STABILIZING DIFFERENT SOILS ON DIFFERENT SLOPES

CLEAN WATER ALABAMA – SEPTEMBER 24TH-25TH , 2025 – PELL CITY, AL

AUBURN STORMWATER

ALDOT Alabama Department of Transportation

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EVALUATING EROSION CONTROLS W/ RAINFALL SIMULATION

- Alabama Department of Transportation (ALDOT) project
- Evaluate erosion control BMP's using ASTM D6459 -19 rainfall simulation on differing site parameters
- Highway construction side slopes are at greater risk of erosion due to site & climactic conditions
- Specific objectives to determine how products perform under varying slope and soil conditions

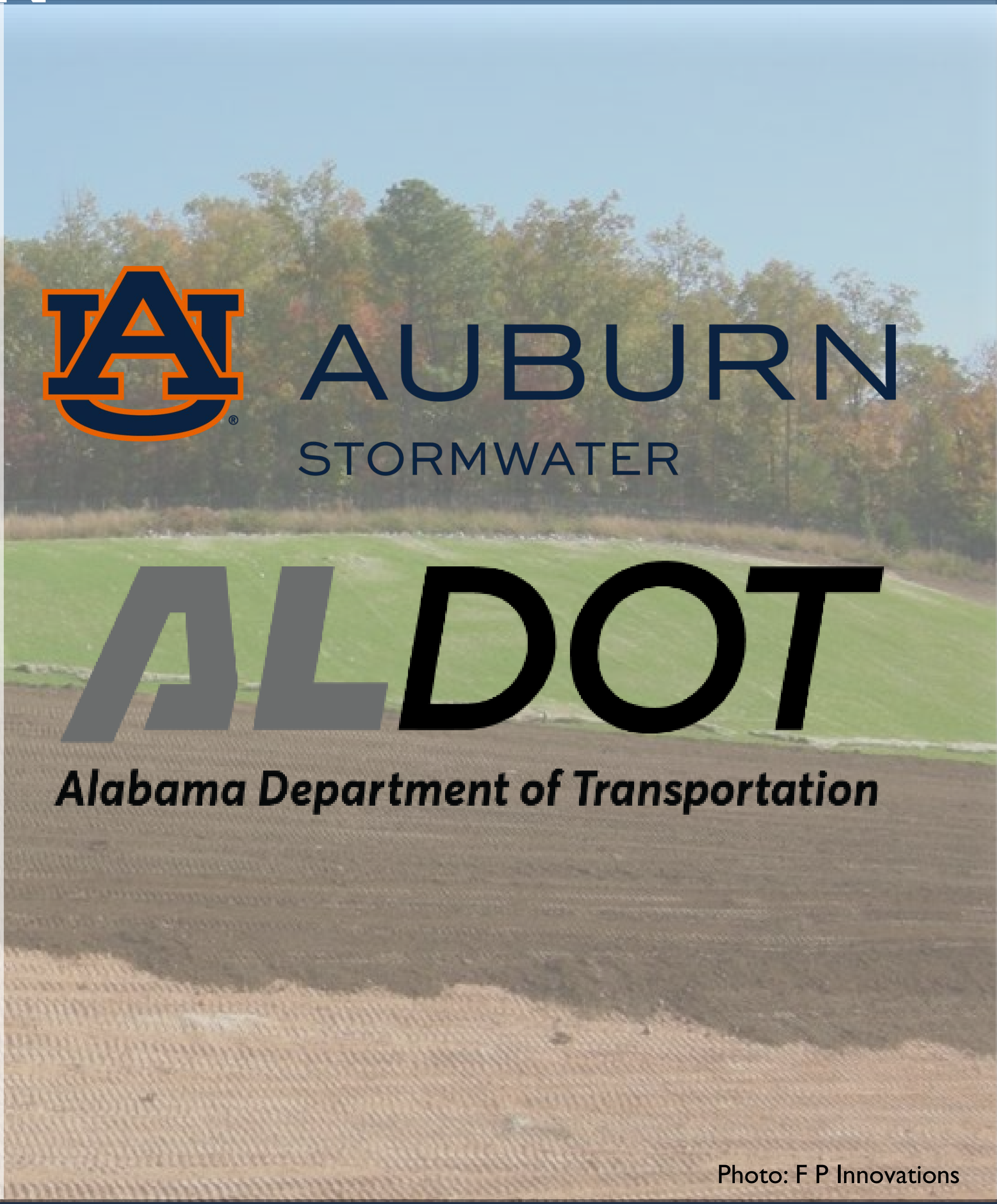


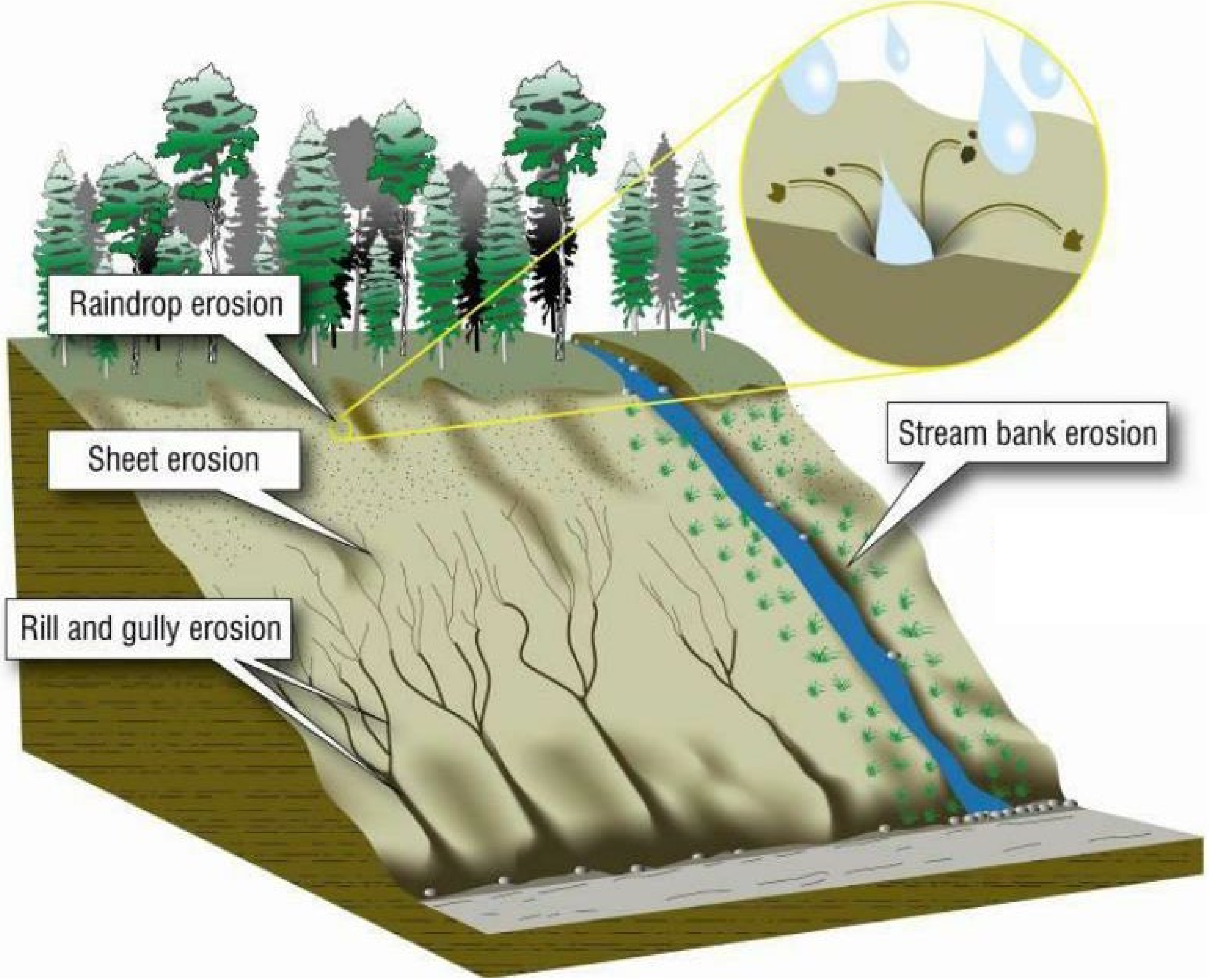
Photo: F P Innovations

THREAT OF SOIL POLLUTION

Soil erosion from construction sites can be devastating to local waterbodies & ecosystems

STORMWATER RUNOFF LEADS TO EXCESSIVE SOIL LOSS

- Types of erosion from stormwater
  - Impact
  - Sheet
  - Rill
  - Gully
  - Streambank

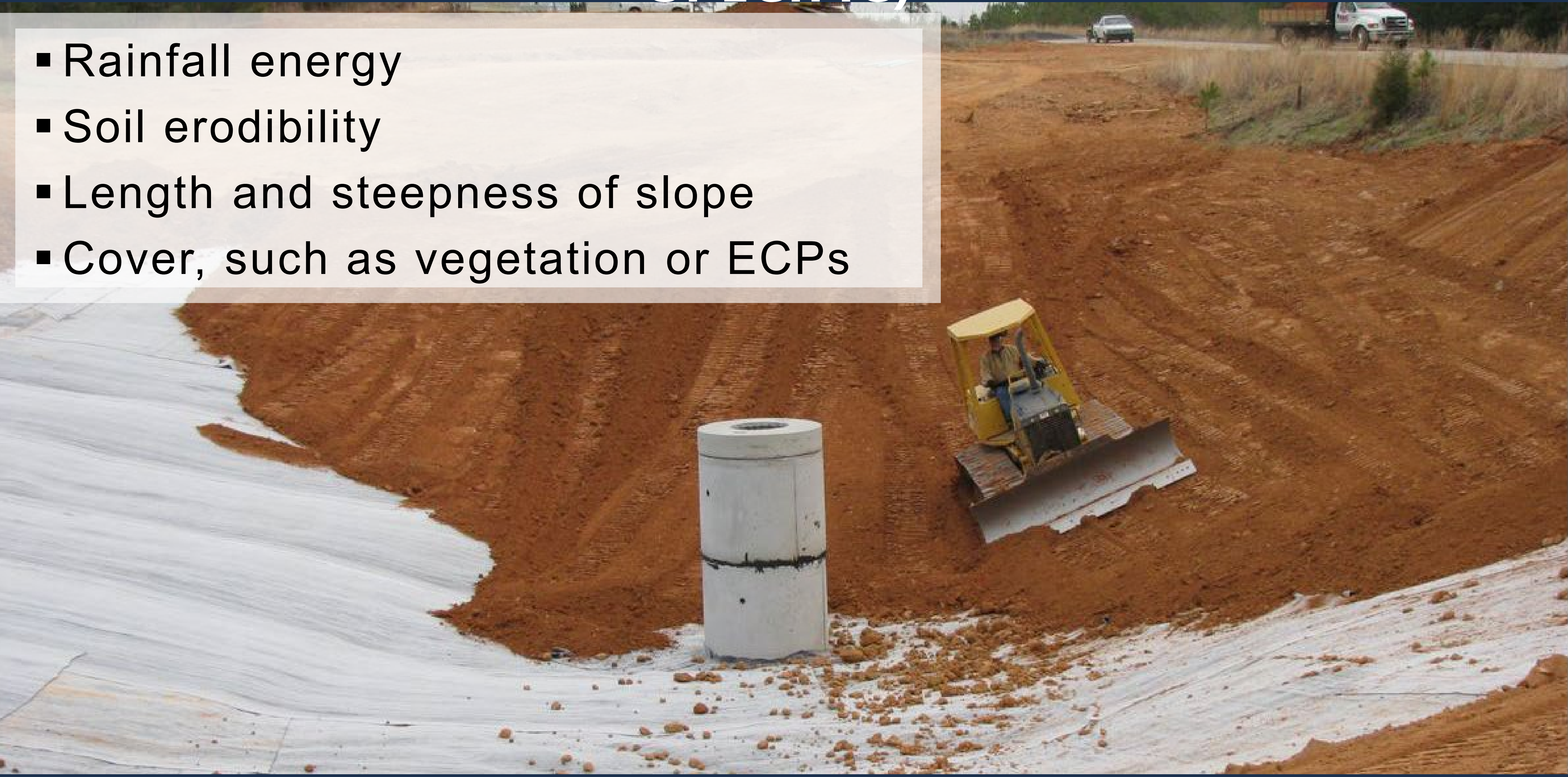


EROSION CONTROL STABILIZES CONSTRUCTION SITES

- Straw
- Mulch
- Hydromulch
- Erosion control blanket
- Turf reinforcement mat
- Vegetation

