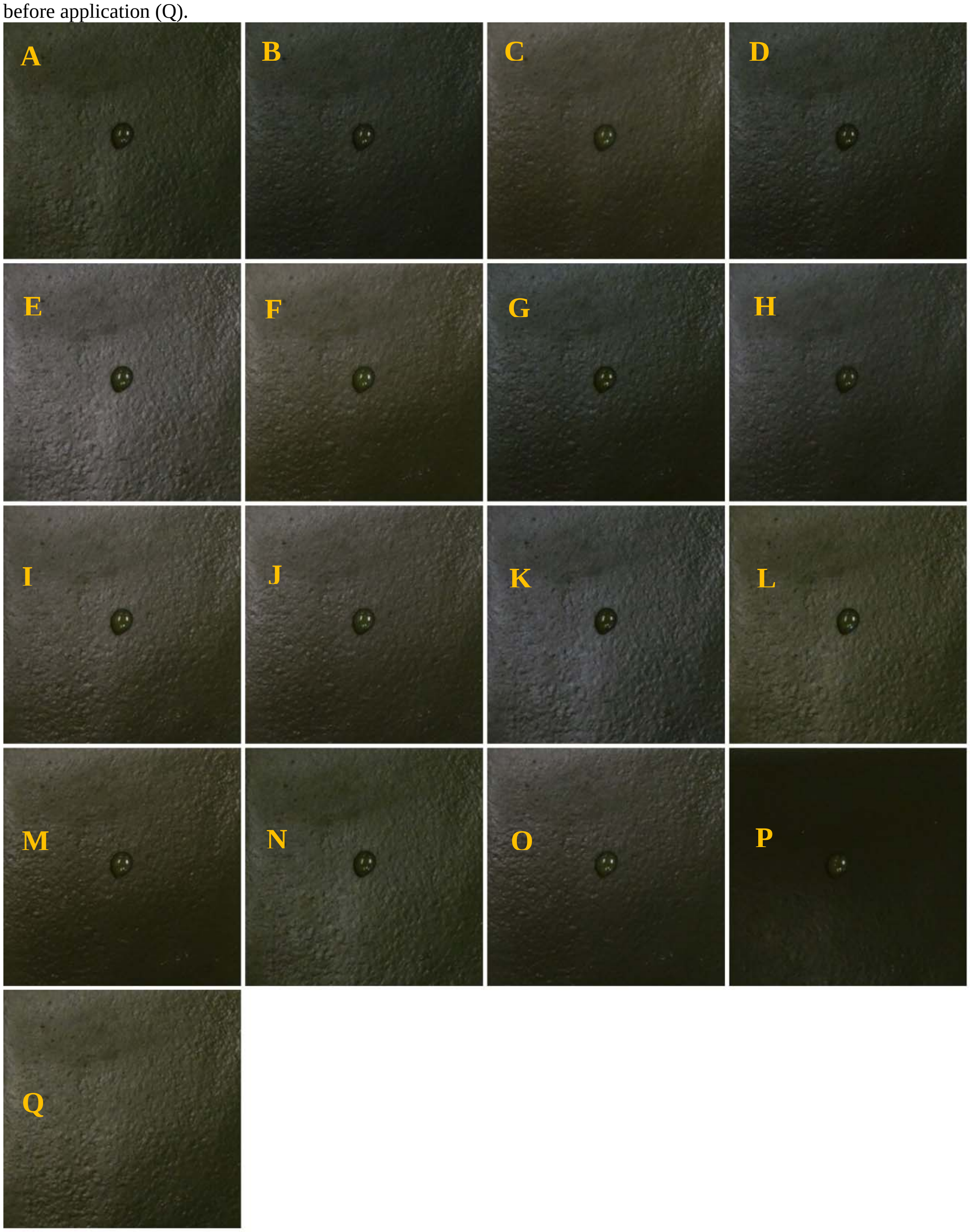


Fig. H2 — MES on ReColor SC2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

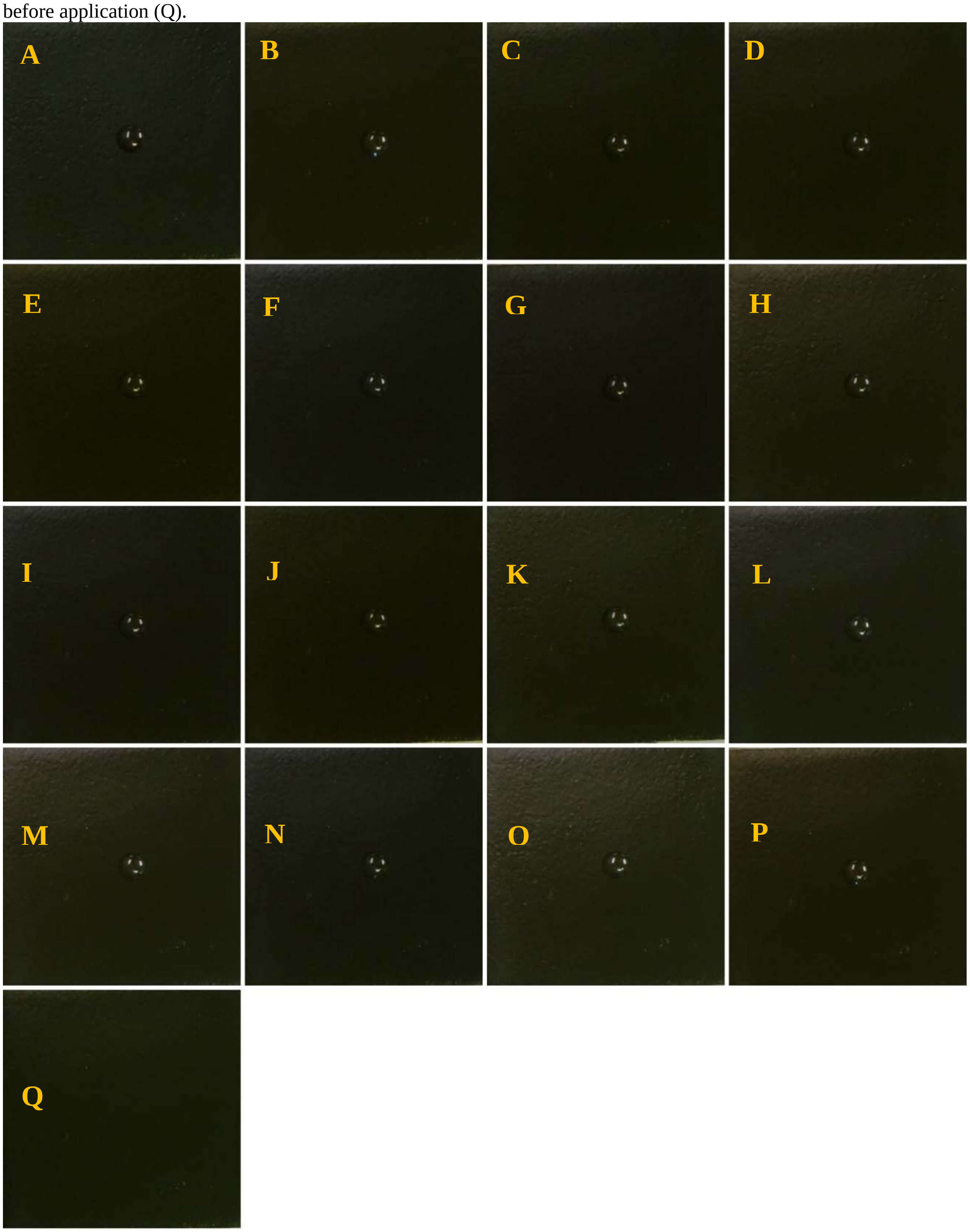
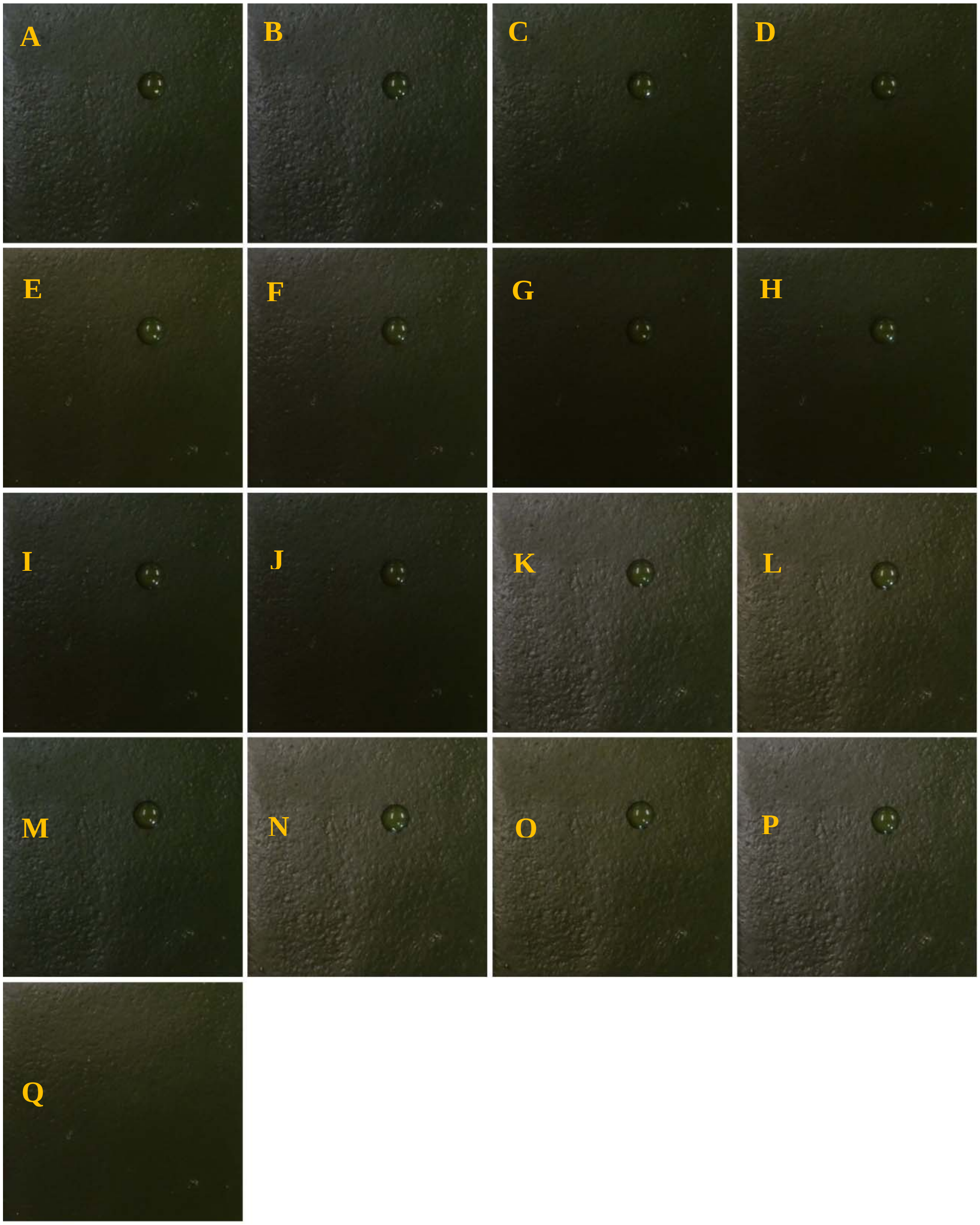


