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CANOPY MODELING/REFLECTANCE WORKSHOP

OPTICAL PROPERTIES OF ASPEN AND BLACK SPRUCE CANOPY COMPONENTS

BY

LARRY BIEHL

CRAIG DAUGHTRY

PURDUE UNIVERSITY/LARS

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OPTICAL PROPERTIES OF CANOPY COMPONENTS

BACKGROUND

- REFLECTANCE MODELS OF VEGETATIVE CANOPIES REQUIRE ESTIMATES OF REFLECTANCE AND TRANSMITTANCE OF LEAVES AND STEMS AND THE REFLECTANCE CHARACTERISTICS OF THE CANOPY UNDERSTORY OR 'BACKGROUND.'
- INSTRUMENTS FOR ACQUIRING THE SPECTRAL DATA OF CANOPY COMPONENTS ARE NOT TRULY SUITED FOR <u>IN-SITU</u> MEASUREMENTS IN REMOTE AREAS.
- IF SPECTRAL PROPERTIES OF LEAVES AND STEMS DO NOT CHANGE RAPIDLY WHEN PROPERLY HANDLED, THEN SAMPLES OF LEAVES AND STEMS COULD BE COLLECTED, PACKED, AND SHIPPED TO LABORATORIES WHERE THE SPECTRAL DATA COULD BE ACQUIRED.

OBJECTIVES

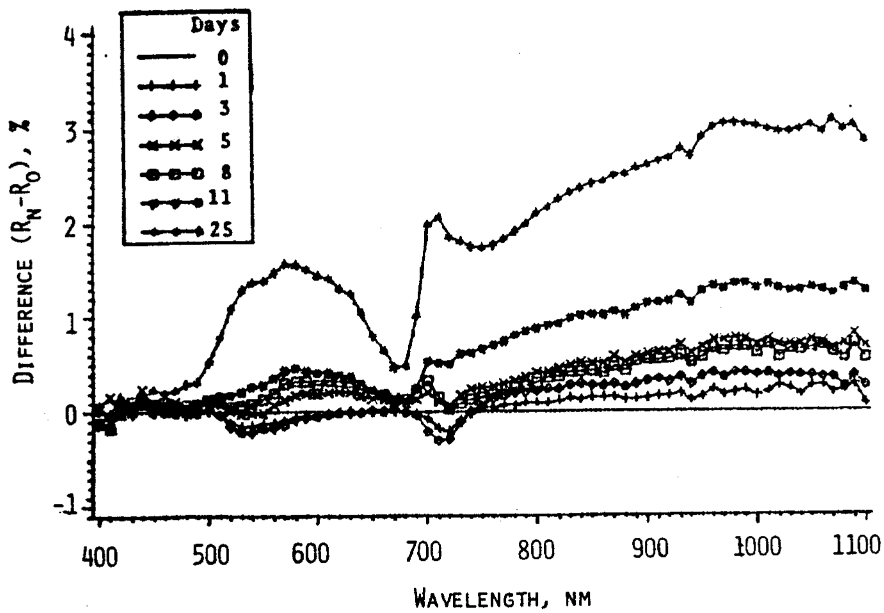
- Determine the reflectance and transmittance of leaves and stems of Aspen and Black Spruce trees.
  1. Determine changes in reflectance and transmittance of leaves with time after excision from host plant.
  2. Develop an acceptable procedure to ship plant components which causes least change in spectral properties.
  3. Develop procedure to measure reflectance and transmittance of needles.
  4. Evaluate optical properties of Aspen leaves and bark and Black Spruce needles and twigs.
  5. Determine variation of optical properties among Aspen and Black Spruce trees within a site.
- Determine the reflectance characteristics of the background within the subset of the Black Spruce and Aspen test sites.

CHANGES IN OPTICAL PROPERTIES OF LEAVES AND NEEDLES AFTER EXCISION

APPROACH

- Collect Red Birch and Red Pine branches. Store in plastic bags. At lab, detach leaves and needles; prepare mat of needles; store in sealed plastic bag at 5°C.
- Measure reflectance and transmittance of Birch leaves and reflectance of one side of mat of Pine needles. 1st time -- within 4 hours after detaching from branches. 8 replications.
- Repeat measurements at 1, 3, 5, 8, 11 and 25 days after excision.
- Analyze data. Determine times after excision when changes in reflectance and transmittance exceed 5, 10, and 20% of value.

DIFFERENCES IN REFLECTANCE OF RED BIRCH LEAVES AFTER EXCISION.
STORAGE TEMP = 5 C.



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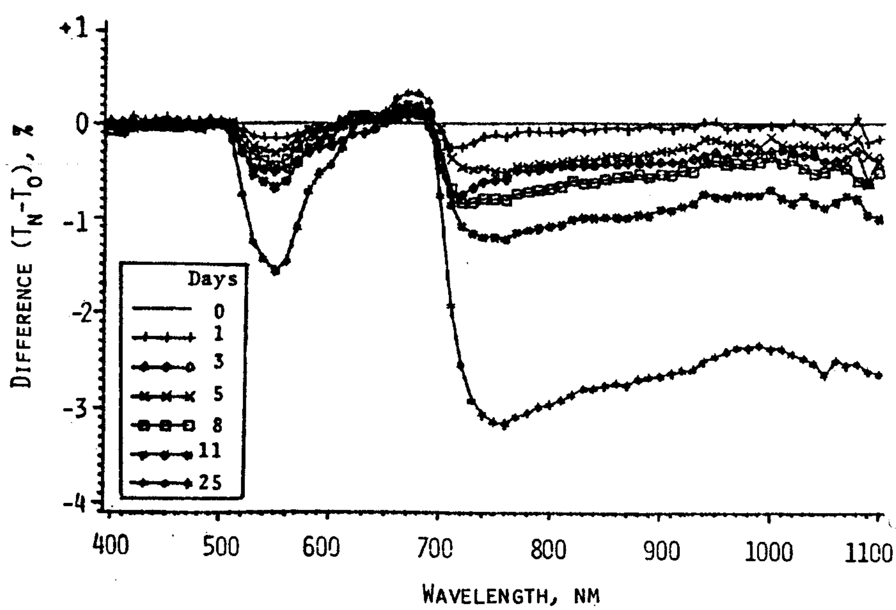
DIFFERENCES IN TRANSMITTANCE OF RED BIRCH LEAVES AFTER EXCISION.
STORAGE TEMP = 5 C.



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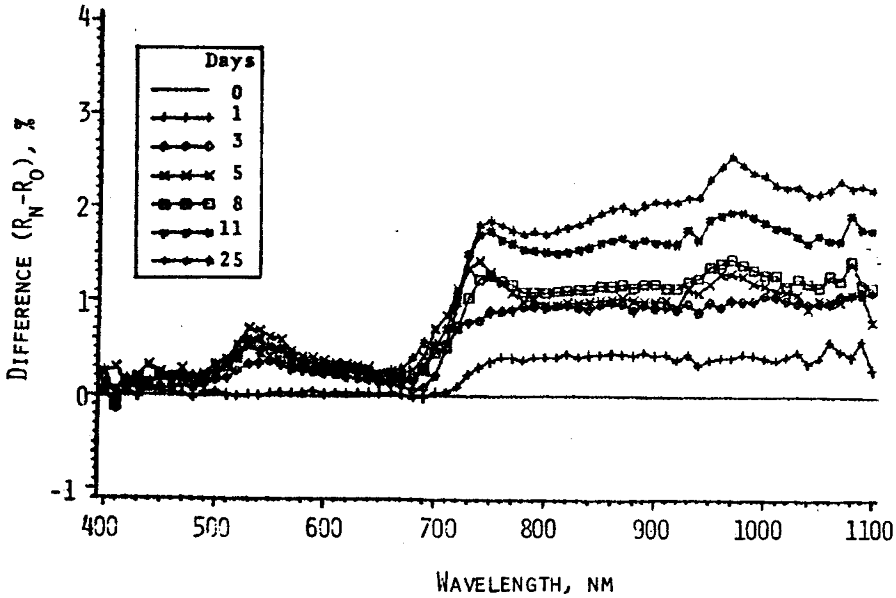
DIFFERENCES IN REFLECTANCE OF RED PINE NEEDLES AFTER EXCISION FROM HOST PLANT. STORAGE TEMP = 5 C.



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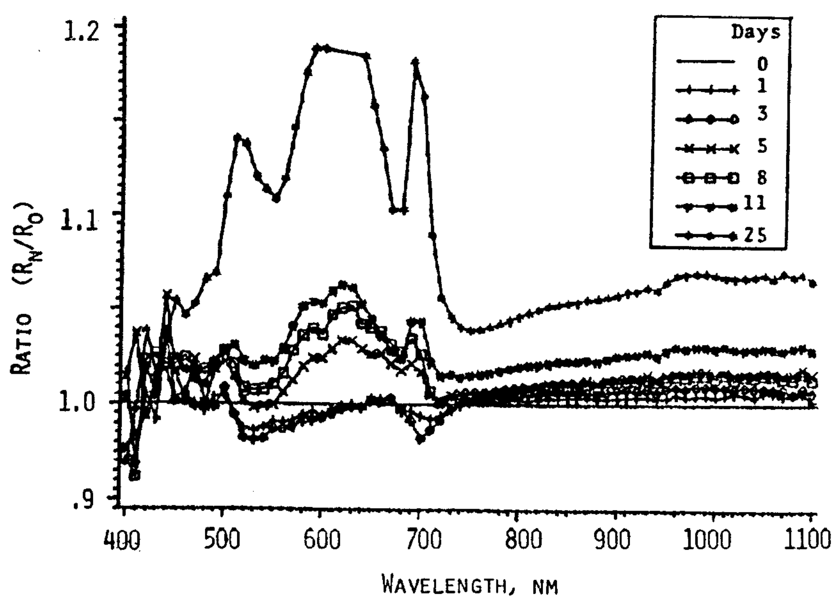
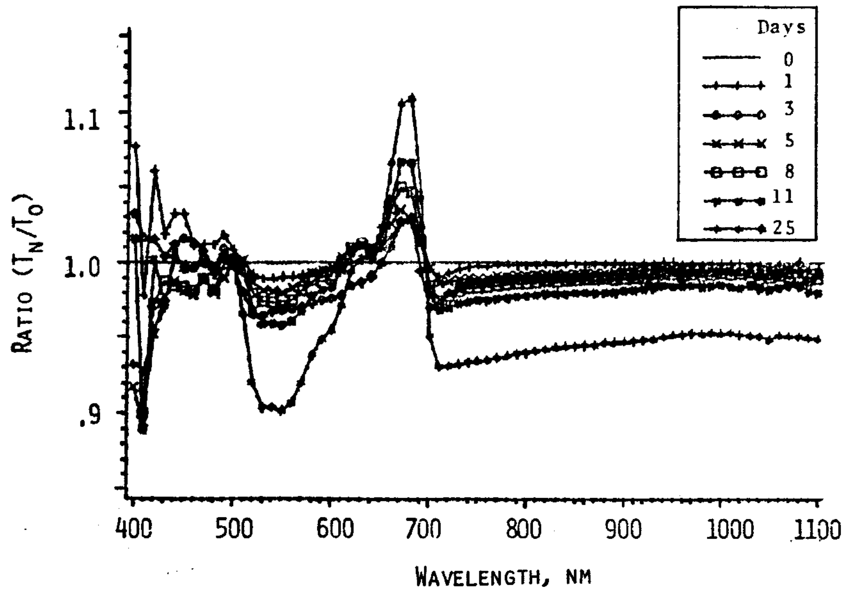
RELATIVE CHANGES IN REFLECTANCE OF RED BIRCH LEAVES AFTER EXCISION. STORAGE TEMP = 5 C.