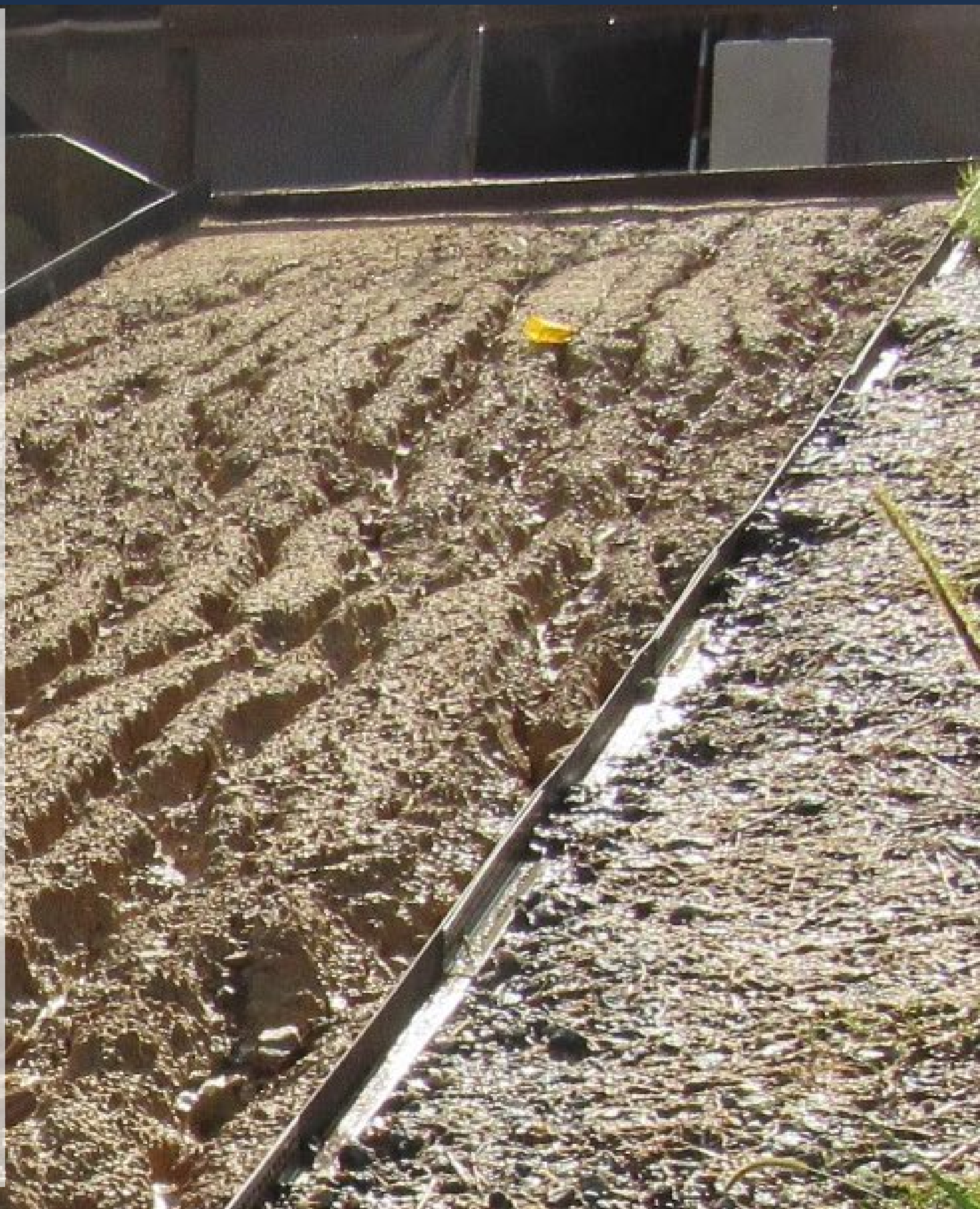
SITE FACTORS AFFECT EROSION POTENTIAL (SITE SPECIFIC)

- Rainfall energy
- Soil erodibility
- Length and steepness of slope
- Cover, such as vegetation or ECPs