Fig. H3 — DMMP on ReColor SC2. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix I

RECOLOR SC2P IMAGES

Fig. I1 — Paraoxon on ReColor SC2P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

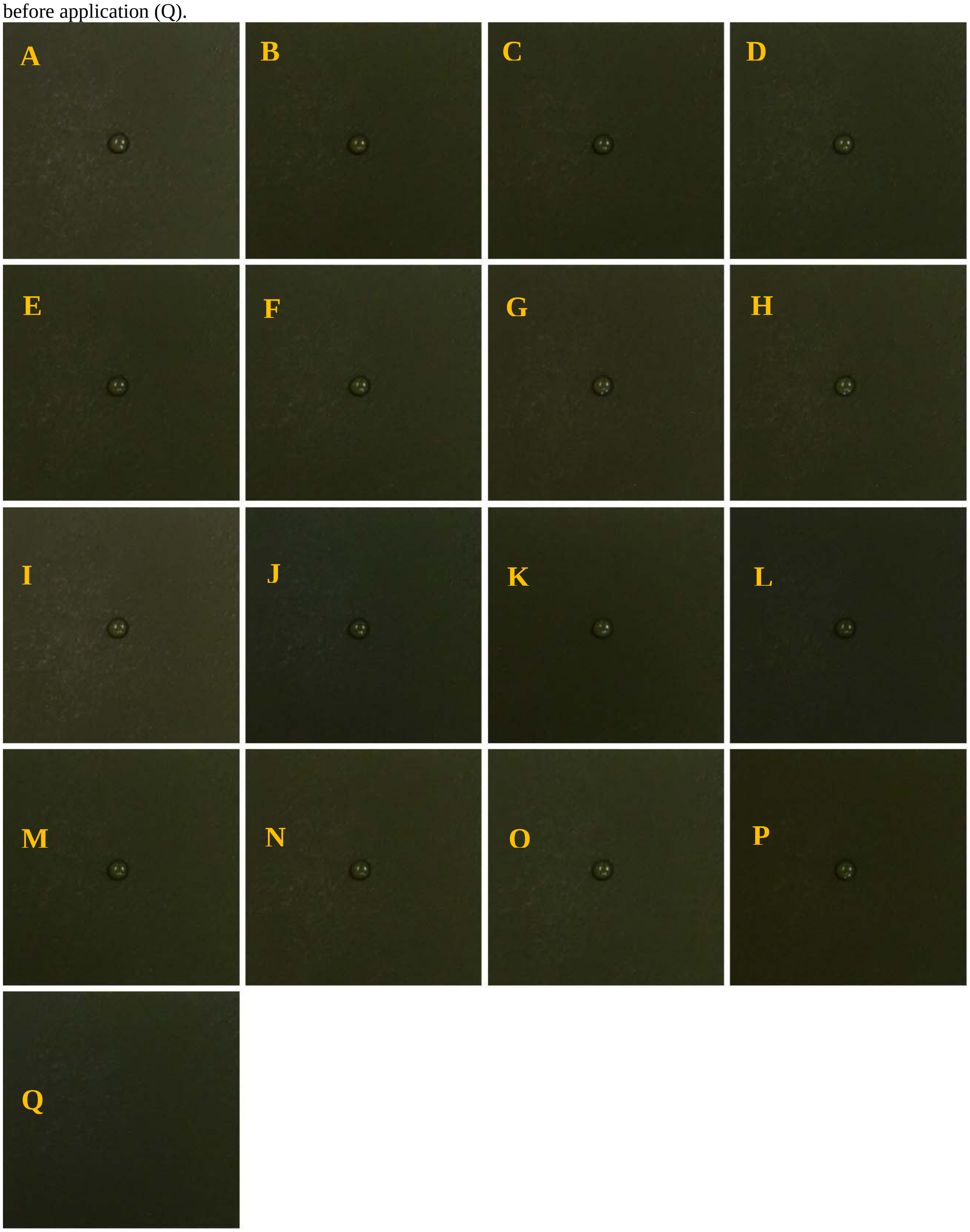


Fig. I2 — MES on ReColor SC2P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