RELATIVE CHANGES IN TRANSMITTANCE OF RED BIRCH LEAVES AFTER EXCISION.
STORAGE TEMP = 5 C.



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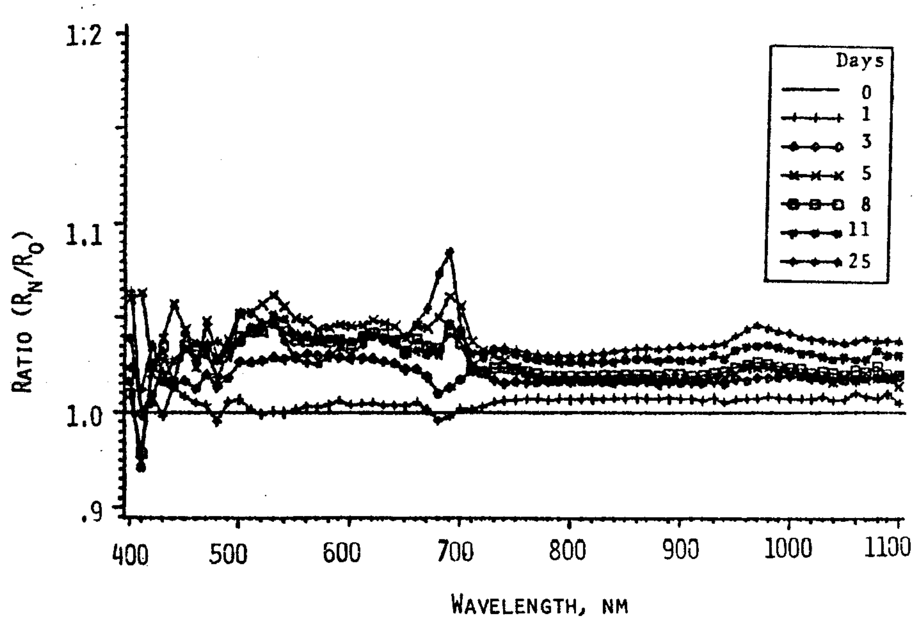
RELATIVE CHANGES IN REFLECTANCE OF RED PINE NEEDLES AFTER EXCISION
FROM HOST PLANT. STORAGE TEMP = 5 C.



CHANGES IN OPTICAL PROPERTIES OF LEAVES AND NEEDLES AFTER EXCISION

CONCLUSIONS

- CHANGES WERE LESS THAN 5% OF VALUE FOR UP TO ONE WEEK.
- DECIDED TO SHIP LEAVES AND NEEDLES IN SEALED PLASTIC BAGS IN INSULATED COOLERS WITH ICE PACKS.

FOLLOW-ON WORK

- LITERATURE REVIEW ON CYTOKININS AND EXPERIMENT USING THEM.

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OPTICAL PROPERTIES OF ASPEN TREE COMPONENTS

EXPERIMENT DESIGN

SITES:	HIGH, MEDIUM, LOW 'PHYTOMASS'
TREES:	HIGH - 24, 25, 26 MEDIUM - 27 LOW - ? (1)
CANOPY LAYERS:	LOWER, MIDDLE, UPPER
TREE COMPONENTS:	LEAVES, BARK
LEAVES:	10 PER LAYER
BARK SAMPLES:	2 PER LAYER
SPECTRAL MEASUREMENTS:	REFLECTANCE AND TRANSMITTANCE OF FRONT AND BACK OF LEAVES. REFLECTANCE OF BARK.
SPECTRAL RANGE:	400 - 1100 NM SAMPLED EVERY 10 NM.

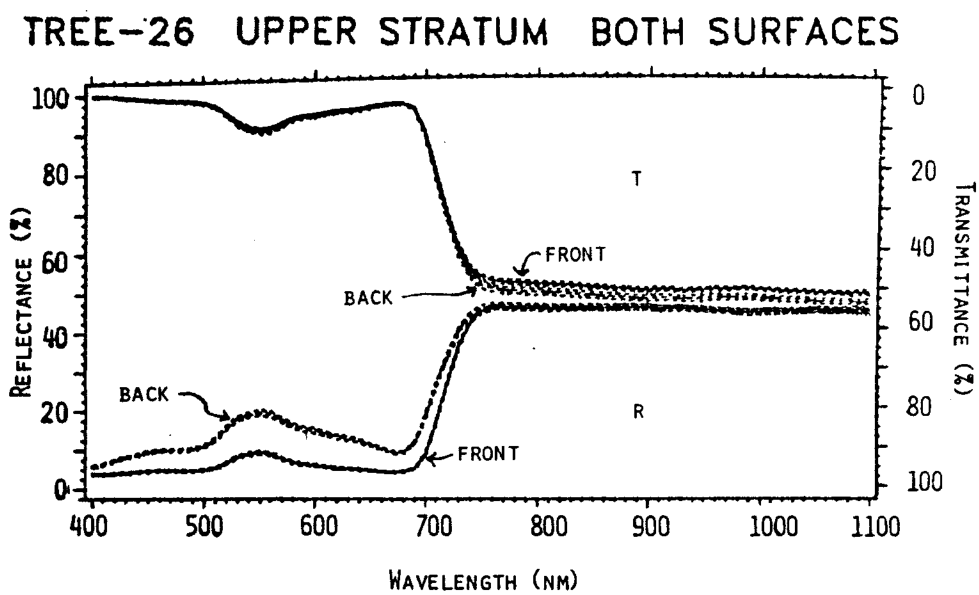
STATISTICAL DESIGN FOR ANALYSIS OF ASPEN LEAVES

SOURCE	VARIABLE TYPE	DF
TREES (T)	RANDOM	4
δ	--	0
LAYER (L)	FIXED	2
TL	--	8
SIDE (S)	FIXED	1
TS	--	4
LS	--	2
TLS	--	8
ERROR (LEAVES AND INTERACTIONS)	RANDOM	270
	TOTAL	299

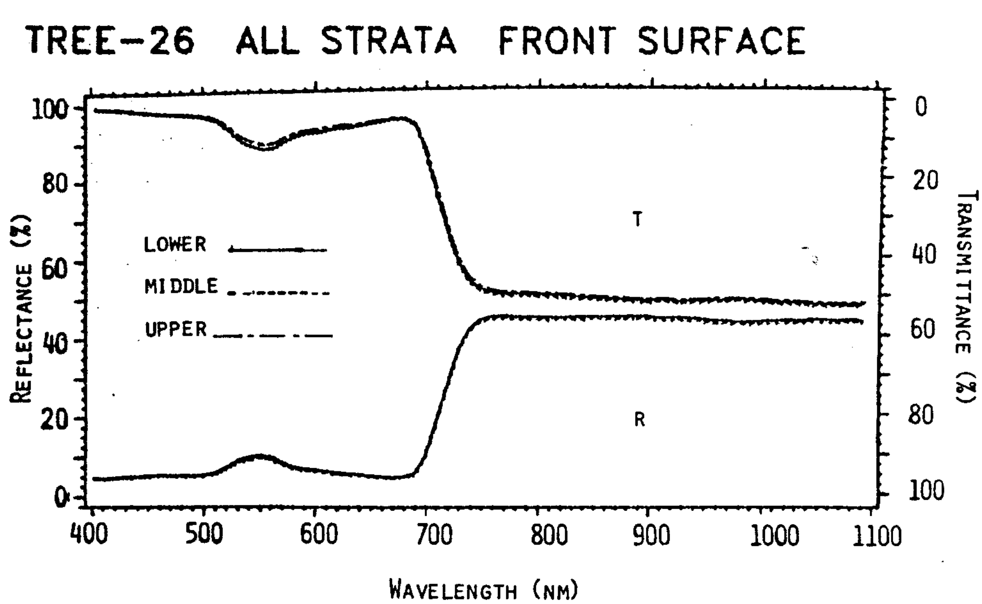
ANALYSIS OF VARIANCE OF OPTICAL PROPERTIES OF ASPEN LEAVES

λ (NM)	REFLECTANCE T	L	S	TL	TS	LS	TRANSMITTANCE T	L	S	TL	TS	LS
400			*	*	*		*					
450	*		*	*	*	*	*		*	*		
500	*		*	*	*	*			*	*		
550			*	*	*				*	*		
600	*		*	*	*	*	*			*		
650	*	*	*	*	*	*	*		*	*		
680	*	*	*	*	*	*	*		*	*		
700			*	*	*		*			*		
750	*	*		*			*	*	*	*		
800	*	*		*			*	*	*	*		
900	*	*		*			*	*	*	*		
1000	*	*		*			*	*	*	*		
1100	*	*	*	*			*	*	*	*		

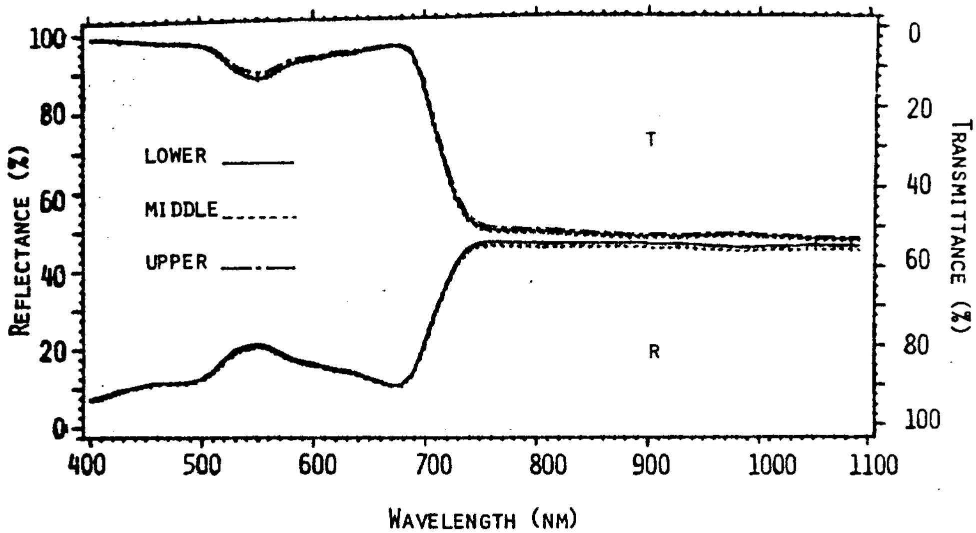
NOT SIGNIFICANT * SIGNIFICANT AT ALPHA = .05


TREE-26 UPPER STRATUM BOTH SURFACES
100
80
60
40
20
0
400
500
600
700
800
900
1000
1100
0
20
40
60
80
100
REFLECTANCE (%)
TRANSMITTANCE (%)
WAVELENGTH (NM)
T
R
FRONT
BACK
BACK
FRONT

15


TREE-26 ALL STRATA FRONT SURFACE
100
80
60
40
20
0
400
500
600
700
800
900
1000
1100
0
20
40
60
80
100
REFLECTANCE (%)
TRANSMITTANCE (%)
WAVELENGTH (NM)
T
R
LOWER
MIDDLE
UPPER