SOIL AND SLOPE IMPACT EROSION POTENTIAL

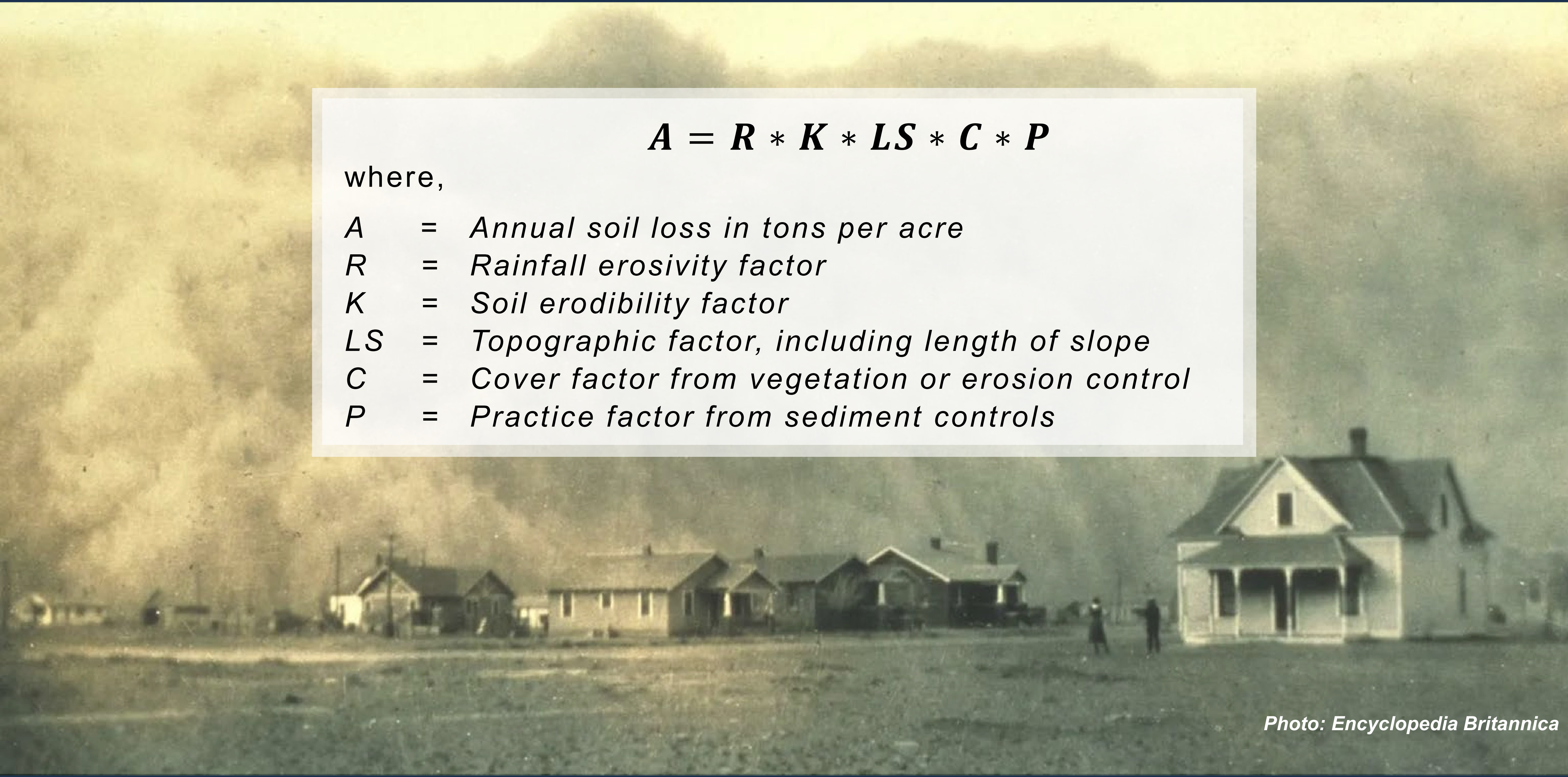
- Soil erodibility varies by soil type
  - Mineralogy
  - Gradation
  - Compaction state
  - Organic content
  - Moisture content
- ASTM D6459 allows for three different soil types: sand, clay, loam
- Slope length and steepness will affect runoff velocity



STANDARDIZED TESTS EVALUATE EROSION CONTROLS

- Erosion controls reduce erosion by reducing impact of raindrops and sheet flow
  - Splash
  - Sheet (interrill)
  - Rill formation
  - Gulley formation
- Rainfall simulators help determine effectiveness of erosion controls by comparing soil loss to bare soil loss
- ASTM D6459-19 is the standard test method for evaluating erosion control methods on a slope

RUSLE EQUATION MODELS SOIL LOSS



$$A = R * K * LS * C * P$$

where,

A	=	*Annual soil loss in tons per acre*
R	=	*Rainfall erosivity factor*
K	=	*Soil erodibility factor*
LS	=	*Topographic factor, including length of slope*
C	=	*Cover factor from vegetation or erosion control*
P	=	*Practice factor from sediment controls*

Photo: Encyclopedia Britannica

EVALUATING EROSION CONTROL PRODUCTS

Biodegradable Straw Blanket

Slopes:	≤ 3H:1V
C factor:	.05
Shear Stress:	1.55 lb/ft² (74 Pa)
Velocity:	4.5 ft/sec (1.4 m/sec)
Functional Longevity[a]:	≤ 12 months

Biodegradable Excelsior Blanket

Slopes:	≤ 1H:1V
C factor:	.022
Shear Stress:	2.5 lb/ft² (120 Pa)
Velocity:	10.0 ft/sec (3.1 m/sec)
Functional Longevity[a]:	≤ 36 months

"High Performance" Hydromulch

Property	Test Method	Tested Value (English)	Tested Value (SI)
Physical			
Mass Per Unit Area	ASTM D6566[1]	≥ 8.3 oz/yd²	≥ 280 g/m²
Water Holding Capacity	ASTM D7367[1]	≥1,000%	≥ 1,000%
Color	Observed	Green	Green
Performance			
Cover Factor[2]	ASTM D8298-Type 1	≤ 0.35	≤ 0.35
% Effectiveness[3]	ASTM D8298-Type 1	≥ 65%	≥ 65%
Vegetation Establishment	ASTM D7322	200%	200%
Functional Longevity[4]	ASTM D5338	≤ 3 months	≤ 3 months
Environmental			
Ecotoxicity[5]	EPA 2021.0	Non-Toxic	Non-Toxic
Biodegradability	ASTM D5338	Yes	Yes
Elemental Impurity Limits	ASTM D8082	Pass	Pass

1. ASTM test methods developed for Rolled Erosion Control Products and have been modified to accommodate Hydraulically-Applied Erosion Control Products.
2. Cover Factor is calculated as soil loss ratio of treated surface versus an untreated control surface.