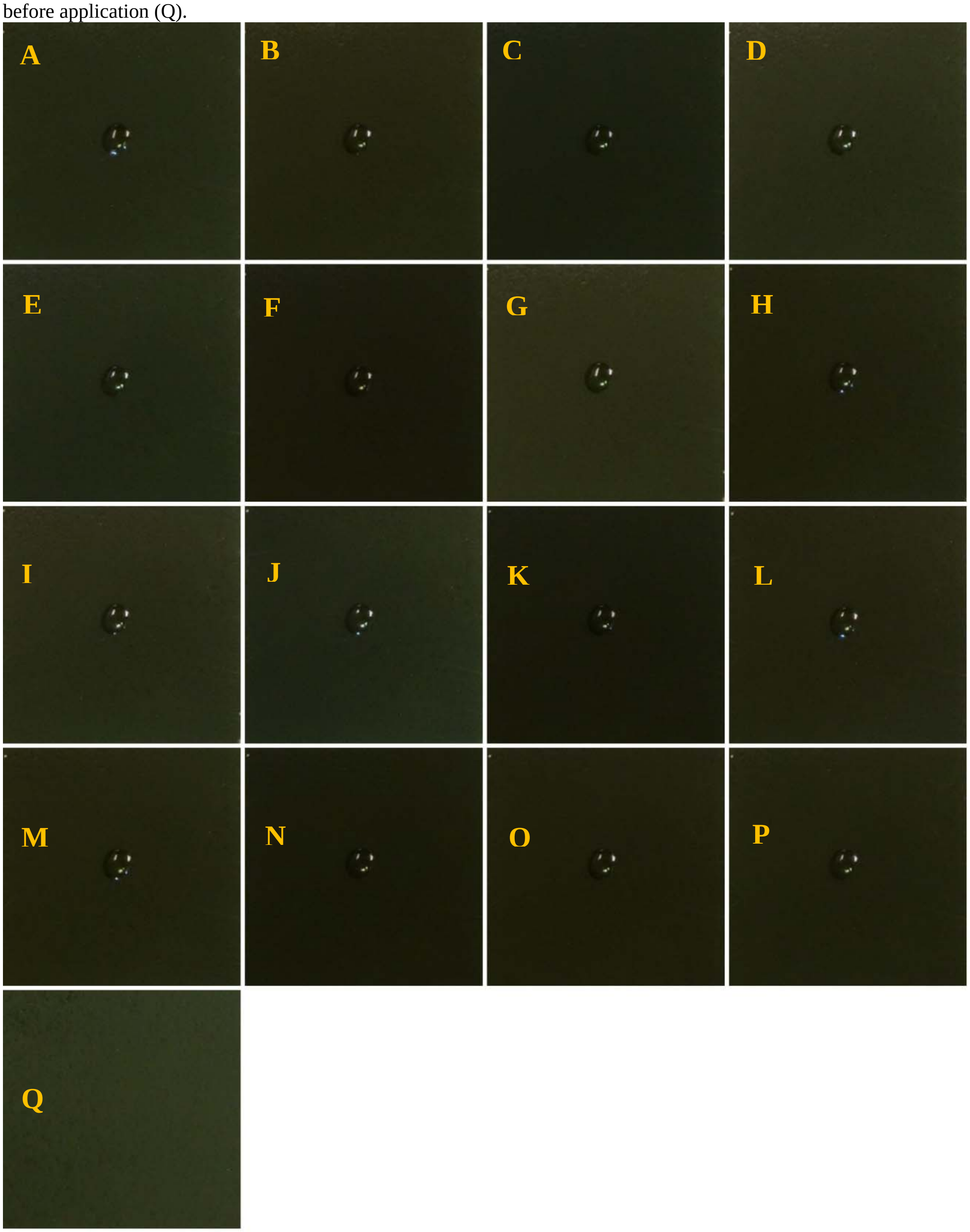
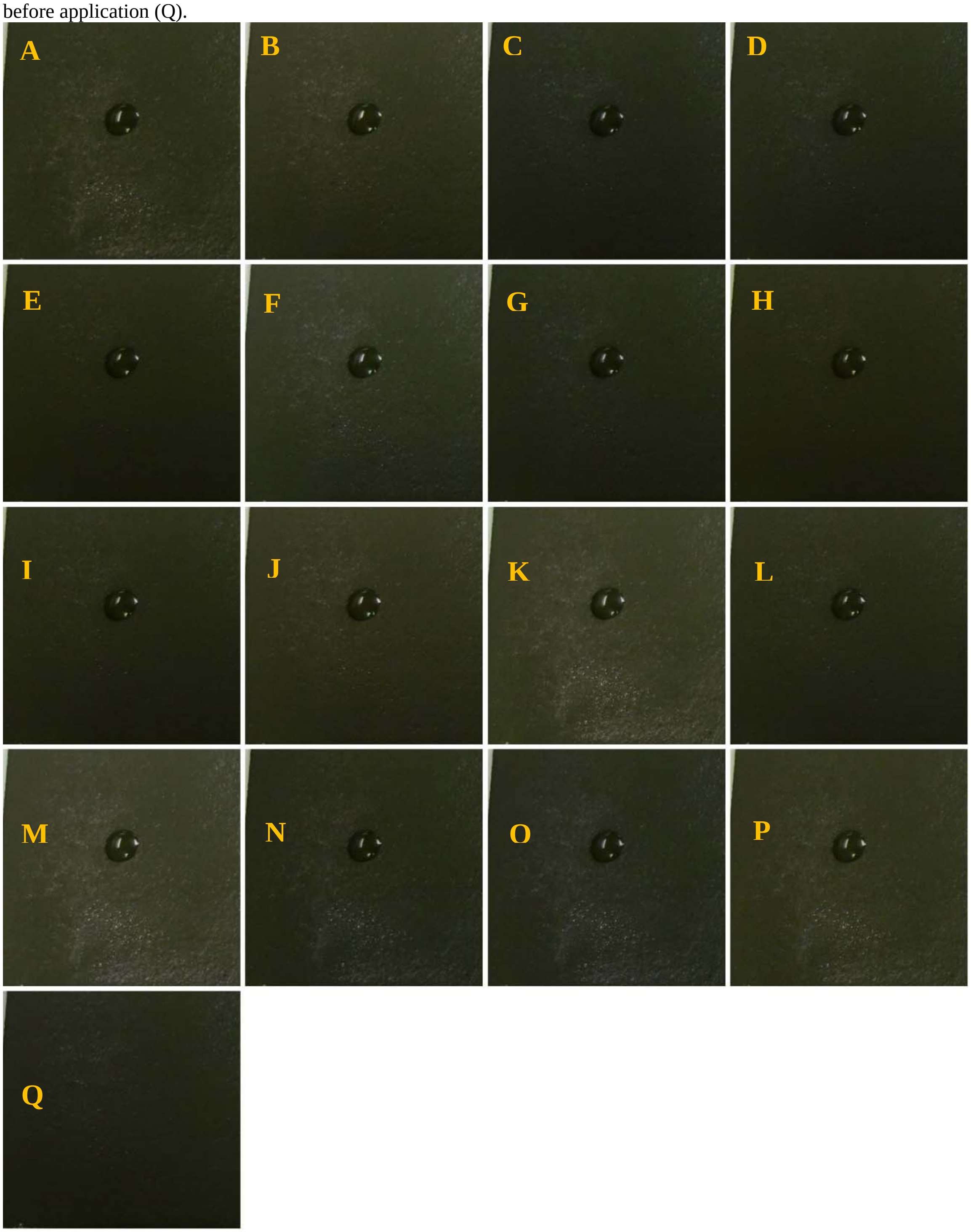


Fig. I3 — DMMP on ReColor SC2P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix J

RECOLOR SC3 IMAGES

Fig. J1 — Paraoxon on ReColor SC3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