TREE-26 ALL STRATA BACK SURFACE



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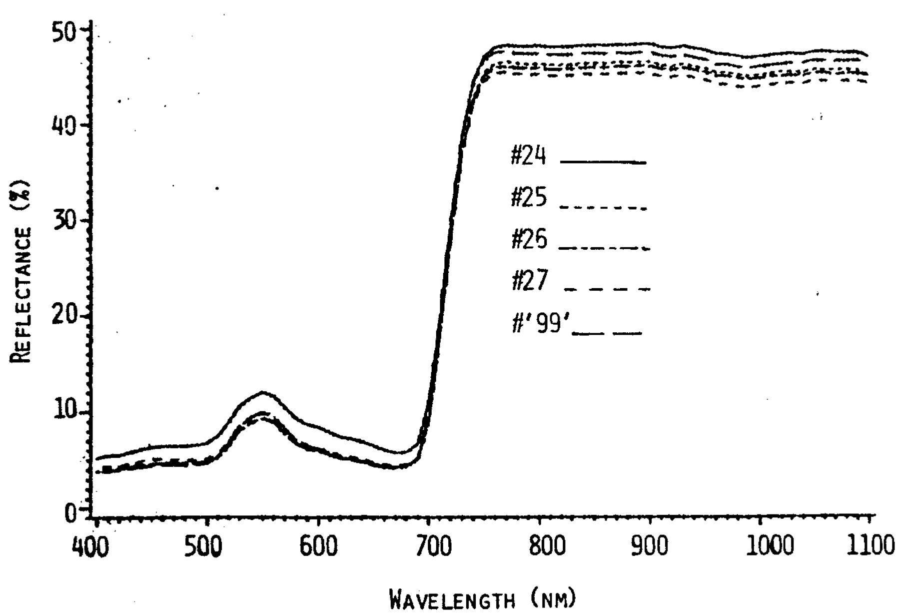
FIVE TREES MIDDLE STRATUM FRONT SURFACE



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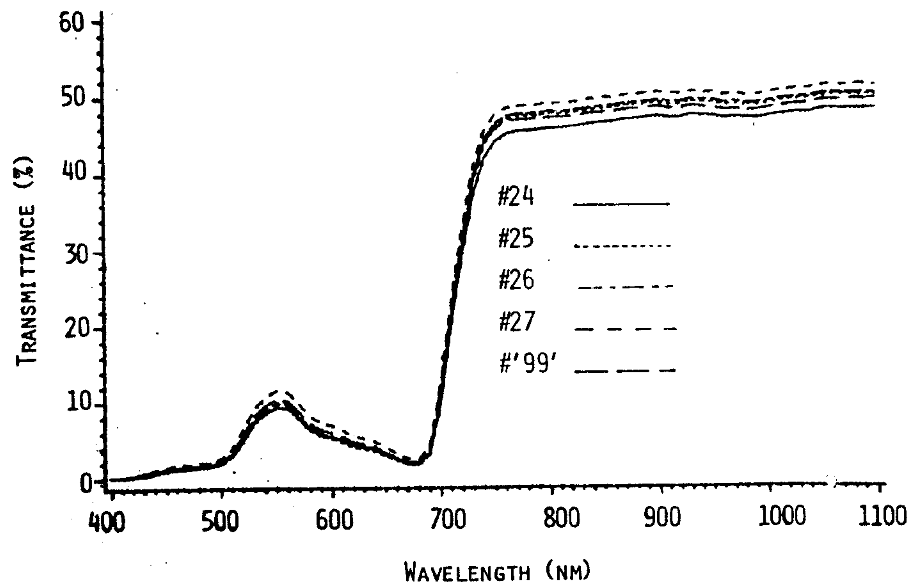
FIVE TREES MIDDLE STRATUM FRONT SURFACE



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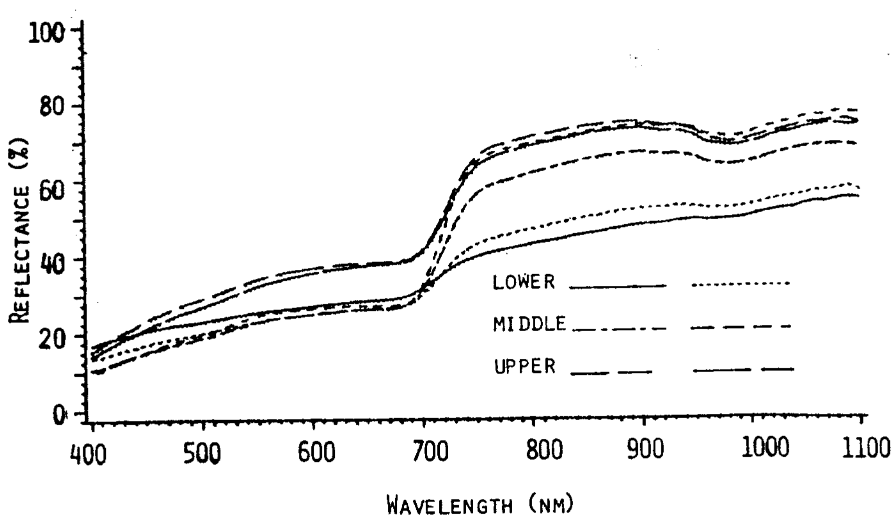
TREE-26 ALL STRATA BARK



DEVELOPMENT OF PROCEDURE TO MEASURE OPTICAL PROPERTIES OF NEEDLES

APPROACH

- DETERMINE THEORETICAL BASIS FOR MEASURING OPTICAL PROPERTIES OF NEEDLES USING LICOR-1800 INTEGRATING SPHERE.
- TEST ALGORITHM AND PROCEDURE USING SIMULATED NEEDLES OF NEXTAL SUEDE COATED PAPER. RESULTS $< \pm 10\%$ OF VALUE.
- TEST PROCEDURE WITH SETS OF 3, 7, AND 11 NEEDLES.
  RESULTS VARIATION IN SETS 3 - 11 $< \pm 8\%$
  7 - 11 $< \pm 5\%$

FLUXES MEASURED BY LICOR 1800 FROM INTEGRATING SPHERE

(SAMPLE ON SPECULARLY TRANSMITTING BACKGROUND)

REFLECTANCE MODE: $\frac{A_E}{A_T}\Phi_I\left[(1-F_6)(P_S+T_S^{\,2}P_B) + F_6P_B\right]B_R$

REFERENCE MODE: $\frac{A_E}{A_T}\Phi_I P_R B_W$

TRANSMITTANCE MODE: $\frac{A_E}{A_T}\Phi_I\left[F_6 P T_B B_T + (1-F_6)T_B T_S B_R\right]$

WHERE: A_E = AREA OF EXIT PORT

A_T = TOTAL SURFACE AREA OF SPHERE

P_R = REFLECTANCE OF CALIBRATION REFERENCE

P = REFLECTANCE OF SPHERE WALL

Φ_I = FLUX ENTERING SPHERE

P_S = REFLECTANCE OF SAMPLE

T_S = TRANSMITTANCE OF SAMPLE

P_B = REFLECTANCE OF BACKGROUND

T_B = TRANSMITTANCE OF BACKGROUND

F_B = PORTION OF BEAM AREA THAT DOES NOT STRIKE SAMPLE

B_R, B_W, B_T = FUNCTIONS OF SPHERE REFLECTANCE AND GEOMETRY AND SAMPLE REFLECTANCE

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CALIBRATION ALGORITHM FOR LICOR INTEGRATING SPHERE DATA

(SAMPLE ON SPECULARLY TRANSMITTING BACKGROUND -- BLACK SPRUCE NEEDLES)

REFLECTANCE: $$\left(\frac{F_R - F_S}{F_W - F_S} \cdot P_R \cdot \frac{1}{B_1} - F_6 P_B\right) \cdot \frac{1}{1 - F_6} - T_S^2 P_B$$

TRANSMITTANCE: $$\left[\frac{F_T}{F_W - F_S} \cdot \frac{P_R}{T_B} - P F_6 \cdot C_1\right] \frac{1}{1 - F_6} \cdot \frac{1}{B_1}$$

CALIBRATION ALGORITHMS FOR LICOR INTEGRATING SPHERE DATA

(SAMPLE NOT ON A BACKGROUND -- RED PINE AND JACK PINE)

REFLECTANCE: $\frac{F_R - F_S}{F_W - F_S} \cdot \frac{P_R}{1 - F_6} \cdot \frac{1}{B_1}$

TRANSMITTANCE: $\left[\frac{F_T}{F_W - F_S} \cdot P_R - P \cdot F_6 \cdot C_1 \right] \frac{1}{1 - F_B} \cdot \frac{1}{B_1}$

CALIBRATION ALGORITHMS FOR LICOR INTEGRATING SPHERE DATA

(SAMPLE COVERS ENTIRE SAMPLE PORT -- ASPEN LEAVES)

REFLECTANCE: $\frac{F_R - F_S}{F_W - F_S} \cdot P_R \cdot \frac{1}{B_1}$

TRANSMITTANCE: $\frac{F_T}{F_W - F_S} \cdot P_R \cdot \frac{1}{B_1}$

WHERE: F_R = FLUX MEASURED BY LICOR IN REFLECTANCE MODE

F_W = FLUX MEASURED BY LICOR IN REFERENCE MODE

F_T = FLUX MEASURED BY LICOR IN TRANSMITTANCE MODE

F_S = FLUX MEASURED BY LICOR IN REFLECTANCE MODE WITH NO SAMPLE, I.E., STRAY LIGHT

B_1, C_1 = FUNCTIONS OF SPHERE REFLECTANCE AND GEOMETRY AND SAMPLE REFLECTANCE; BETWEEN 1 AND 1.008. ASSUMED IN CALCULATIONS TO BE 1.

MEASUREMENT OF OPTICAL PROPERTIES OF BLACK SPRUCE NEEDLES

PROCEDURE

- MEASURE REFLECTANCE AND TRANSMITTANCE OF TAPE (STICKY SIDE).
- DETACH 4-5 NEEDLES FROM TWIG AND PLACE ON TAPE WITH APPROXIMATELY 1 NEEDLE SPACE IN BETWEEN.
- PUT SPACER ON TAPE -- ABOUT 1/2 NEEDLE THICKNESS -- AND PLACE IN SAMPLE PORT WITH NEEDLES TOWARD SPHERE.
- COLLECT MEASUREMENTS IN REFLECTANCE MODE AND REFERENCE MODE.
- ROTATE NEEDLE SAMPLE SO NEEDLES ARE AWAY FROM SPHERE. THEN COLLECT MEASUREMENTS IN TRANSMITTANCE MODE AND REFERENCE MODE.

BLACK SPRUCE NEEDLE MEASUREMENT (CONT.)

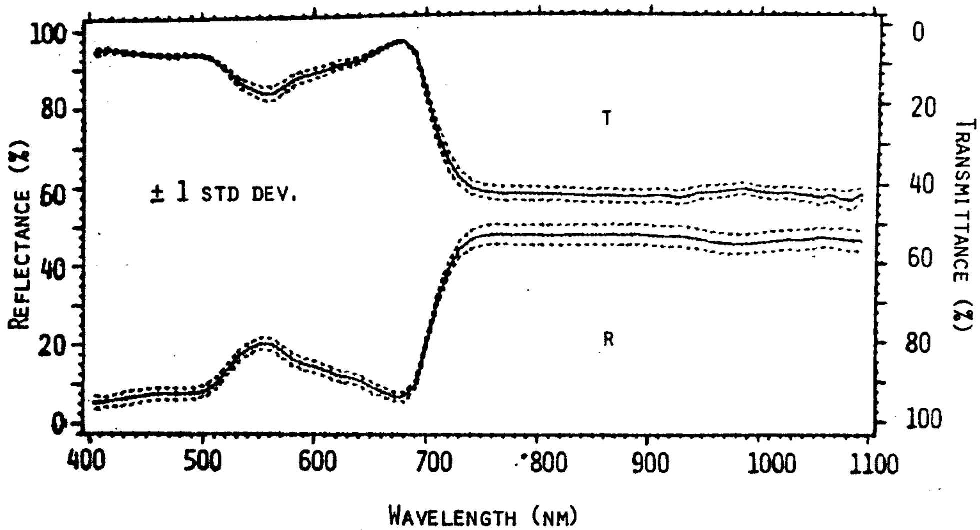
- BLACKEN SAMPLE OF NEEDLE SETS AND REMEASURE TRANSMITTANCE TO OBTAIN ESTIMATE OF TRANSMITTANCE IN RED.
- COMPUTE F_6 AT 680 NM USING BLACKENED NEEDLE SET. ASSUME T_S(680 NM) IS 0.
- COMPUTE T_S OF NON-BLACKENED NEEDLE SET.
- COMPUTE R_S OF NEEDLE SET.