HOW RAINFALL SIMULATORS USE RUSLE

$$A = R * K * LS * C * P$$

Plot design → LS-factor

Rain simulation → R-factor

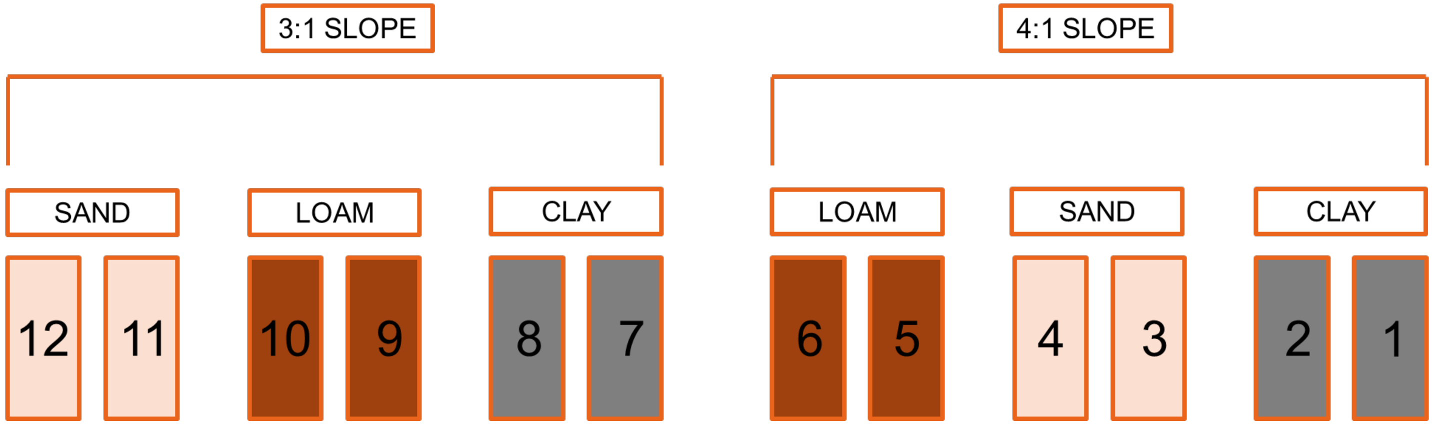
Bare soil tests → K-factor

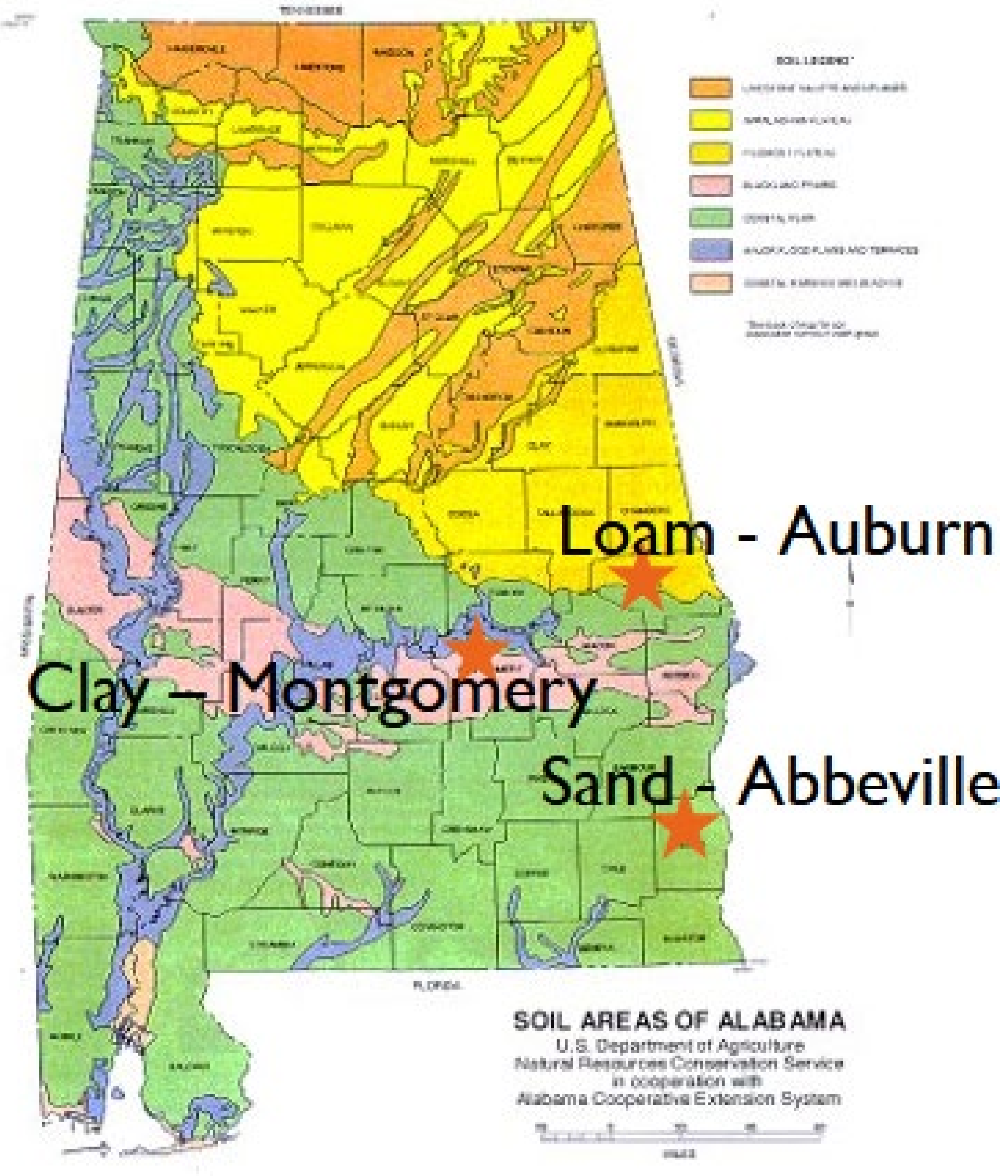
Erosion control tests → C-factor

- No practice factor → P=1
- Soil loss is measured directly

AU-SRF RAINFALL SIMULATORS SOIL SOURCES

- Auburn University – Stormwater Research Facility
  - 12 rainfall simulators
  - ASTM D6459-19
  - Sand, loam, clay on 3H:1V & 4H:1V