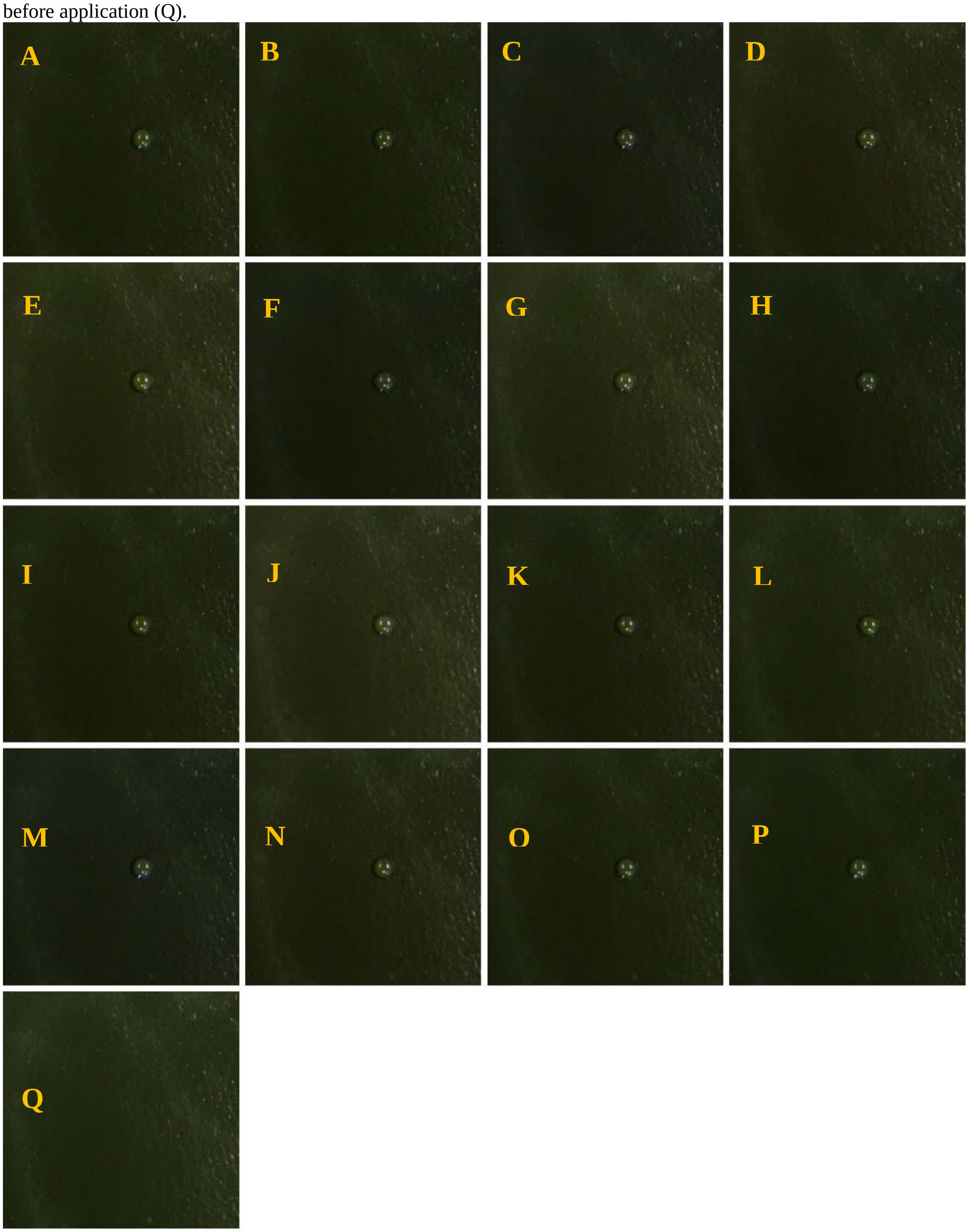


Fig. J2 — MES on ReColor SC3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

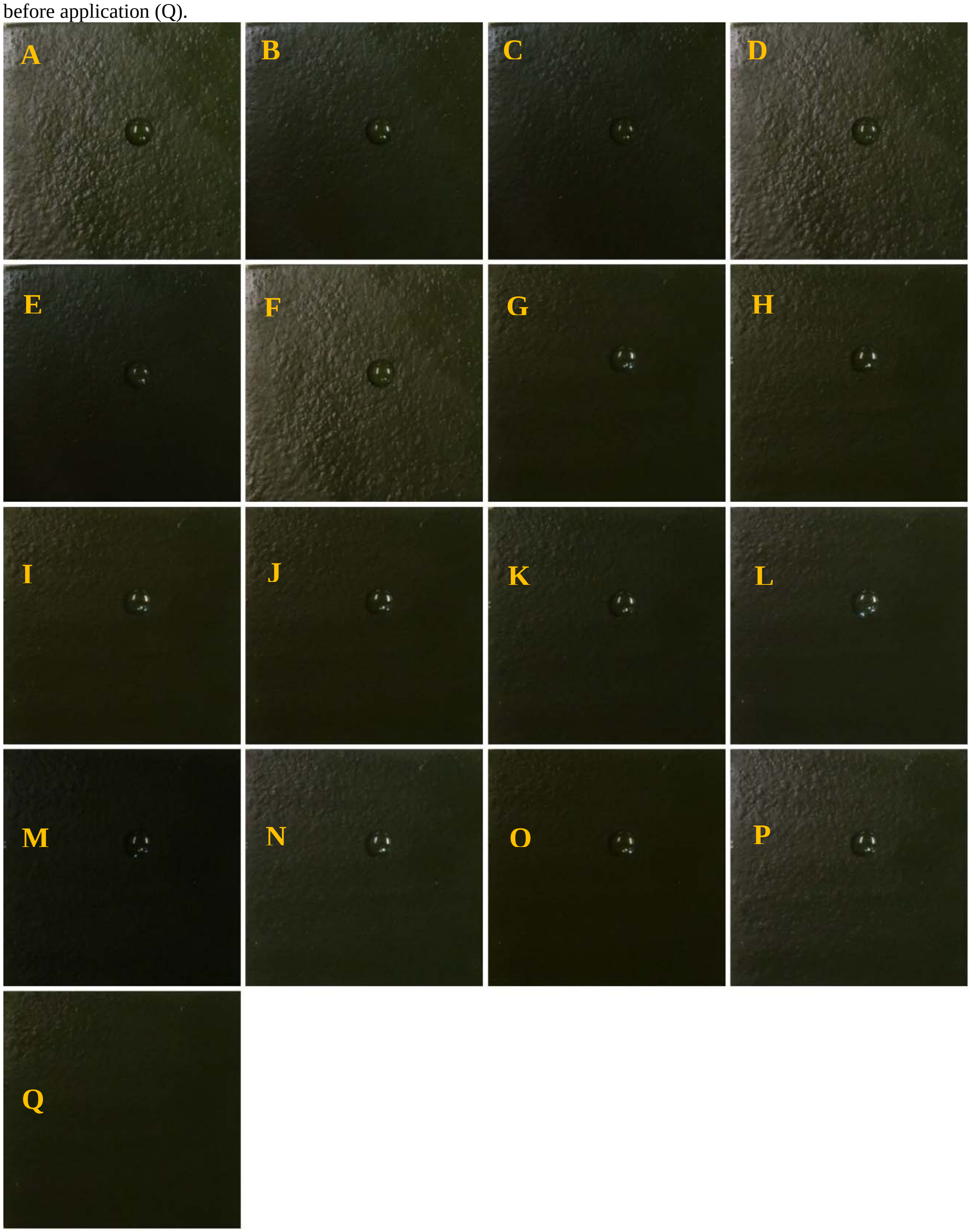
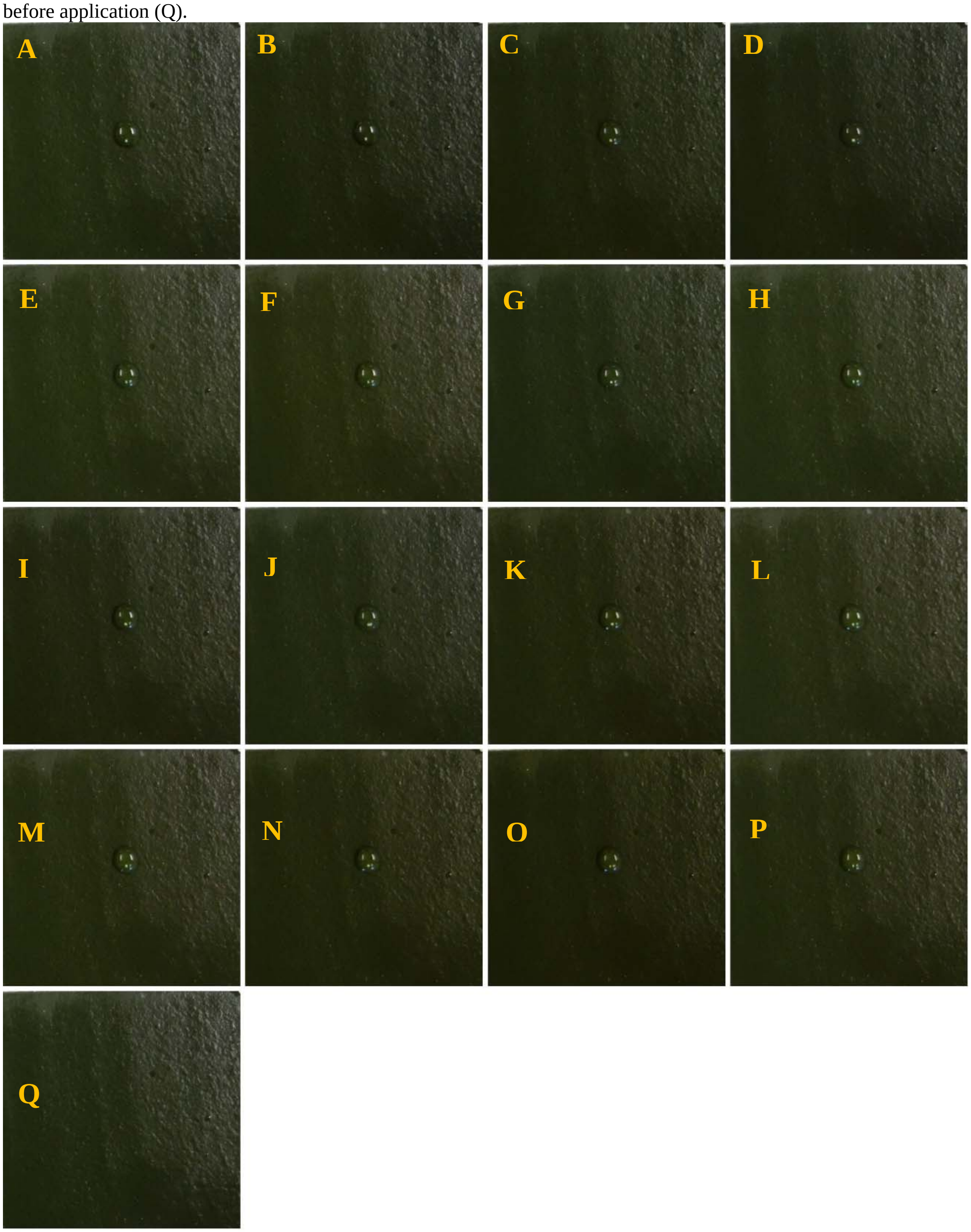