OPTICAL PROPERTIES OF BLACK SPRUCE COMPONENTS

EXPERIMENT DESIGN

SITES:	HIGH, MEDIUM, LOW 'PHYTOMASS'
TREES:	HIGH - 55 MEDIUM - 53 LOW - 54
CANOPY LAYER:	LOWER, MIDDLE, UPPER
TREE COMPONENTS:	NEEDLES, TWIGS, BARK
NEEDLES:	6 SETS EACH CURRENT YEAR AND OLDER PER LAYER
TWIGS:	1 EACH CURRENT YEAR AND OLDER PER LAYER
SPECTRAL MEASUREMENTS:	REFLECTANCE AND TRANSMITTANCE OF FRONT AND BACK OF NEEDLES SETS. REFLECTANCE OF TWIGS.
SPECTRAL RANGE:	400 - 1100 NM SAMPLED EVERY 10 NM.

BLACK SPRUCE-54 FRONT CURRENT YEAR NEEDLES



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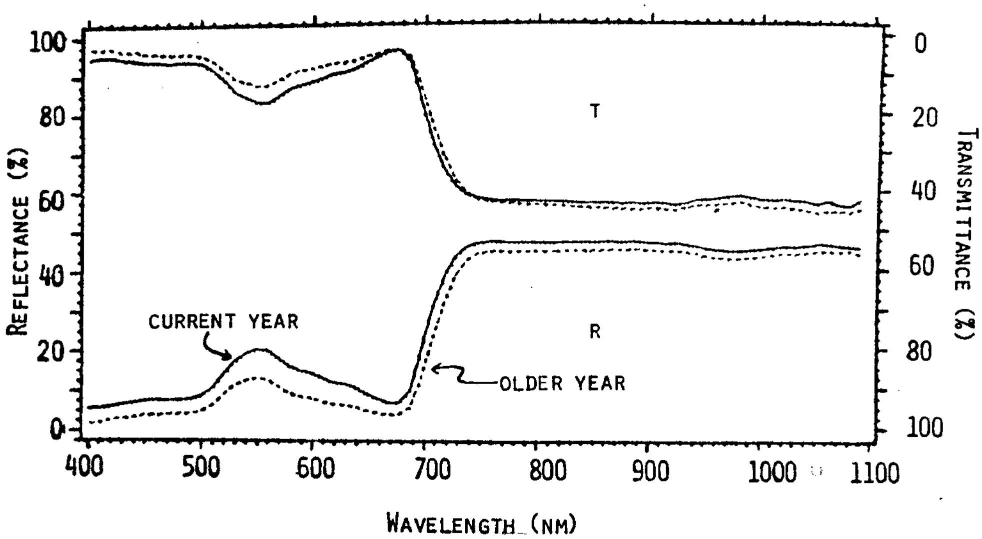
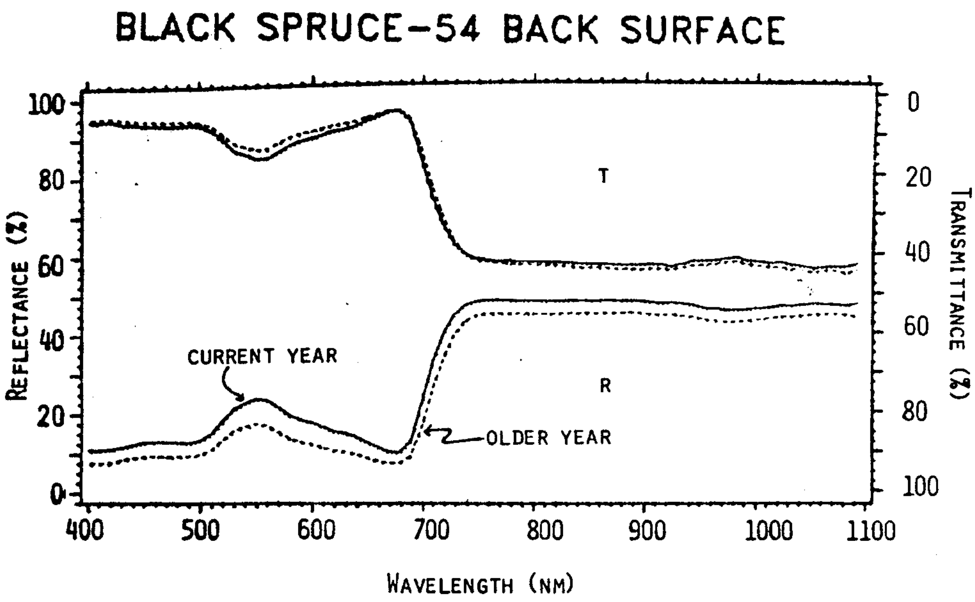
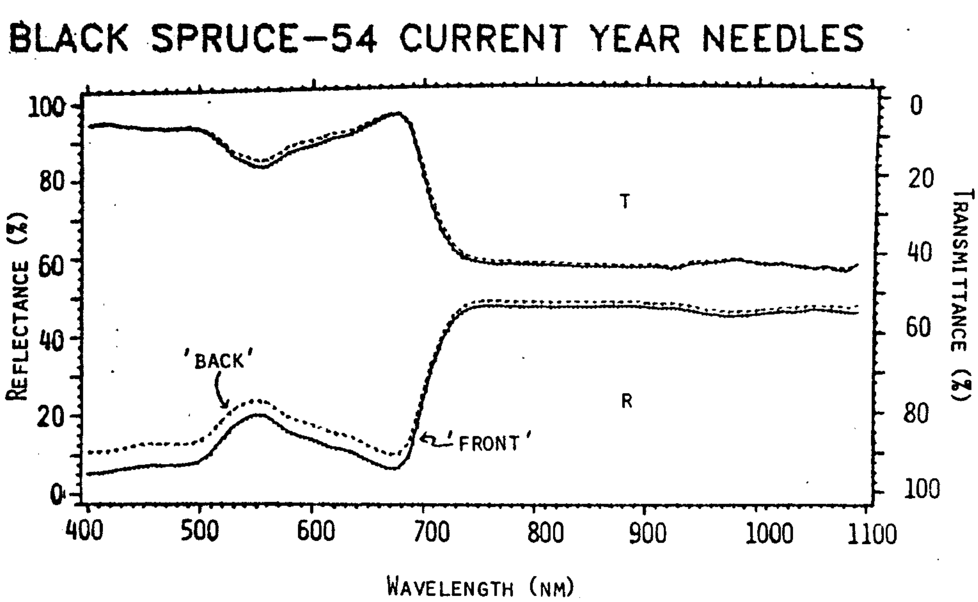
BLACK SPRUCE-54 FRONT SURFACE

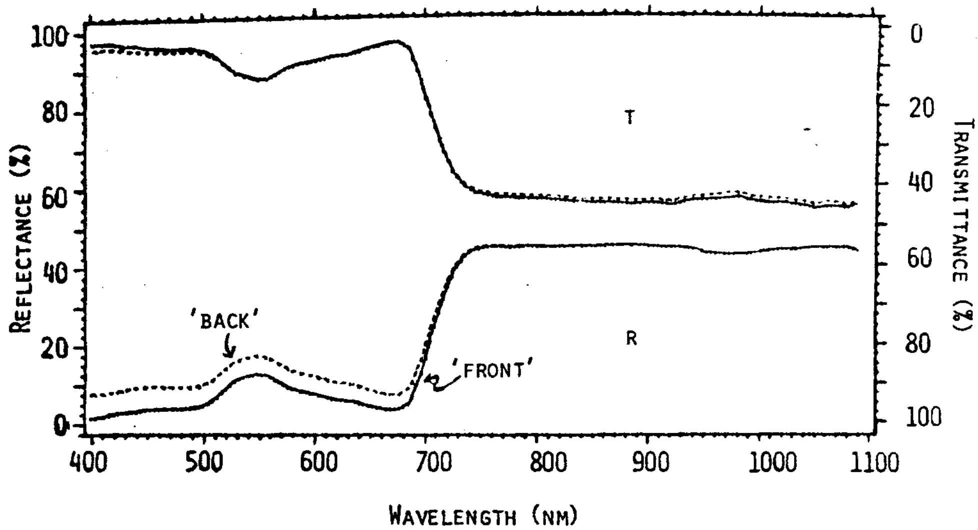



BLACK SPRUCE-54 BACK SURFACE
REFLECTANCE (%)
TRANSMITTANCE (%)
T
R
CURRENT YEAR
OLDER YEAR
WAVELENGTH (NM)
0
20
40
60
80
100
400
500
600
700
800
900
1000
1100

33


BLACK SPRUCE-54 CURRENT YEAR NEEDLES
REFLECTANCE (%)
TRANSMITTANCE (%)
T
R
'BACK'
'FRONT'
WAVELENGTH (NM)
0
20
40
60
80
100
400
500
600
700
800
900
1000
1100

BLACK SPRUCE-54 OLDER YEAR NEEDLES



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CALIBRATED DATA SETS

~~Means~~ Means and Standard Deviations of:

ASPEN -- Reflectance and transmittance of front and back of Aspen leaves and reflectance of bark

Overall	MeanRT Aspen
By layer	MeanL Aspen
By tree	MeanT Aspen
By tree and layer	Mean TL Aspen