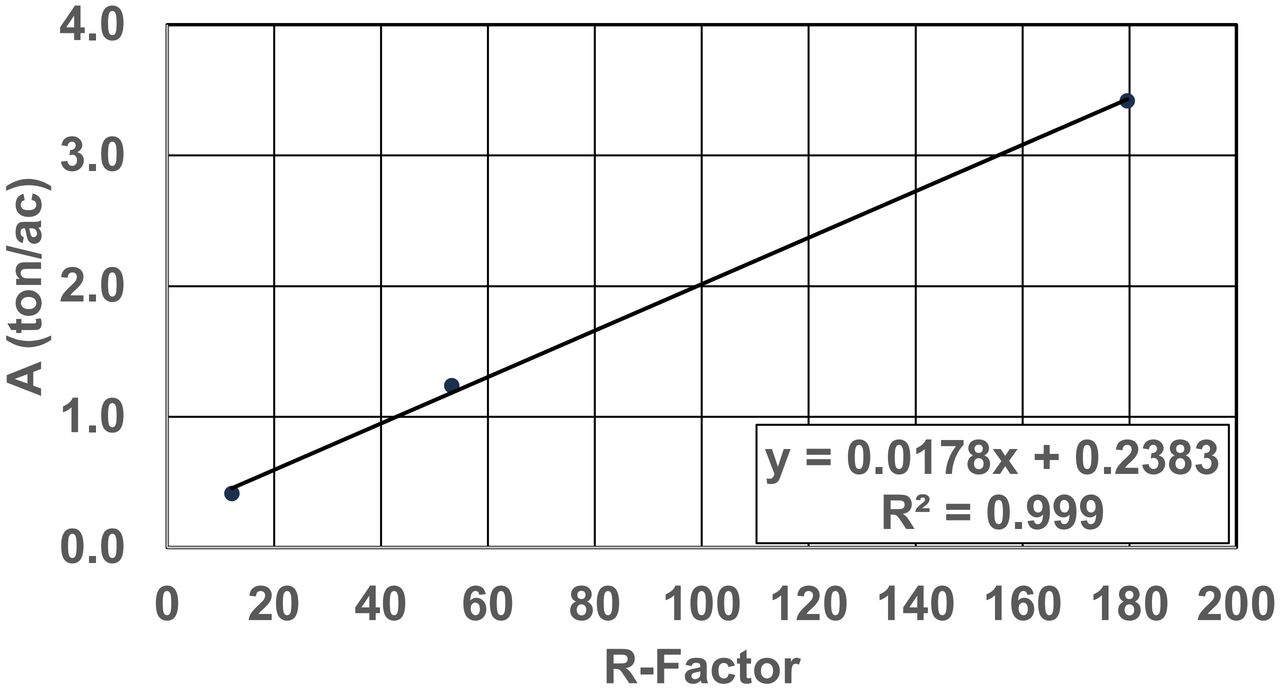


RUNOFF SEDIMENT CAPTURE

- Sediment settled for at least 24 hr
- Supernatant water pumped out and sediment weighed
- Moisture content collected for each soil type for dry weight
- Turbidity & TSS calculated from samples collected during test

RUSLE FACTOR CALCULATION

- K-factor and C-factor calculations are required to determine soil erodibility and erosion control effectiveness
- The calculation normalizes soil loss (tons/acre) as a function of incremental rainfall erosivity (R-factor)
- C-factor assumed to be 1.0 for K-factor calculation on bare soil



C = A/RLSKP

A = 2.88

Theoretical R = 148.51

LS Factor = 2.23

K= 0.37

P = 1

A/R = 0.0194

C = 0.023

TESTING OVERVIEW

- 27 tests were performed on the 4:1 ASTM plots
  - Sand
  - Clay
  - Loam
- Experimental K-factors obtained using bare soil (control) tests
- C-factors calculated for blown straw & single net ECB on each soil condition

BARE SOIL TESTING

- Bare soil control tests are performed with no product applied
- Helps to determine the experimental K-factor (soil erodibility)
- Serves as basis of comparison to product tests


SANDY LOAM


LOAM

BARE SOIL CONTROL TEST RESULTS

- 4:1 **sand** plots
- Avg. total soil loss of 1,977 lb (897 kg)

4:1 Sand Bare Soil Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.45 (6.22)	4.18 (10.62)	5.67 (14.40)
Dry Weight of sediment Avg. lbs (Kg)	325.95 (147.85)	284.58 (129.08	1367.33 (620.21)

BARE SOIL CONTROL TEST RESULTS

- 4:1 **loam** plots
- Avg. total soil loss of 236 lb (107 kg)

Loam Bare Soil Test Results			
Parameter	Values		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.32 (5.89)	3.97 (10.08)	6.00 (15.24)
Dry Weight of Sediment Avg. lbs (Kg)	16.18 (7.34)	74.69 (33.88)	145.30 (65.91)

BARE SOIL CONTROL TEST RESULTS

- 4:1 **clay** plots
- Avg. total soil loss of 114 lb (52 kg)

Clay Bare Soil Test Results			
Parameter	Values		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.48 (6.30)	4.42 (11.23)	6.95 (17.65)
Dry Weight of Sediment Avg. lbs (Kg)	5.06 (7.34)	21.97 (33.88)	87.17 (65.91)

BARE SOIL TEST RESULTS (K-FACTOR)

- Experimental K-factor determined for each soil type
- K-factor and dry sediment weight results concluded that sand is the most erodible soil followed by loam and clay
- K-factors were obtained using
  - LS-factor of 2.23
  - Experimental R-factor of 148.5 obtained from calibration
  - C- & P-factor of 1.0

Bare Soil K-Factor Results	
Soil Type	**Average K-factor**
Sand	0.370
Loam	0.043
Clay	0.013

BLOWN STRAW TEST RESULTS

- 4:1 **sand** plots
- Avg. total soil loss of 44 lb (20 kg)
- Bare soil control:
  - Avg. total soil loss of 1,977 lb (897 kg)

Sand Blown Straw Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.34 (5.94)	4.18 (10.62)	6.33 (16.08)
Dry Weight of Sediment Avg. lb (Kg)	3.45 (7.61)	12.19 (26.87)	28.67 (63.21)

BLOWN STRAW TEST RESULTS

- 4:1 **loam** plots
- Avg. total soil loss of 7 lb (3 kg)
- Bare soil control
  - Avg. total soil loss of 236 lb (107 kg)

Loam Blown Straw Test Results

Parameter	Values		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.28 (5.79)	3.90 (9.91)	5.38 (13.67)
Dry Weight of Sediment Avg. lb (Kg)	0.91 (0.41)	1.86 (0.84)	3.97 (1.80)

BLOWN STRAW TEST RESULTS

- 4:1 **clay** plots
- Avg. total soil loss of 16.6 lb (8 kg)
- Bare soil control
  - Avg. total soil loss of 114 lb (52 kg)

Clay Blown Straw Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.08)	4 (10.16)	6 (15.24)
Experimental Intensity Avg. in./hr (cm./hr)	2.45 (6.22)	4.68 (11.89)	6.75 (17.15)
Dry Weight of Sediment Avg. lb (Kg)	1.64 (0.74)	2.79 (1.27)	12.7 (5.76)

BLOWN STRAW TEST RESULTS (C-FACTOR)

- Experimental C-factor was determined for each soil type
- C-factor results indicated that straw effectiveness varied with soil type
  - LS factor of 2.23
  - R-factor of 148.5
  - K-factor determined for each soil type