Fig. J3 — DMMP on ReColor SC3. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix K

RECOLOR SC3P IMAGES

Fig. K1 — Paraoxon on ReColor SC3P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

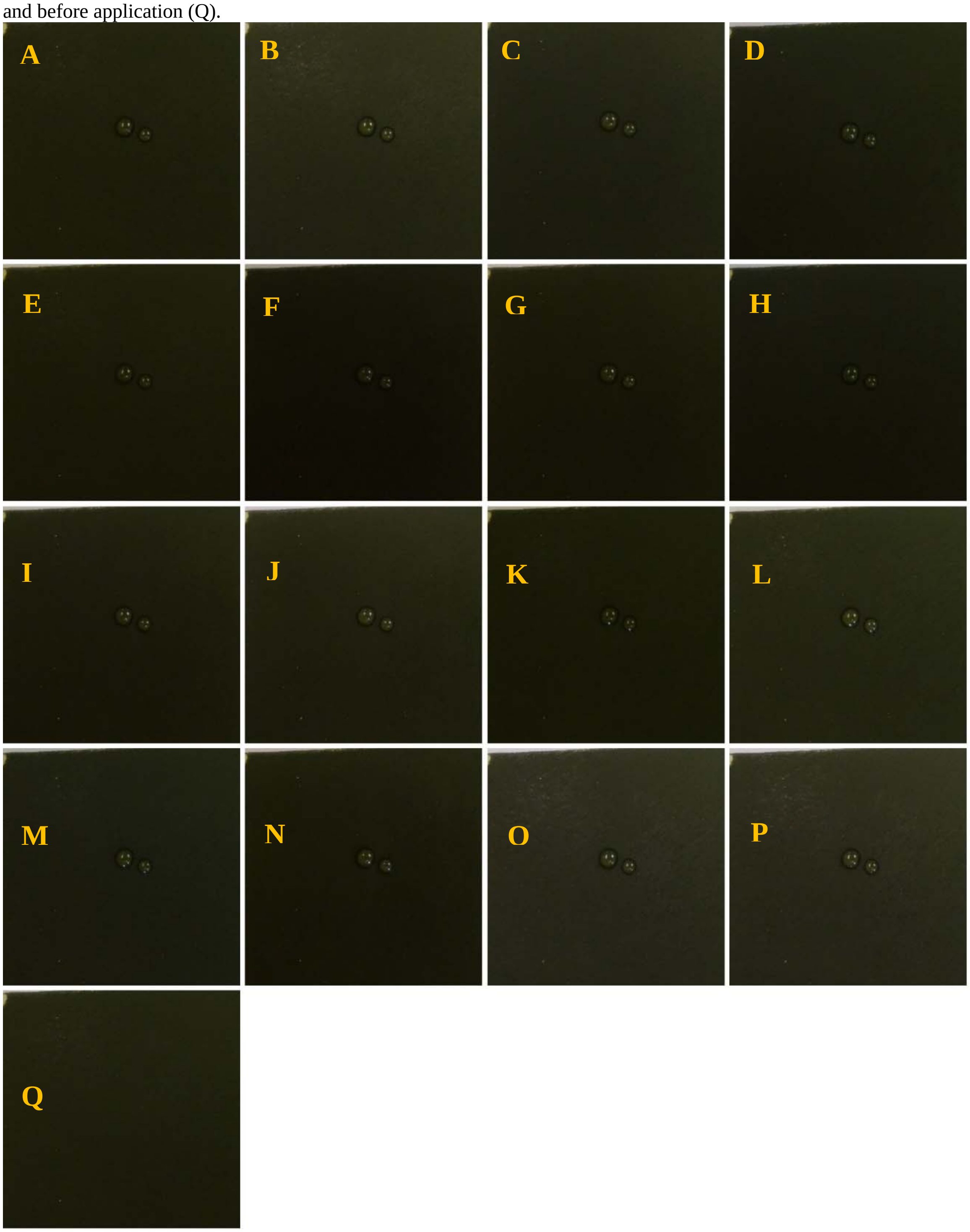


Fig. K2 — MES on ReColor SC3P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