Black Spruce --

[illegible] LEAVES
MEAN OF 10 SAMPLES BY TREE AND LAYER

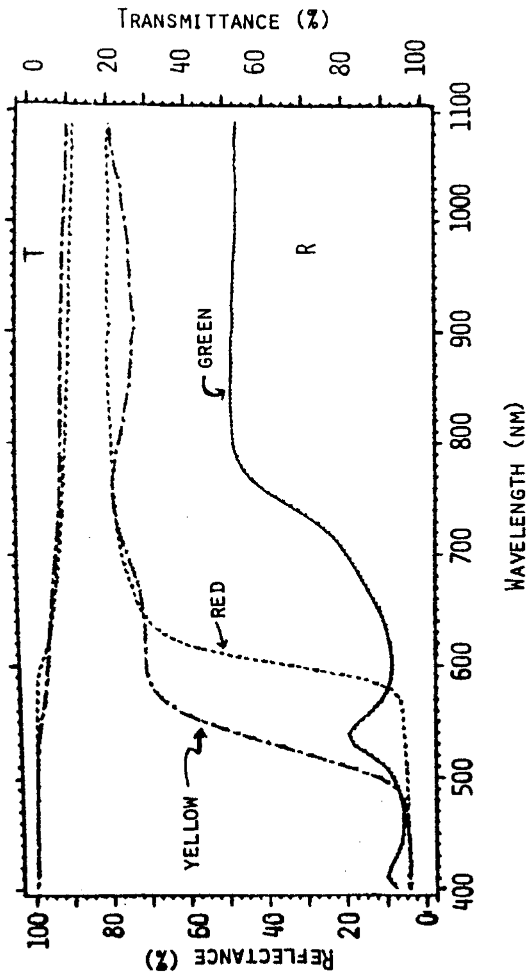
VARIABLE	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	C V
		TREE=27	LAYER=1		
W40	4.36	0.41	3.71	5.08	9.45
W41	4.41	0.40	3.88	5.06	8.96
W42	4.50	0.36	4.11	5.13	7.92
W43	4.70	0.31	4.33	5.28	6.65
W44	4.90	0.37	4.25	5.49	7.52
W45	5.11	0.36	4.51	5.62	7.02
W46	5.18	0.32	4.69	5.70	6.18
W47	5.16	0.36	4.60	5.72	6.92
W48	5.13	0.34	4.68	5.75	6.65
W49	5.12	0.35	4.63	5.71	6.76
W50	5.23	0.35	4.67	5.82	6.74
W51	5.75	0.39	5.12	6.26	6.77
W52	7.19	0.52	6.28	7.82	7.29
W53	9.11	0.70	7.85	9.94	7.73
W54	10.16	0.81	8.78	11.27	8.00
W55	10.76	0.88	9.30	12.11	8.22
W56	10.39	0.88	8.96	11.70	8.45
W57	8.99	0.79	7.71	10.16	8.75
W58	7.68	0.67	6.59	8.64	8.76
W59	7.03	0.61	6.02	7.83	8.75
W60	6.73	0.58	5.79	7.46	8.65
W61	6.27	0.54	5.41	6.95	8.66
W62	5.77	0.50	5.00	6.38	8.64
W63	5.58	0.48	4.85	6.16	8.61
W64	5.34	0.48	4.65	5.99	8.94
W65	4.96	0.44	4.34	5.72	8.84
W66	4.69	0.43	4.10	5.52	9.08
W67	4.51	0.42	3.97	5.38	9.27
W68	4.62	0.43	4.08	5.55	9.34
W69	5.34	0.48	4.65	6.11	8.92
W70	10.35	0.91	8.86	11.72	8.78
W71	20.03	1.38	17.88	22.29	6.88
W72	30.13	1.41	27.70	32.25	4.67
W73	38.24	1.22	35.74	39.67	3.19
W74	43.04	1.05	40.73	44.13	2.44
W75	45.13	1.02	42.96	46.38	2.26
W76	45.87	1.02	43.77	47.18	2.22
W77	46.03	1.04	43.87	47.38	2.26
W78	45.87	1.02	43.78	47.26	2.23
W79	45.85	1.02	43.76	47.25	2.23
W80	45.84	1.01	43.81	47.26	2.19
W81	45.71	1.00	43.69	47.16	2.20
W82	45.69	1.00	43.68	47.09	2.19
W83	45.73	0.99	43.73	47.12	2.16
W84	45.84	1.01	43.81	47.24	2.21
W85	45.88	0.99	43.96	47.33	2.15
W86	45.87	0.98	43.97	47.33	2.13
W87	45.97	0.98	44.04	47.36	2.14
W88	46.00	0.96	44.10	47.36	2.10
W89	46.02	0.97	44.15	47.41	2.11
W90	46.04	0.96	44.16	47.39	2.08
W91	45.70	0.95	43.85	47.05	2.08
W92	45.60	0.95	43.77	46.93	2.09
W93	45.79	0.93	44.04	47.20	2.03
W94	45.54	0.95	43.74	46.87	2.08
W95	45.34	0.96	43.62	46.77	2.12
W96	44.93	0.92	43.20	46.27	2.04
W97	44.86	0.90	43.22	46.18	2.00
W98	44.65	0.91	43.04	46.01	2.04
W99	44.52	0.90	42.89	45.81	2.01
W100	44.64	0.88	43.05	46.02	1.98
W101	44.77	0.85	43.17	46.07	1.91
W102	44.91	0.87	43.31	46.22	1.93
W103	45.02	0.86	43.40	46.28	1.91
W104	44.95	0.86	43.42	46.25	1.92
W105	45.11	0.91	43.48	46.42	2.01
W106	45.19	0.84	43.75	46.51	1.86
W107	45.14	0.91	43.38	46.43	2.02
W108	45.14	0.85	43.62	46.49	1.88
W109	45.17	0.84	43.82	46.54	1.86
W110	44.96	1.02	43.39	46.54	2.26

REFLECTANCE OF FRONT OF CURRENT YEAR BLACK SPRUCE NEEDLES
MEAN OF 4 SAMPLES BY TREE AND LAYER

VARIABLE	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	C V
	TREE=54	LAYER=1	SPECT=R	SIDE=F	AGE=C
W40	5.16	1.82	3.22	7.59	35.36
W41	5.29	1.32	3.92	7.05	24.96
W42	5.68	1.41	3.75	7.06	24.87
W43	6.26	1.79	3.89	8.04	28.67
W44	6.68	1.54	4.64	8.16	23.01
W45	7.16	1.64	5.10	8.97	22.89
W46	7.37	1.49	5.26	8.66	20.23
W47	7.34	1.52	5.24	8.76	20.75
W48	7.39	1.48	5.33	8.64	20.07
W49	7.57	1.46	5.53	8.84	19.22
W50	8.30	1.48	6.21	9.55	17.88
W51	10.24	1.54	7.97	11.28	15.00
W52	13.79	1.45	11.62	14.60	10.49
W53	17.24	1.43	15.13	18.31	8.31
W54	19.25	1.48	17.19	20.57	7.67
W55	20.50	1.51	18.54	21.88	7.39
W56	20.38	1.57	18.45	21.73	7.72
W57	18.38	1.58	16.43	19.77	8.59
W58	16.28	1.57	14.31	17.75	9.66
W59	15.05	1.56	13.08	16.57	10.33
W60	14.40	1.52	12.44	15.92	10.58
W61	13.32	1.49	11.37	14.79	11.18
W62	12.05	1.46	10.13	13.54	12.11
W63	11.60	1.43	9.69	13.02	12.31
W64	10.76	1.42	8.87	12.23	13.22
W65	9.11	1.38	7.23	10.54	15.14
W66	7.90	1.31	6.13	9.27	16.53
W67	6.65	1.26	4.97	7.99	18.94
W68	6.53	1.21	4.90	7.77	18.56
W69	9.72	1.22	8.04	10.93	12.53
W70	20.53	1.43	19.03	21.87	6.96
W71	31.64	1.69	29.98	33.57	5.35
W72	39.73	1.88	37.55	42.09	4.73
W73	44.83	2.13	42.21	47.34	4.76
W74	47.43	2.46	44.38	49.99	5.19
W75	48.46	2.63	45.25	51.04	5.43
W76	48.86	2.66	45.70	51.48	5.45
W77	48.91	2.62	45.71	51.44	5.35
W78	48.75	2.65	45.59	51.32	5.44
W79	48.72	2.72	45.46	51.36	5.59
W80	48.75	2.67	45.53	51.30	5.48
W81	48.70	2.69	45.46	51.32	5.52
W82	48.65	2.65	45.50	51.25	5.44
W83	48.74	2.66	45.58	51.32	5.46
W84	48.80	2.73	45.52	51.45	5.60
W85	48.82	2.66	45.59	51.35	5.45
W86	48.81	2.70	45.59	51.40	5.53
W87	48.88	2.73	45.66	51.54	5.58
W88	48.81	2.70	45.57	51.43	5.53
W89	48.92	2.74	45.67	51.61	5.61
W90	48.80	2.68	45.69	51.38	5.49
W91	48.54	2.64	45.43	51.10	5.44
W92	48.34	2.76	45.04	50.89	5.71
W93	48.44	2.74	45.10	51.10	5.65
W94	48.10	2.77	44.77	50.83	5.76
W95	47.64	2.64	44.53	50.29	5.55
W96	46.97	2.62	43.78	49.65	5.58
W97	46.70	2.71	43.35	49.39	5.81
W98	46.36	2.61	43.19	48.84	5.63
W99	46.41	2.57	43.26	48.88	5.54
W100	46.60	2.52	43.57	49.09	5.42
W101	46.89	2.69	43.78	49.61	5.73
W102	47.19	2.68	43.90	49.79	5.69
W103	47.56	2.61	44.52	50.17	5.48
W104	47.42	2.74	44.12	50.06	5.78
W105	47.65	2.80	44.11	50.21	5.87
W106	48.12	2.65	44.89	50.67	5.52
W107	47.97	2.50	45.03	50.18	5.22
W108	47.64	2.84	44.23	50.71	5.95
W109	47.26	2.86	43.21	49.58	6.04
W110	47.18	2.67	44.76	50.39	5.66

PAPER SQUARES FOR COMPARING LICOR & CARY

NEXTAL PAPER SQUARES



WAVE	RGREEN	RRED	TRED	RYELLOW	TYELLOW
400	6.76	3.44	0.00	3.35	0.00
410	9.17	3.66	0.12	3.15	0.17
420	8.15	3.24	0.04	3.04	0.08
430	6.57	3.33	0.11	3.17	0.00
440	5.37	3.38	0.10	3.15	0.03
450	4.91	3.54	0.00	3.44	0.09
460	4.77	3.50	0.00	3.68	0.03
470	4.77	3.50	0.02	3.97	0.06
480	5.18	3.51	0.01	4.76	0.03
490	6.05	3.60	0.01	6.50	0.02
500	7.30	3.64	0.04	10.66	0.01
510	9.13	3.72	0.01	18.36	0.03
520	12.91	3.90	0.00	28.17	0.12
530	17.37	4.15	0.00	37.90	0.29
540	18.64	4.37	0.03	47.07	0.59
550	16.34	4.50	0.01	55.60	1.05
560	12.96	4.72	0.02	62.44	1.57
570	10.29	5.18	0.04	66.96	2.00
580	8.57	7.25	0.06	69.66	2.37
590	7.67	14.97	0.21	71.09	2.63
600	7.37	30.34	0.82	71.57	2.83
610	7.46	47.83	1.88	71.77	3.00
620	7.83	60.20	2.84	71.84	3.18
630	8.41	66.73	3.49	71.85	3.34
640	9.17	70.23	3.96	72.00	3.52
650	10.30	72.47	4.37	72.24	3.73
660	11.73	73.87	4.68	72.62	3.91
670	13.35	74.83	4.94	73.19	4.12
680	14.96	75.74	5.23	73.90	4.32
690	16.55	76.88	5.53	74.9[illegible]	4.56
700	18.20	77.67	5.79	76.0[illegible]	4.79
710	20.06	78.22	5.98	77.06	5.02
720	22.52	78.71	6.19	78.13	5.24
730	25.81	79.12	6.36	78.92	5.43
740	30.09	79.43	6.54	79.61	5.62
750	34.86	79.68	6.67	79.98	5.77
760	39.62	80.02	6.82	80.29	5.90
770	43.42	80.34	6.96	80.33	5.99
780	45.81	80.17	7.09	79.81	6.05
790	47.41	80.46	7.23	79.47	6.11
800	48.37	80.62	7.38	79.03	6.14
810	48.67	80.64	7.48	78.26	6.16
820	48.82	80.74	7.60	77.73	6.18
830	49.00	80.95	7.73	77.21	6.20
840	49.18	81.11	7.86	76.79	6.24
850	49.16	81.31	7.98	76.29	6.26
860	49.15	81.27	8.05	75.71	6.29
870	49.07	81.45	8.17	75.56	6.34
880	49.04	81.53	8.27	75.25	6.37
890	49.06	81.60	8.39	75.10	6.45
900	49.01	81.52	8.46	74.96	6.48
910	48.64	80.92	8.45	74.47	6.48
920	48.56	80.90	8.56	74.48	6.57
930	48.81	81.59	8.69	74.97	6.70
940	48.61	81.47	8.78	75.20	6.85
950	48.50	81.54	8.80	75.59	6.91
960	48.34	81.25	8.89	75.44	7.02
970	48.34	81.58	8.96	75.89	7.05
980	48.05	81.17	9.01	75.82	7.12
990	47.85	81.02	9.06	75.95	7.17
1000	47.74	80.97	9.14	76.40	7.27
1010	47.76	81.10	9.30	76.82	7.37
1020	47.62	80.98	9.33	77.27	7.56
1030	47.57	80.96	9.45	77.62	7.65
1040	47.36	80.97	9.59	77.79	7.74
1050	47.47	81.23	9.74	78.52	8.02
1060	47.66	81.15	9.75	79.35	8.09
1070	47.50	81.22	9.71	79.53	8.07
1080	47.68	81.50	9.97	80.28	8.17
1090	47.47	81.15	9.76	80.52	8.42
1100	47.21	80.70	9.84	80.42	8.21