Bare Soil K-Factor Results	
Soil Type	**Average K-factor**
Sand	0.370
Loam	0.043
Clay	0.013

Blown Straw C-Factor Results	
Soil Type	**Average C-factor**
Sand	0.021
Loam	0.047
Clay	0.193

BLOWN STRAW TEST RESULTS (C-FACTOR)

- RUSLE equation should account for soil variability with K-factor
- C-factor variance with soil type has been observed in other rainfall simulation studies as well (Clopper et al. 2001 – ASCE).
  - Clopper et al. also saw:
    - Sand w/ highest K-factor and clay w/ lowest
    - Sand w/ lowest C-factor and clay w/ highest
  - C-factor variance is not accounted for in published manufacturer data

SINGLE NET ECB TEST RESULTS

- 4:1 **sand** plots
- Avg. total soil loss of 80 lb (36 kg)
- Bare soil control
  - Avg. total soil loss of 1,977 lb (897 kg)

Sand Single Net Straw Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.1)	4 (10.2)	6 (15.2)
Experimental Intensity Avg. in./hr (cm./hr)	2.2 (5.5)	4.5 (11.3)	5.3 (13.5)
Dry Weight of Sediment Avg. lb (Kg)	3.3 (1.5)	22.7 (10.3)	53.9 (24.5)

SINGLE NET ECB TEST RESULTS

- 4:1 **loam** plots
- Avg. total soil loss of 25.7 lb (11.7 kg)
- Bare soil control
  - Avg. total soil loss of 236 lb (107 kg)

Loam Single Net Straw Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.1)	4 (10.2)	6 (15.2)
Experimental Intensity Avg. in./hr (cm./hr)	2.2 (5.6)	3.9 (10.0)	5.4 (13.6)
Dry Weight of Sediment Avg. lb (Kg)	1.7 (0.8)	5.7 (2.6)	12.7 (5.7)

SINGLE NET ECB TEST RESULTS

- 4:1 **clay** plots
- Avg. total soil loss of 17.1 lb (8 kg)
- Bare soil control
  - Avg. total soil loss of 114 lb (52 kg)

Clay Single Net Straw Test Results			
Parameter	**Values**		
Target Intensity in./hr (cm./hr)	2 (5.1)	4 (10.2)	6 (15.2)
Experimental Intensity Avg. in./hr (cm./hr)	2.2 (5.7)	3.8 (9.6)	4.9 (12.6)
Dry Weight of Sediment Avg. lb (Kg)	1.5 (0.7)	1.8 (0.8)	13.3 (6.0)

SINGLE NET STRAW TEST RESULTS (C-FACTOR)

- Experimental C-factor was determined for each soil type on the 4:1 plots
- The C-factor results indicated that single net straw effectiveness varied with soil type like the crimped straw
  - LS factor of 2.23
  - R-factor of 148.5
  - K-factor determined for each soil type

Bare Soil K-Factor Results		Single Net Straw C-Factor Results	
Soil Type	Average K-factor	Soil Type	Average C-factor
Sand	0.370	Sand	0.042
Loam	0.043	Loam	0.131
Clay	0.013	Clay	0.310

RUSLE FACTOR RESULTS SUMMARY

K-Factor Results

Soil Type	Test	K-factor
Sand	1	0.18
	2	0.22
	3	0.71
	Avg.	**0.37**
Loam	1	0.06
	2	0.01
	3	0.06
	Avg.	**0.043**
Clay	1	0.02
	2	0.01
	3	0.01
	Avg.	**0.013**

C-Factor Results Blown Straw

Soil Type	Test	C-factor
Sand	1	0.023
	2	0.015
	3	0.024
	Avg.	**0.021**
Loam	1	0.003
	2	0.084
	3	0.054
	Avg.	**0.047**
Clay	1	0.21
	2	0.04
	3	0.33
	Avg.	**0.193**

C-Factor Results Single Net Straw

Soil Type	Test	C-factor
Sand	1	0.039
	2	0.050
	3	0.037
	Avg.	**0.042**
Loam	1	0.084
	2	0.113
	3	0.196
	Avg.	**0.131**
Clay	1	0.40
	2	0.25
	3	0.27
	Avg.	**0.31**

TEST CONCLUSIONS

- Bare soil testing provided K-factors describing soil erodibility
  - K-factor is intended to normalize erodibility of different soils
  - Single practice-specific C-factor is published regardless of soil types
- Blown straw & single net ECB resulted in differing C-factors w/ K-factors accounting for soil erodibility
- ASTM 6459-19 testing concerns
  - Is RUSLE the appropriate method for determining C-factors using simulated rainfall methods?
    - RUSLE was developed using long-term field observational data
    - MUSLE (Modified Universal Soil Loss Equation) is storm specific, not temporal based: uses storm volume runoff and peak flowrate instead of R-factor

MUSLE EQUATION MODELS SOIL LOSS

$$Y = 11.8\left(Q \times q_p\right)^{0.56} * K * LS * C * P$$

where,

Y	=	*Sediment yield in tons*
Q	=	*Stormwater runoff (acre-ft)*
q_p	=	*Peak runoff rate (cfs)*
K	=	*Soil erodibility factor*
LS	=	*Topographic factor, including length of slope*
C	=	*Cover factor from vegetation or erosion control*
P	=	*Practice factor from sediment controls*