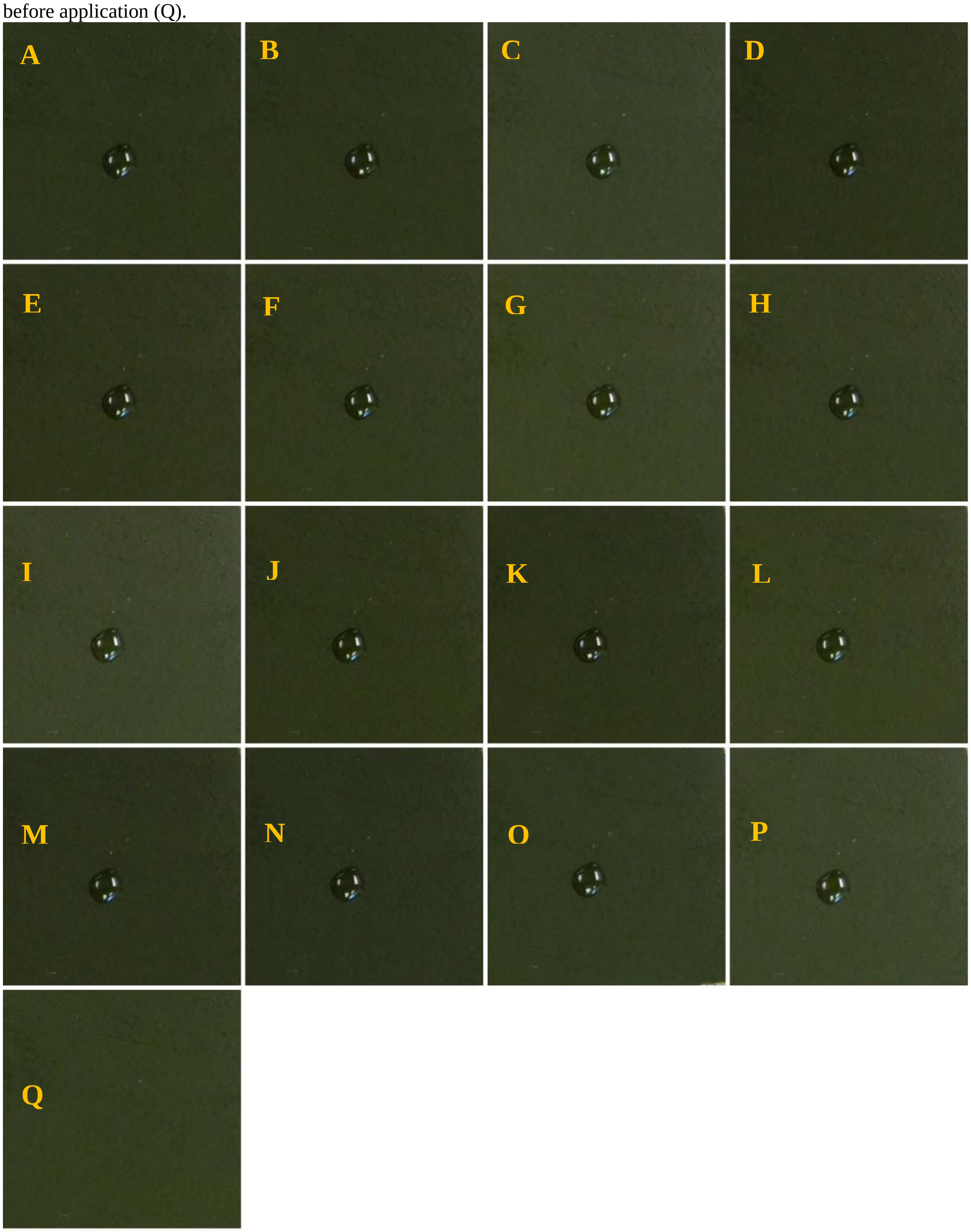
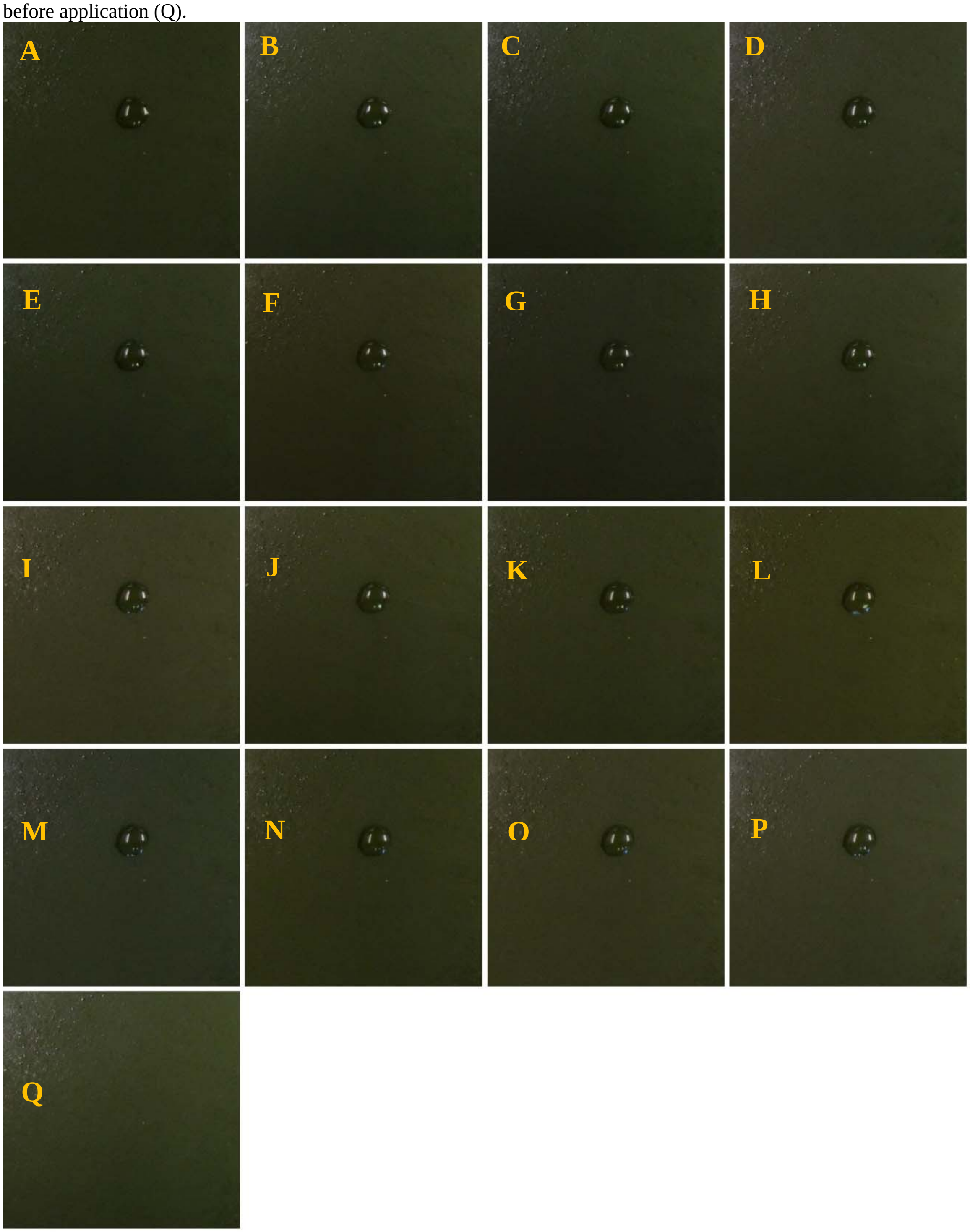


Fig. K3 — DMMP on ReColor SC3P. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix L

ORIGINAL WIPE NEW IMAGES

Fig. L1 — MES on Original Wipe New. Images of the coating on a painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).