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REFLECTANCE CALIBRATION OF HELICOPTER MMR DATA
COLLECTED AT SUPERIOR NATIONAL FOREST

LARRY BIEHL

PURDUE UNIVERSITY/LARS

10/83-1

REFLECTANCE FACTOR CALIBRATION ALGORITHM FOR HELICOPTER MMR DATA AT SUPERIOR NATIONAL FOREST TEST SITE

ASSUMING ILLUMINATION CONDITIONS AT SCENE (TEST SITE) AND REFERENCE PANEL SITE ARE THE SAME:

$$R_S(\lambda,\theta) = \frac{D_S(\lambda)-DL_S(\lambda)}{D_R(\lambda)-DL_R(\lambda)} \cdot F(\lambda) \cdot R_R(\lambda,\theta)$$

WHERE: $R_S(\lambda,\theta), R_R(\lambda,\theta)$ = IN-BAND REFLECTANCE FACTOR OF SCENE AND REFERENCE PANEL, RESPECTIVELY (%)

$D_S(\lambda)$ = IN-BAND RESPONSE OF HELICOPTER MMR TO SCENE

$D_R(\lambda)$ = IN-BAND RESPONSE OF CALIBRATION MMR TO REFERENCE PANEL NEAREST IN TIME TO MMR RESPONSE TO SCENE (MAXIMUM TIME DIFFERENCE OF 1 MINUTE)

$DL_S(\lambda)$
$DL_R(\lambda)$ = RESPONSE OF MMRS TO NO LIGHT INPUT (DARK LEVEL)

θ = SOLAR ZENITH ANGLE AT TIME OF OBSERVATION OF REFERENCE PANEL

$F(\lambda)$ = FACTOR RELATING HELICOPTER AND CALIBRATION MMRS

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INSTRUMENT CORRELATION FACTOR

$F(\lambda)$ IS COMPUTED USING SIMULTANEOUS CALIBRATION AND HELICOPTER MMR RESPONSES TO REFERENCE PANEL AT BEGINNING AND END OF DATA ACQUISITION DAYS.

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IN-SITU DATA COLLECTION

SUMMARY OF

DATA COLLECTION OF CANOPY COMPONENT OPTICAL PROPERTIES

BY

LARRY BIEHL

PURDUE UNIVERSITY/LARS

OCTOBER 18, 1983

10/83-1

ACCOMPLISHMENTS

- STUDY CONDUCTED TO DETERMINE CHANGE IN OPTICAL PROPERTIES OF RED BIRCH LEAVES AND RED PINE NEEDLES AFTER EXCISION. (CONCLUDED CHANGE LESS THAN ±5% OF VALUE FOR UP TO 1 WEEK FOR SAMPLES STORED IN SEALED PLASTIC BAGS AT 5° C.)

- PROCEDURE DEVELOPED TO MEASURE REFLECTANCE AND TRANSMITTANCE OF NEEDLES.

- OPTICAL PROPERTIES OF 150 ASPEN LEAVES, 22 ASPEN BARK SAMPLES, 108 BLACK SPRUCE NEEDLE SETS, 18 BLACK SPRUCE TWIGS, 5 RED PINE NEEDLE SETS, AND 5 JACK PINE NEEDLE SETS WERE MEASURED.

- APPROACH TO UNDERSTANDING ROLE OF BACKGROUND REFLECTANCE DEVELOPED.

OPTICAL PROPERTIES OF ASPEN TREE COMPONENTS

EXPERIMENT DESIGN

SITES:	HIGH, MEDIUM, LOW 'PHYTOMASS'
TREES:	HIGH - 24, 25, 26 MEDIUM - 27 LOW - ? (1)
CANOPY LAYERS:	LOWER, MIDDLE, UPPER
TREE COMPONENTS:	LEAVES, BARK
LEAVES:	10 PER LAYER
BARK SAMPLES:	2 PER LAYER
SPECTRAL MEASUREMENTS:	REFLECTANCE AND TRANSMITTANCE OF FRONT AND BACK OF LEAVES. REFLECTANCE OF BARK.
SPECTRAL RANGE:	400 - 1100 NM SAMPLED EVERY 10 NM.

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OPTICAL PROPERTIES OF BLACK SPRUCE COMPONENTS

EXPERIMENT DESIGN

SITES:	HIGH, MEDIUM, LOW 'PHYTOMASS'
TREES:	HIGH - 55 MEDIUM - 53 LOW - 54
CANOPY LAYER:	LOWER, MIDDLE, UPPER
TREE COMPONENTS:	NEEDLES, TWIGS, BARK
NEEDLES:	6 SETS EACH CURRENT YEAR AND OLDER PER LAYER
TWIGS:	1 EACH CURRENT YEAR AND OLDER PER LAYER
SPECTRAL MEASUREMENTS:	REFLECTANCE AND TRANSMITTANCE OF FRONT AND BACK OF NEEDLES SETS. REFLECTANCE OF TWIGS.
SPECTRAL RANGE:	400 - 1100 NM SAMPLED EVERY 10 NM.

OPTICAL PROPERTIES OF 'OTHER' SPECIES

EXPERIMENT DESIGN

SPECIES:	RED PINE JACK PINE
NEEDLES:	5 SETS
SPECTRAL MEASUREMENTS:	REFLECTANCE AND TRANSMITTANCE OF 'FRONT' AND 'BACK' OF NEEDLE SETS
SPECTRAL RANGE:	400-1100 NM SAMPLED EVERY 10 NM

DATES DATA COLLECTED

ASPEN LEAVES AND BARK:	AUGUST 20 - 28
BLACK SPRUCE NEEDLES AND TWIGS:	SEPTEMBER 24 - OCTOBER 4
RED PINE NEEDLES:	SEPTEMBER 30
JACK PINE NEEDLES:	SEPTEMBER 30

SUMMARY OF MEASUREMENTS USING LICOR 1800 INTEGRATING SPHERE

Component	Number of Measurements	
	Component Part	Calibration
Aspen Leaves	648	324
Aspen Bark	22	22
Black Spruce Needles	216	216
Black Spruce Twigs	18	18
Red Pine Needles	20	10
Jack Pine Needles	30	20

Total number of measurements = 1564

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SAMPLES SENT TO NASA/JSC FOR MEASUREMENT WITH CARY-14

(Spectral coverage of Cary-14 is .4 - 2.5 μm)

- ASPEN – 3 leaves/layer for trees 25, 26, 27 & 'low phytomass'

  1 - 2 bark samples per layer

- Green, Yellow, and Red Squares of 3M Nextal Suede Paper for LiCor and Cary-14 measurements comparison

BACKGROUND REFLECTANCE

- GENERAL BACKGROUND CLASSES:

  BLACK SPRUCE - MOSS
  - GRASS
  - SCATTERED LOW SHRUBS

  ASPEN - SCATTERED LOW SHRUBS (.3 - 1.0 METER)
  - SCATTERED HIGH SHRUBS (2 - 2.5 METER)

- PROCEDURES AND INSTRUMENT MOUNT WERE DEVELOPED DURING SEPTEMBER TO MAKE 'REFLECTANCE' MEASUREMENTS OF MOSS, GRASS, AND LOW SHRUBS WITHIN CANOPY.

- A GOOD SET OF MEASUREMENTS WAS NOT MADE BECAUSE OF CLOUD COVER. 12 MEASUREMENTS OF MOSS IN 6 LOCATIONS AT SITE 41 WERE MADE ON 9/12/83 UNDER OVERCAST CONDITIONS FOR TEST.

APPROACH TO UNDERSTANDING ROLE OF BACKGROUND REFLECTANCE

- CONCENTRATE ON LOW 'UNIFORM' BACKGROUNDS -- MOSS, MAYBE GRASS. (SHRUBS ARE MUCH MORE COMPLICATED BECAUSE OF 3-DIMENSIONAL NATURE AND NON-UNIFORMITY.)

- COLLECT REFLECTANCE MEASUREMENTS OF BACKGROUND AT >20 LOCATIONS IN SITE WITH REFERENCES TO REFLECTANCE PANEL AT SAME LOCATION AND SECOND REFERENCE PANEL IN OPEN. REPEAT 4 - 5 TIMES THRU DAY. SUNNY CONDITION; NO CLOUDS NEAR SUN. DETERMINE VARIATION AS FUNCTION OF DAY AND SPATIAL LOCATION.

- MEASURE REFLECTANCE OF AT LEAST 4 SAMPLES OF MOSS TAKEN TO AN OPEN AREA.

- COLLECT MEASUREMENTS OF CANOPY WITH SNOW BACKGROUND SEVERAL TIMES THRU DAY. COLLECT REFLECTANCE MEASUREMENTS OF SNOW ONLY.

- USE MEASUREMENTS FROM CONTROLLED EXPERIMENT WITH BACKGROUND VARIATION.

BACKGROUND REFLECTANCE ISSUES

- WHAT REFLECTANCE MEASUREMENT OF BACKGROUND DO MODELS REQUIRE?
  - BACKGROUND ONLY
  - BACKGROUND UNDER CANOPY

- HOW SENSITIVE ARE MODELS TO BACKGROUND REFLECTANCE?

SUMMARY OF HEMISPHERICAL PHOTOGRAPHY

DATA ACQUISITION

DATES	SITES	CONDITION OF ASPEN
5/16	ASPEN - 22	NO LEAVES
EARLY SEPTEMBER	ASPEN - 16, 71, 73	LEAVES ON TREE
	BLACK SPRUCE - 2, 12, 56	--
MID-OCTOBER	ASPEN - 16, 71, 73	SOME LEAVES ON TREE
	BLACK SPRUCE - 2, 12, 56	--
NOVEMBER	ASPEN - 16, 71, 73	NO LEAVES
	BLACK SPRUCE - 2, 12, 56	--

FUTURE PLANS

- Complete measurements of 'low phytomass' of Aspen bark and Black Spruce bark.
- Preprocess optical measurements of Black Spruce components and summarize results.
- Digitize hemispherical photography.