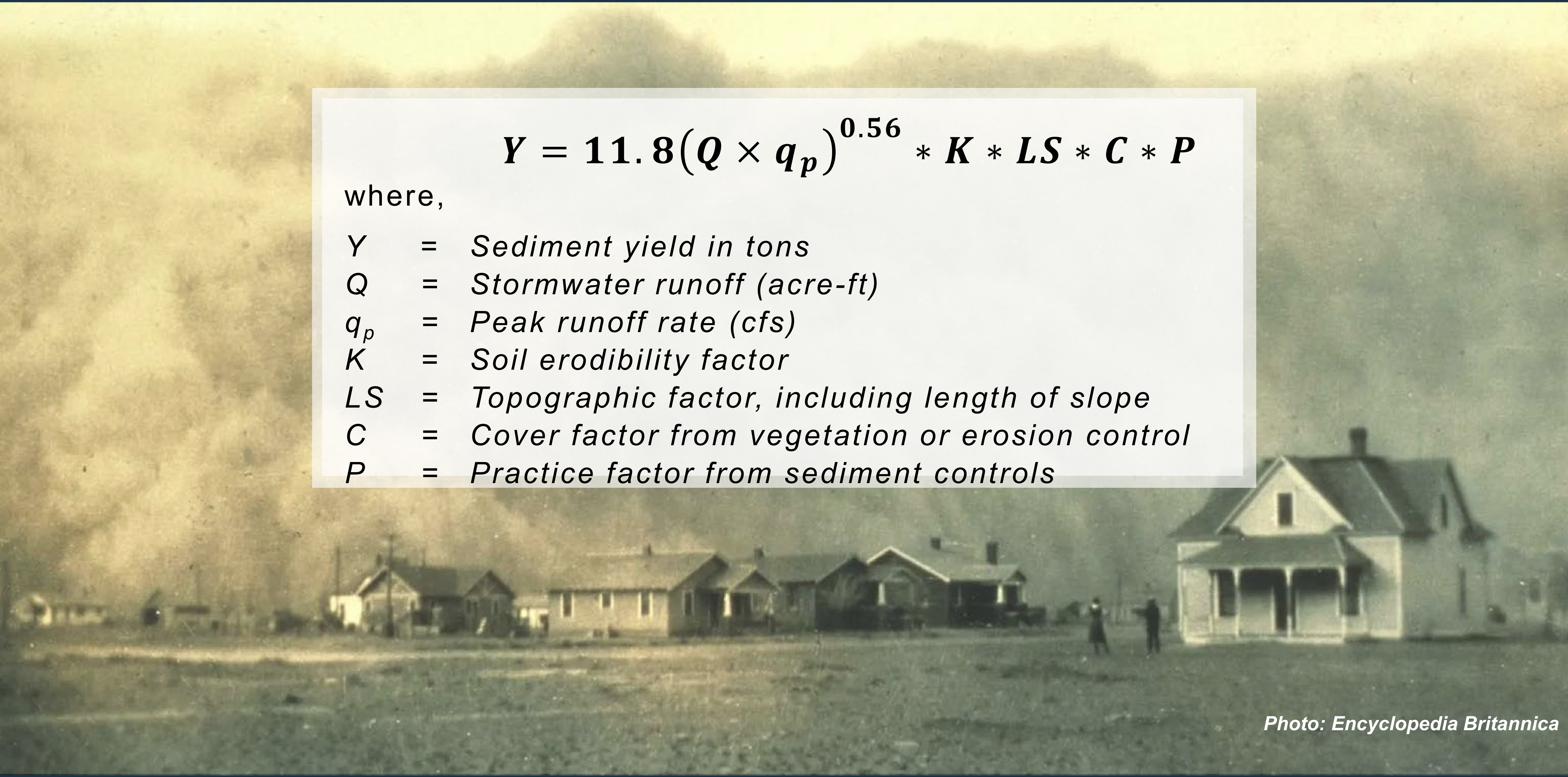


Photo: Encyclopedia Britannica

MUSLE FACTOR RESULTS SUMMARY

K-Factor Results

Soil Type	Test	K-factor
Sand	1	0.42
	2	0.42
	3	0.83
	Avg.	**0.56**
Loam	1	0.09
	2	0.05
	3	0.14
	Avg.	**0.092**
Clay	1	0.12
	2	0.07
	3	0.05
	Avg.	**0.08**

C-Factor Results Blown Straw

Soil Type	Test	C-factor
Sand	1	0.077
	2	0.045
	3	0.054
	Avg.	**0.059**
Loam	1	0.006
	2	0.088
	3	0.090
	Avg.	**0.061**
Clay	1	0.83
	2	0.079
	3	0.79
	Avg.	**0.57**

C-Factor Results Single Net Straw

Soil Type	Test	C-factor
Sand	1	0.10
	2	0.050
	3	0.12
	Avg.	**0.09**
Loam	1	0.12
	2	0.13
	3	0.11
	Avg.	**0.12**
Clay	1	0.29
	2	0.17
	3	0.20
	Avg.	**0.22**

RUSLE VS. MUSLE C-FACTOR BLOWN STRAW RESULTS

RUSLE Avg. C-Factor: 0.261

C-Factor Results Blown Straw

Soil Type	Test	C-factor
Sand	1	0.023
	2	0.015
	3	0.024
	Avg.	**0.021**
Loam	1	0.003
	2	0.084
	3	0.054
	Avg.	**0.047**
Clay	1	0.21
	2	0.04
	3	0.33
	Avg.	**0.193**

MUSLE Avg. C-Factor: 0.23

C-Factor Results Blown Straw

Soil Type	Test	C-factor
Sand	1	0.077
	2	0.045
	3	0.054
	Avg.	**0.059**
Loam	1	0.006
	2	0.088
	3	0.090
	Avg.	**0.061**
Clay	1	0.83
	2	0.079
	3	0.79
	Avg.	**0.57**

RUSLE VS. MUSLE C-FACTOR STRAW BLANKET RESULTS

RUSLE Avg. C-Factor: 0.161

C-Factor Results Single Net Straw

Soil Type	Test	C-factor
Sand	1	0.039
	2	0.050
	3	0.037
	Avg.	**0.042**
Loam	1	0.084
	2	0.113
	3	0.196
	Avg.	**0.131**
Clay	1	0.40
	2	0.25
	3	0.27
	Avg.	**0.31**

MUSLE Avg. C-Factor: 0.143

C-Factor Results Single Net Straw

Soil Type	Test	C-factor
Sand	1	0.10
	2	0.050
	3	0.12
	Avg.	**0.09**
Loam	1	0.12
	2	0.13
	3	0.11
	Avg.	**0.12**
Clay	1	0.29
	2	0.17
	3	0.20
	Avg.	**0.22**

SUMMARY CONCLUSIONS

- ASTM D6459-19 – industry standard to compare erosion control practices & products performance
  - RUSLE & MUSLE do not normalize soil loss based on soil erodibility (K-factor) very well using ASTM D6459
  - C-factors determined through ASTM D6459 should be described as soil specific regardless of K-factor
- RUSLE & MUSLE both have limitations
  - RUSLE - temporal based
  - MUSLE - storm specific (may be a better alternative)
- Practitioners must consider soil type with expected product performance

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