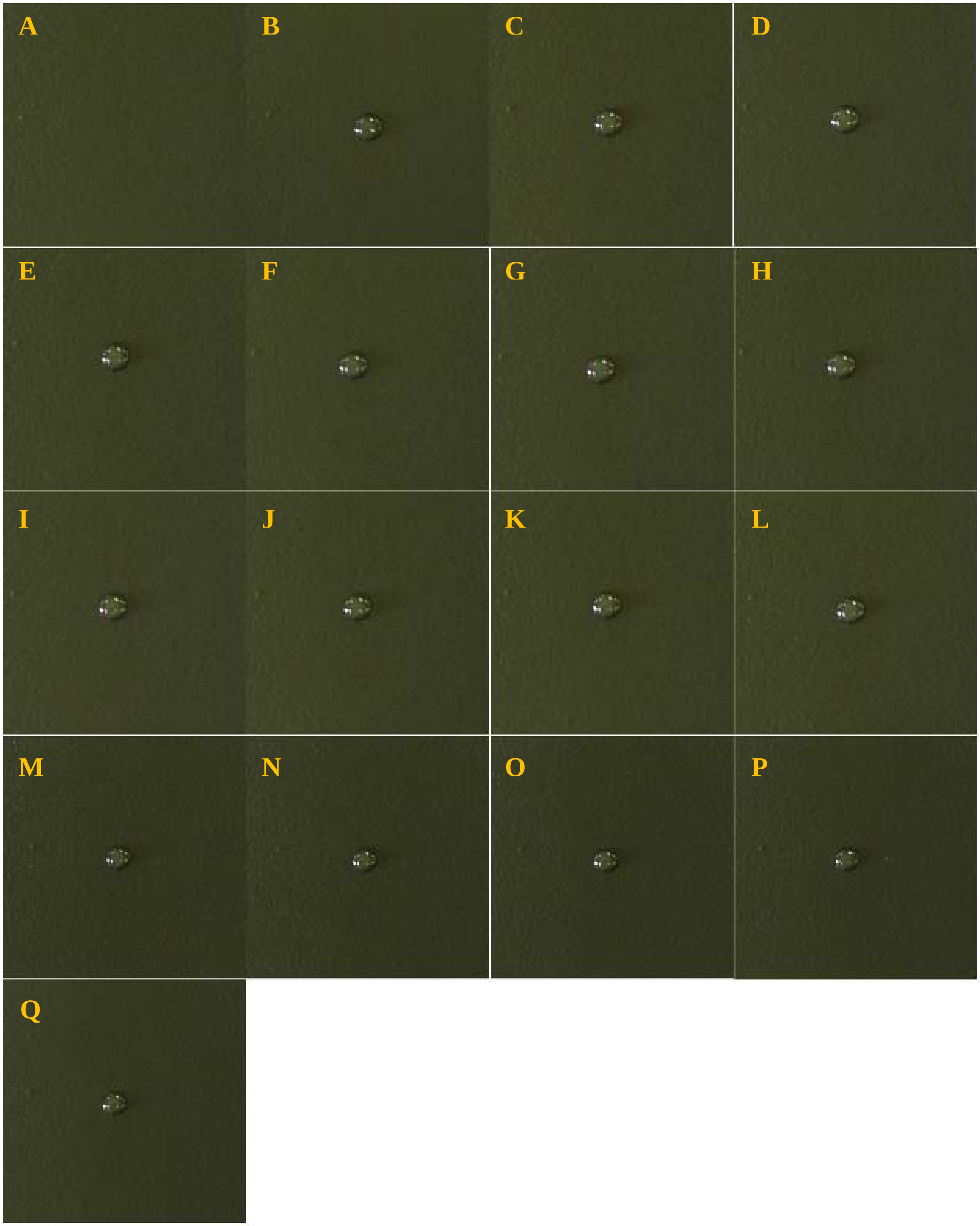
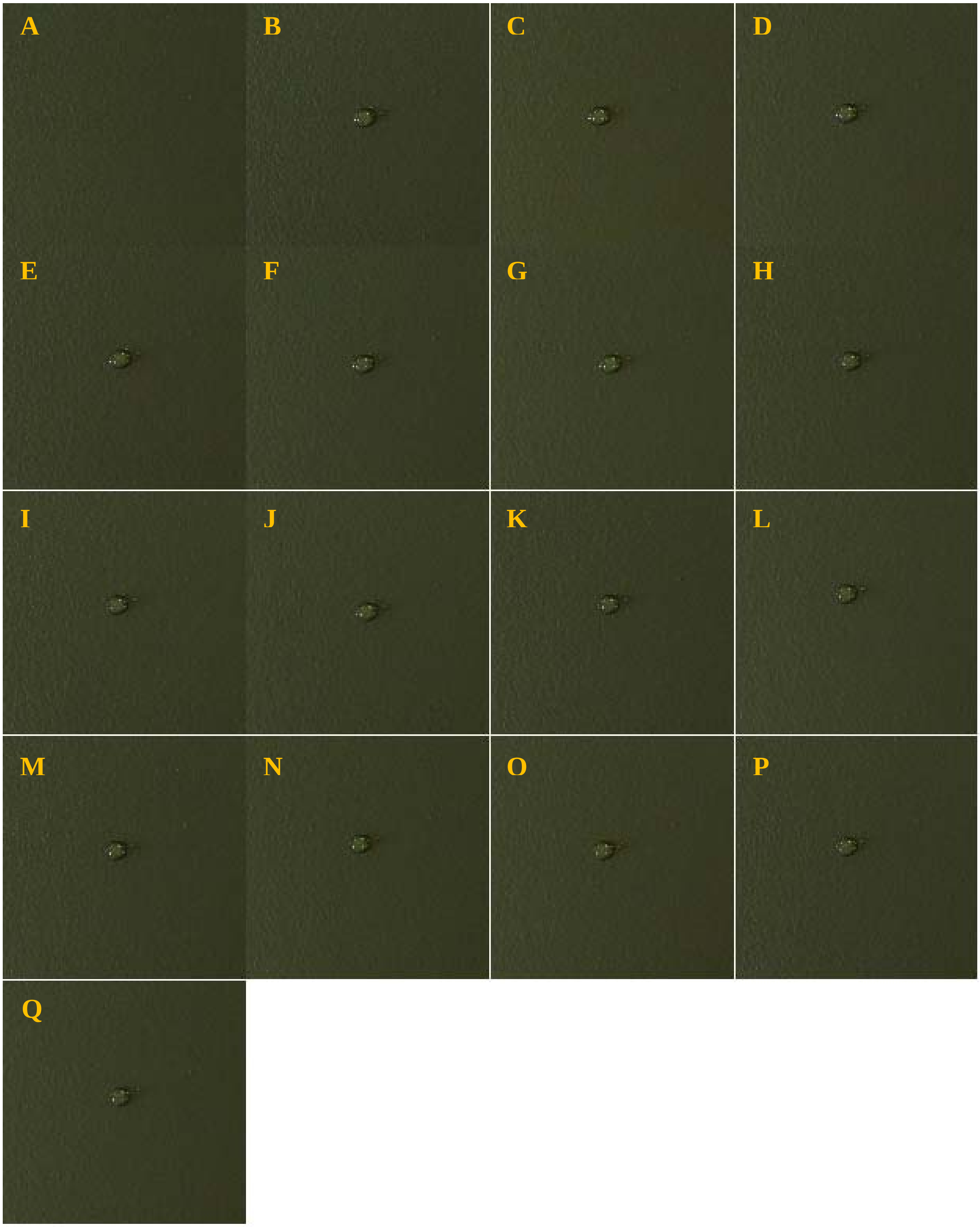


Fig. L3 — DMMP on Original Wipe New. Images of a film supported by painted coupon at 0 (A), 0.5 (B), 1.0 (C), 1.5 (D), 2.0 (E), 2.5 (F), 3.0 (G), 3.5 (H), 4.0 (I), 4.5 (J), 5 (K), 10 (L), 15 (M), 20 (N), 25 (O), and 30 (P) min following application of the target and before application (Q).



Appendix D

PAINTED COUPON IMAGES

Fig. D1 — Paraoxon on paint. Images of a coupon before application (A) and at 0 (B), 0.5 (C), 1.0 (D), 1.5 (E), 2.0 (F), 2.5 (G), 3.0 (H), 3.5 (I), 4.0 (J), 4.5 (K), 5.5 (L), 10 (M), 15 (N), 20 (O), 25 (P), and 30 (Q) min following application of the target.