DIURNAL CHANGES IN REFLECTANCE FACTOR OF VEGETATIVE CANOPIES

BY

CRAIG DAUGHTRY, LARRY BIEHL, MARVIN BAUER

PURDUE UNIVERSITY/LARS

OCTOBER 18, 1983

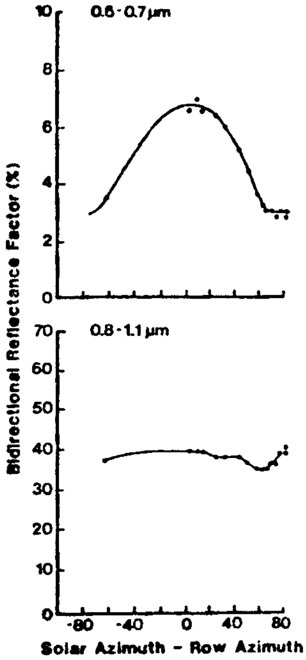
10/83-1

DIURNAL CHANGES IN REFLECTANCE FACTOR OF VEGETATIVE CANOPIES

BACKGROUND

- REMOTELY-SENSED SPECTRAL MEASUREMENTS OF VEGETATION ARE INFLUENCED BY MANY FACTORS INCLUDING:
  - TYPE - SPECIES, VARIETY
  - CONDITION - AGE, STRESS, DISEASE, % COVER
  - SOIL BACKGROUND - SOIL TYPE, COLOR, MOISTURE
  - ATMOSPHERE - OPTICAL DEPTH, HAZE, CLOUDS
  - CANOPY GEOMETRY - PLANT SPACING, HEIGHT, WIDTH, LEAF ANGLES
  - ILLUMINATION - SOLAR AZIMUTH AND ZENITH ANGLES
  - SENSOR - VIEW ANGLE, SIZE OF RESOLUTION ELEMENT
- PREVIOUS RESEARCH HAS SHOWN AND SOME CANOPY MODELS PREDICT THAT AS PROPORTIONS OF SUNLIT AND SHADED SOIL AND VEGETATION CHANGE, REFLECTANCE OF THE COMPOSITE SCENE MAY VARY MORE THAN 100%, ESPECIALLY IN VISIBLE WAVELENGTHS.

CHANGES IN REFLECTANCE IN RED (0.6-0.7 UM) AND NEAR INFRARED (0.8-1.1 UM) BANDS PLOTTED AGAINST DIFFERENCES BETWEEN SOLAR AND ROW AZIMUTH. SOIL COVER IS 64%.



- RED REFLECTANCE CHANGED MORE THAN 100% OF VALUE DURING THE DAY DUE TO VARYING AMOUNT OF SHADOW WITHIN THE CANOPY.

- VARIATIONS IN NEAR INFRARED REFLECTANCE ARE LOWER (RELATIVE OF MINIMUM REFLECTANCE OBSERVED) THAN THAT NOTED IN RED REGION. CHANGES IN IR ARE NOT AS CLEARLY RELATED TO SUN-ROW INTERACTIONS AS IN VISIBLE.

- ABSOLUTE CHANGES IN REFLECTANCE ARE SIMILAR IN BOTH REGIONS.

KOLLENKARK, ET AL., 1982. APPLIED OPTICS 21:1179-1184.

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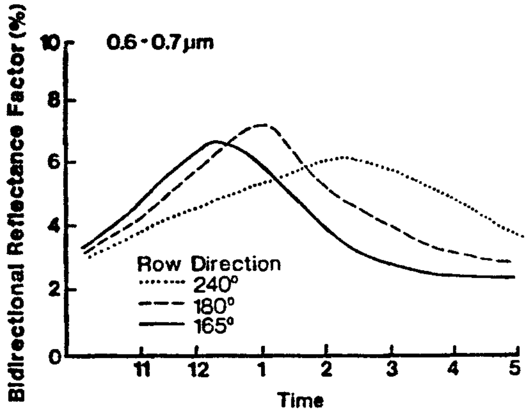
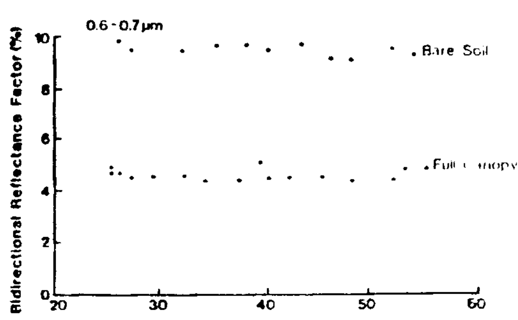


REFLECTANCE OF SOYBEANS IN RED WAVELENGTH REGION (0.6-0.7 UM) FOR THREE ROW DIRECTIONS OVER TIME. (64% SOIL COVER).



REFLECTANCE IN RED WAVELENGTH REGION FOR BARE SOIL AND FULL (100% COVER) CANOPY OF SOYBEANS WITH CHANGES IN SOLAR ZENITH ANGLE.

- KOLLENKARK, J.C., V.C. VANDERBILT, C.S.T. DAUGHTRY AND M.E. BAUER. 1982. INFLUENCE OF SOLAR ILLUMINATION ANGLE ON SOYBEAN CANOPY REFLECTANCE. APPLIED OPTICS 21:1179-1184.

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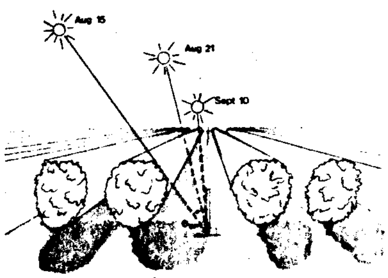
PROJECTED SOLAR ANGLE, θ_{SP}

$$\theta_{SP} = \tan^{-1}(\tan\theta \ \sin\phi)$$

WHERE: θ = SOLAR ZENITH ANGLE
ϕ = DIFFERENCE BETWEEN ROW AZIMUTH AND SUN AZIMUTH ANGLES.



PROJECTED SOLAR ANGLE ACCOUNTS FOR THE SIZE OF THE SHADOW OF THE FOLIAGE PROJECTED ON THE SOIL.

ILLUSTRATION OF THE PROJECTED SOLAR ANGLE, θ_{SP}, AS OBSERVED WHEN LOOKING TO THE WEST. THREE DATES AND THE CORRESPONDING TIMES RESULT IN THE SAME SHADOW PATTERN AND $\theta_{SP} \cong 26$ DEGREES.

DATE	TIME	ZENITH	AZIMUTH	θ_{SP}
15 AUG	12:00	26.3	180.0	26.3
21 AUG	2:09	40.1	234.2	26.3
10 SEP	4:49	73.7	261.7	26.3

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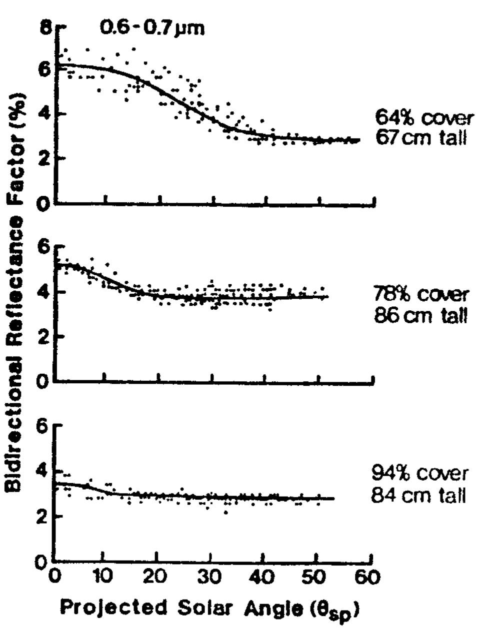
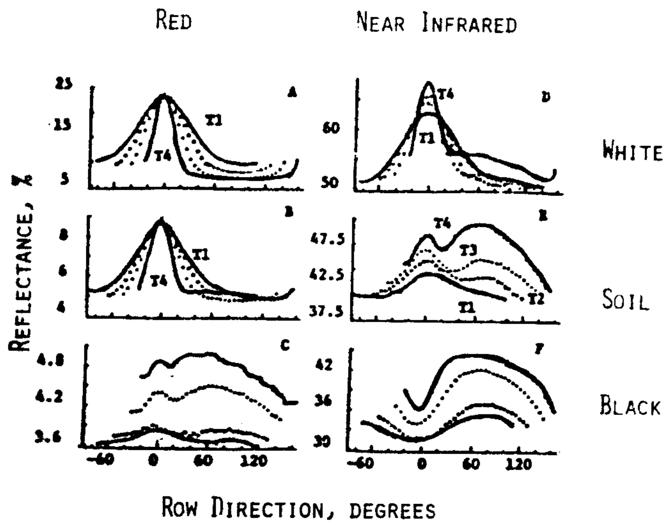
RELATIONSHIP BETWEEN RED REFLECTANCE AND PROJECTED SOLAR ANGLE FOR THREE SOYBEAN CANOPIES



- CANOPIES WITH LOW SOIL COVERS SHOWED GREATER CHANGES IN REFLECTANCE DUE TO CHANGING SUN ANGLE THAN THE NEAR FULL CANOPY.
- TWO FUNCTIONS PRESENT:
  1. DEPENDENT ZONE - WHERE REFLECTANCE IS CHANGING RAPIDLY WITH SOLAR ANGLE. MEASURED REFLECTANCE IS A FUNCTION OF SUNLIT SOIL REFLECTANCE AND VEGETATIVE REFLECTANCE.
  2. INDEPENDENT ZONE - WHERE SOIL SURFACE IS COMPLETELY SHADOWED. MEASURED REFLECTANCE IS FUNCTION OF PERCENT SOIL COVER.
- CRITICAL ANGLE SHIFTS TO LOWER PROJECTED SOLAR ANGLES FOR HIGHER SOIL COVERS OR CANOPY HEIGHTS.

KOLLENKARK ET AL., 1982. APPLIED OPTICS 21:1179-1184.

REFLECTANCE OF SOYBEAN CANOPIES WITH ROW DIRECTION AND SOLAR ZENITH ANGLE.
ZERO IS SUN AZIMUTH DIRECTION. COVER IS 60%.

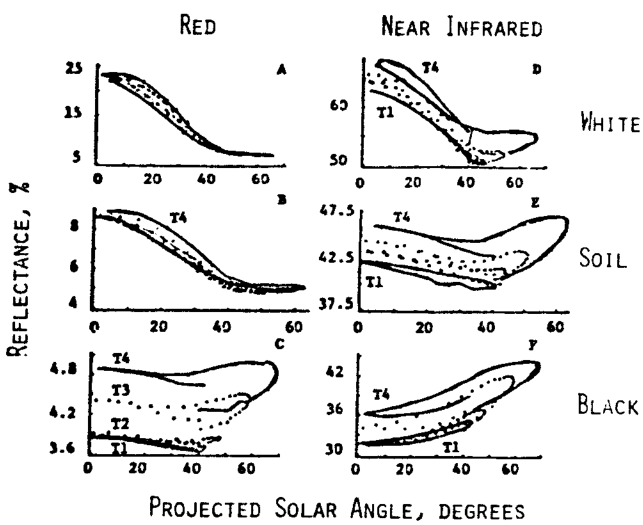


T1 = TIME INTERVAL WITH AVERAGE SOLAR ZENITH OF 22°.
T4 = TIME INTERVAL WITH AVERAGE SOLAR ZENITH OF 39°.

- RED REFLECTANCE OF CANOPIES ORIENTED AT 0° ROW DIRECTION DID NOT CHANGE WITH SOLAR ZENITH FOR WHITE AND SOIL. AT ALL OTHER ROW DIRECTIONS RED REFLECTANCE DECREASED AS ZENITH ANGLE INCREASED.
- NEAR IR REFLECTANCE INCREASED AS SOLAR ZENITH INCREASED.
- DARK BACKGROUNDS ARE DIFFERENT.
  - RED REFLECTANCE HAD TWO LOCAL MAXIMA.
  - IR REFLECTANCE HAD MAXIMA AT 60-90° TO ROW DIRECTION.

- VANDERBILT, V.C., J.C. KOLLENKARK, L.L BIEHL, B.F. ROBINSON, M.E. BAUER, AND K.J. RANSON. 1980 DIURANL CHANGES IN REFLECTANCE FACTOR DUE TO SUN-ROW DIRECTION INTERACTIONS. INT'L COLLOQUIUM ON SPECTRAL SIGNATURES OF OBJECTS IN REMOTE SENSING. AVIGNON, FRANCE. 8-11 SEP 1980. (LARS TECH. REPORT 090881).