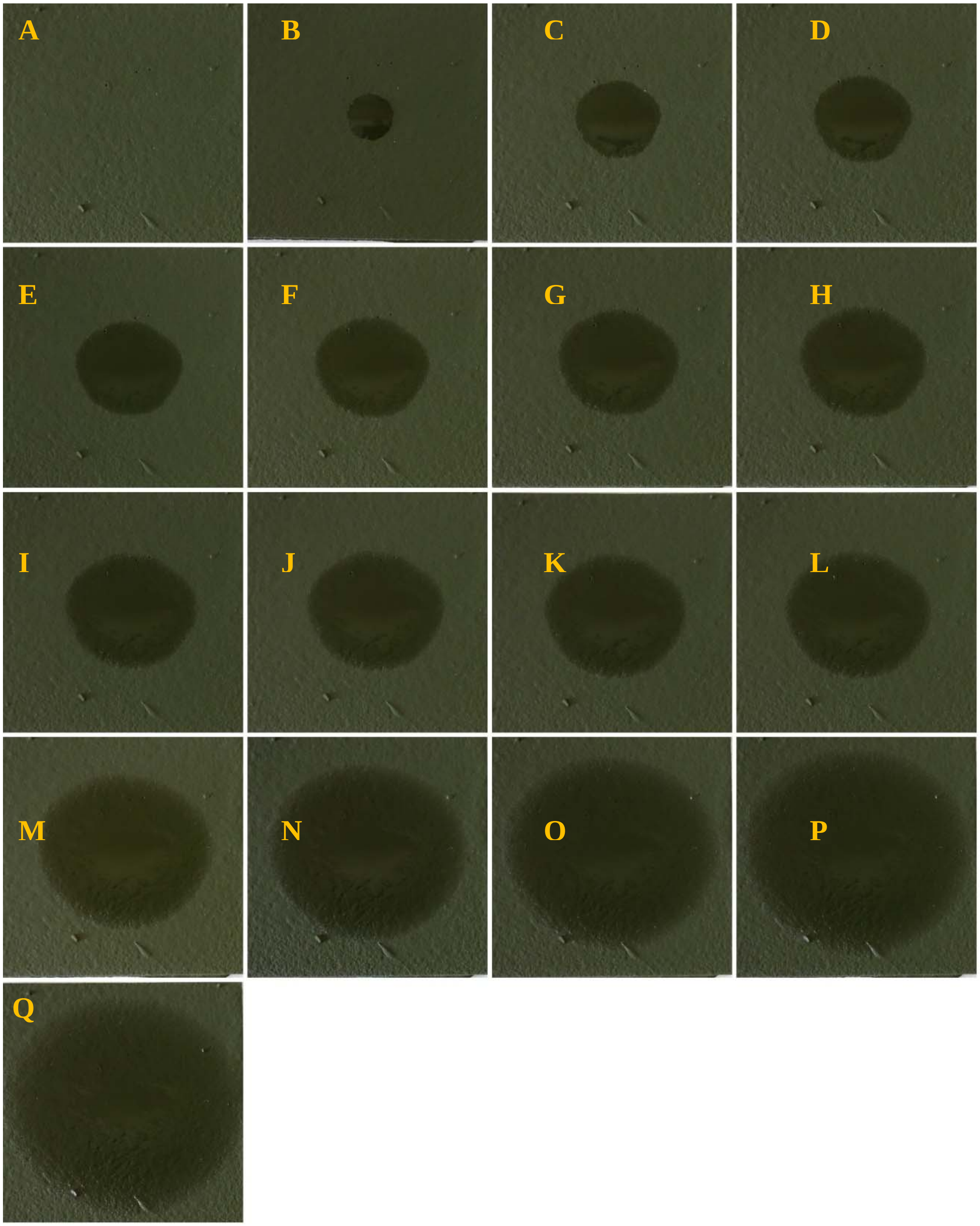


Fig. D2 — MES on paint. Images of a coupon before application (A) and at 0 (B), 0.5 (C), 1 (D), 1.5 (E), 2 (F), 2.5 (G), 3 (H), 3.5 (I), 4 (J), 4.5 (K), 5 (L), 10 (M), 15 (N), 20 (O), 25 (P), and 30 (Q) min following application of the target.

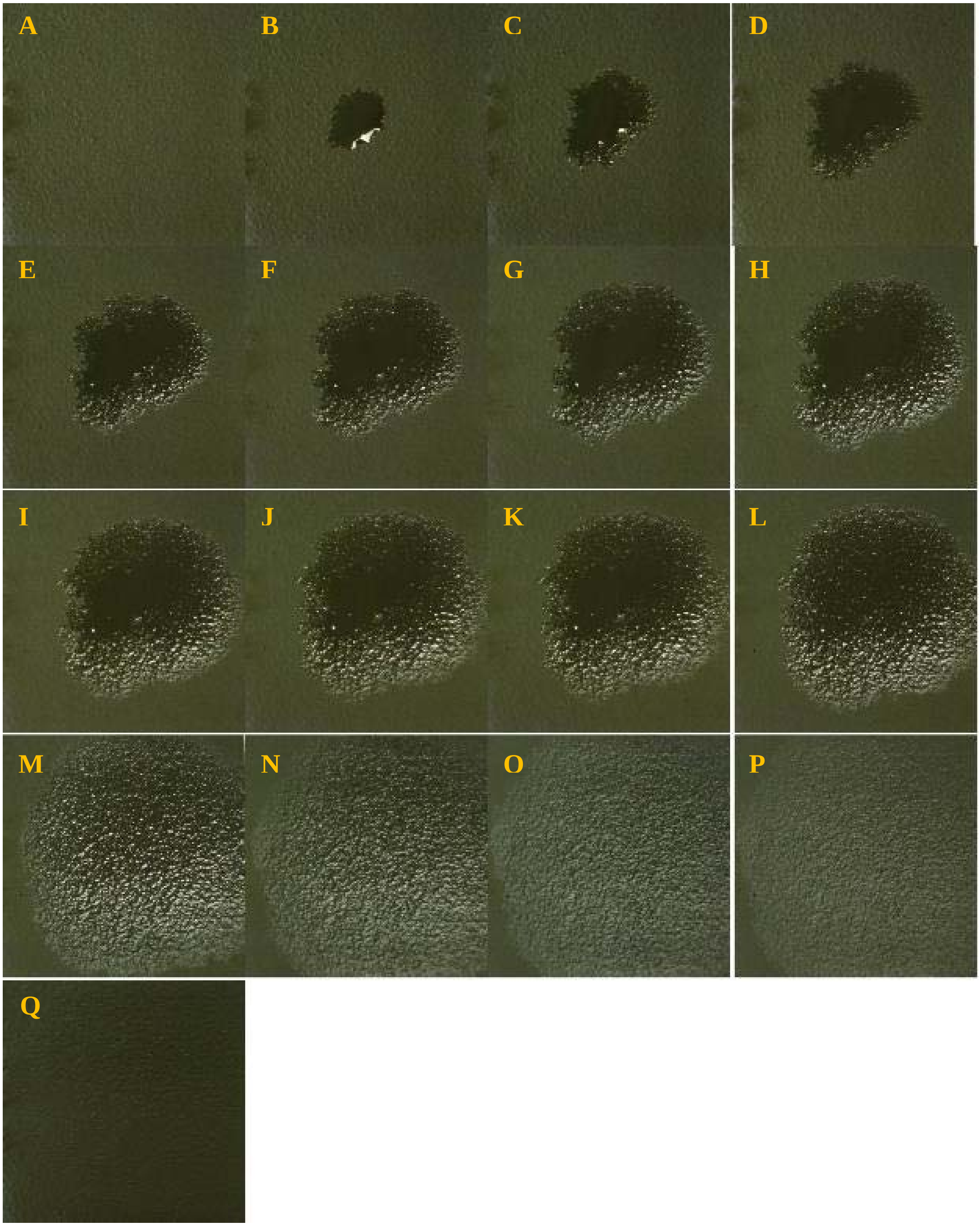


Fig. D3 — DMMP on paint. Images of a coupon before application (A) and at 0 (B), 0.5 (C), 1 (D), 1.5 (E), 2 (F), 2.5 (G), 3 (H), 3.5 (I), 4 (J), 4.5 (K), 5 (L), 10 (M), 15 (N), 20 (O), 25 (P), and 30 (Q) min following application of the target.