REFLECTANCE OF SOYBEAN CANOPIES AS FUNCTION OF PROJECTED SOLAR ANGLE



T1 = TIME INTERVAL WITH AVERAGE ZENITH OF 22°.
T4 = TIME INTERVAL WITH AVERAGE ZENITH OF 39°.

- CANOPY REFLECTANCE IS A FUNCTION OF PROJECTED SOLAR ANGLE AND BACKGROUND REFLECTANCE.
- PROJECTED SOLAR ANGLE EXPLAINS MOST OF VARIATION IN RED REFLECTANCE OF CANOPIES WITH WHITE AND SOIL BACKGROUNDS.
- BOTH PROJECTED SOLAR ANGLE AND SOLAR ZENITH ANGLE AFFECT REFLECTANCE IN IR REGION AND IN RED REGION WITH BLACK BACKGROUND.
- RESULTS FOR RED SUPPORT MOST CANOPY REFLECTANCE MODELS.

* VANDERBILT, ETAL., 1980. LARS TECH. REPORT 090881.

OBJECTIVES

To investigate changes in spectral reflectance of vegetative canopies related to sun angle, background, and plant density.

APPROACH

1. Design/modify equipment to acquire spectral data at two view angles of simulated canopies on a turntable.
2. Arrange pots of small (1 m) Balsam Fir trees in equidistant patterns on a turntable to simulate canopies with different densities of trees.
3. Acquire spectral reflectance data of canopy with Barnes MMRs.
4. Rotate the turntable (360 degrees in 10-degree increments) and change the background between the trees (white-and-black painted boards plus grass).

APPROACH (cont.)

5. Measure key biophysical characteristics of representative trees including:
   - height and width of crown
   - number and length of branches
   - length, width, and area of needles
   - weights of stems, branches, and needles
   - reflectance and transmittance of needles, twigs, bark
6. Analyze these data plus previously acquired data for wheat, sorghum, and soybeans. Describe changes in reflectance as functions of solar illumination and sensor view angles as well as key biophysical characteristics.

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STUDIES OF THE EFFECTS OF SUN ANGLE AND VIEW ANGLE ON REFLECTANCE OF VEGETATION CANOPIES

BY

JON RANSON

LARRY BIEHL

PURDUE UNIVERSITY/LARS

OCTOBER 18, 1983

10/18-1

OUTLINE

- SUMMARY OF DATA SETS
- EFFECTS OF SUN ANGLE ON REFLECTANCE FACTOR WITH NORMAL VIEW ANGLE
- EFFECTS OF SUN ANGLE ON TRANSFORMATIONS WITH NORMAL VIEW ANGLE
- EFFECTS OF SUN ANGLE/VIEW ANGLE ON REFLECTANCE FACTOR
- EFFECTS OF SUN ANGLE/VIEW ANGLE ON TRANSFORMATIONS

Table 1. Summary of Sun-view Angle Data Sets for Soybeans (1980) and Corn(1982).

DATE	START TIME (GMT)	END TIME (GMT)	SOLAR ZENITH ANGLE RANGE (DEGREES) MAX-MIN-MAX	SOLAR AZIMUTH ANGLE RANGE (DEGREES)	NUMBER OF DATA SETS	CLOUD COVER (%)	
July 18,1980	17:59	21:35	19-50	183-265	5	10-20	*
July 25,1980	15:14	18:49	40-21-24	109-214	6	1-20	*
Aug 27,1980	15:15	18:49	40-30-60	132-237	12	0	*
June 13,1982	17:24	21:58	18-17-55	162-272	9	1-10	*
June 14,1982	15:58	18:01	27-17	118-190	6	10-20	
June 21,1982	14:52	19:16	41-17-25	101-233	9	10-40	
June 23,1982	16:55	18:45	21-17-21	142-218	5	5-30	
June 24,1982	14:07	18:38	49-18-20	92-214	10	5-10	*
July 6,1982	15:10	18:21	38-18-19	105-201	3	3-60	
July 9,1982	15:26	16:14	36-28	109-123	2	10-17	
July 12,1982	14:30	16:43	46-26	110-136	5	0-35	
July 14,1982	14:59	15:21	41-37	103-108	2	15-25	
July 15,1982	15:07	16:11	40-29	105-123	3	1-10	
July 16,1982	16:58	17:07	22-21	144-149	1	15	
July 23,1982	14:25	22:42	49-23-64	98-275	17	1-10	*
July 30,1982	14:01	15:27	54-42	96-109	4	0- 3	
July 31,1982	13:46	16:50	57-26	93-143	7	0-32	
Aug 11,1982	14:14	18:27	51-25-26	103-197	12	0-20	
Aug 12,1982	14:08	19:15	53-25-31	102-222	24	0-20	*
Aug 19,1982	14:58	19:17	48-31-37	118-219	16	5-20	
Aug 28,1982	16:00	17:48	39-31	135-180	7	15-30	
Sept 4,1982	14:13	21:30	48-33-70	123-262	24	0- 1	*
Oct 25,1982	16:30	21:30	53-52-80	170-245	18	10-15	

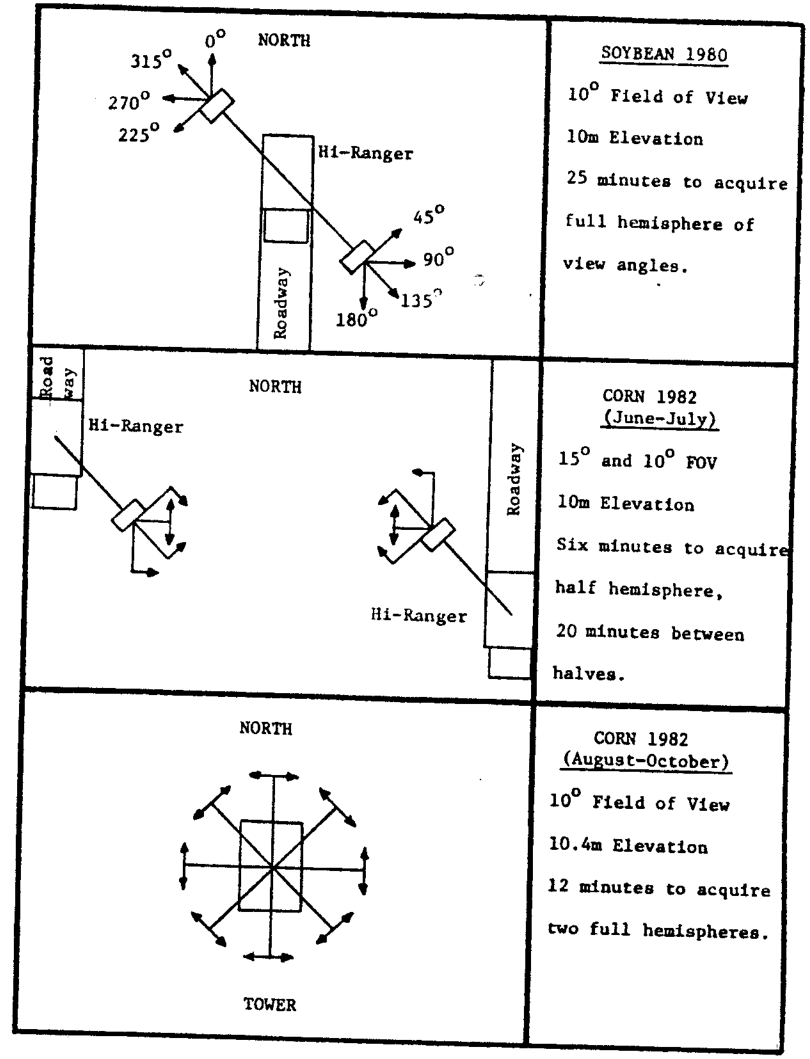
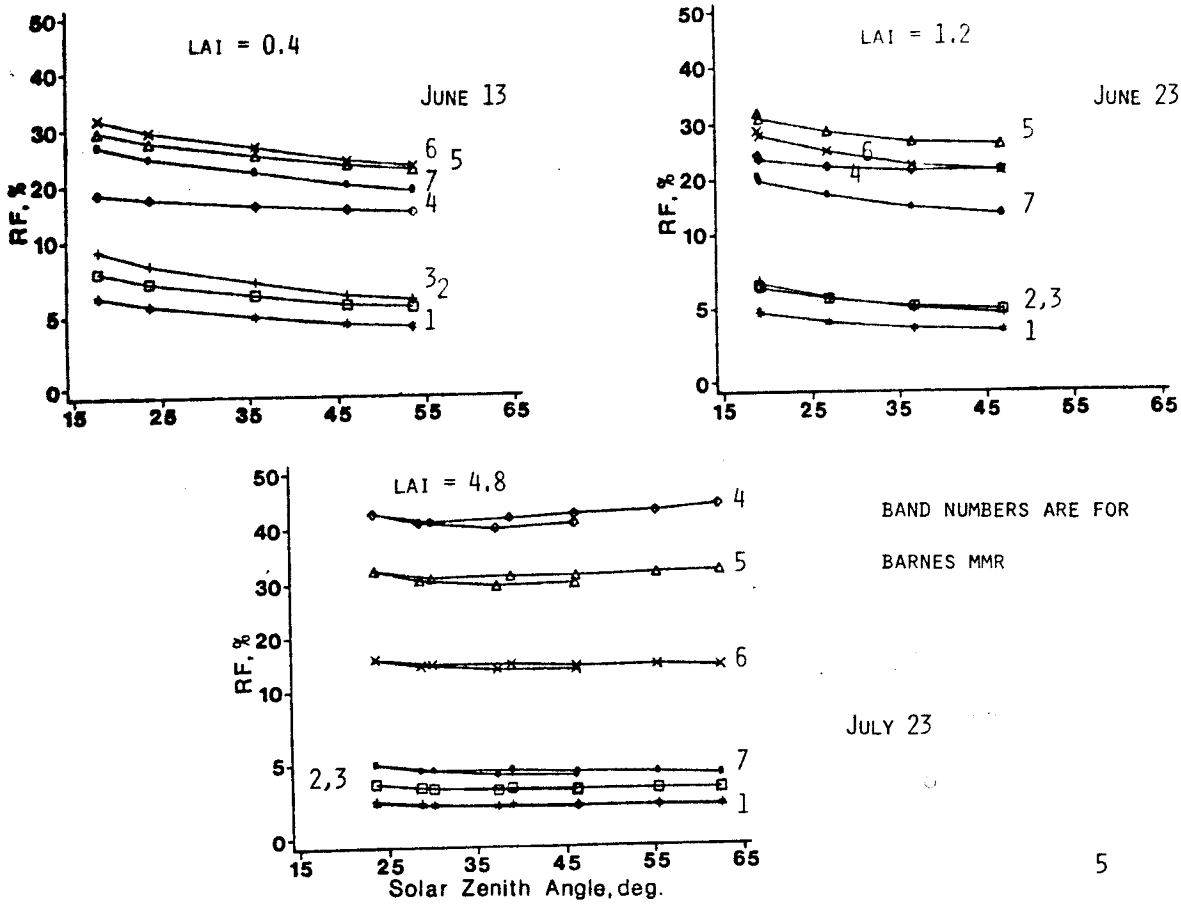


Figure 6-2. Spectral data collection configurations for 1980 and 1982 sun-view angle experiments. Arrows indicate view azimuths.

REFLECTANCE FACTOR AS A FUNCTION OF SOLAR ZENITH ANGLE. CORN.
VIEW ANGLE (θ_V) IS 0°



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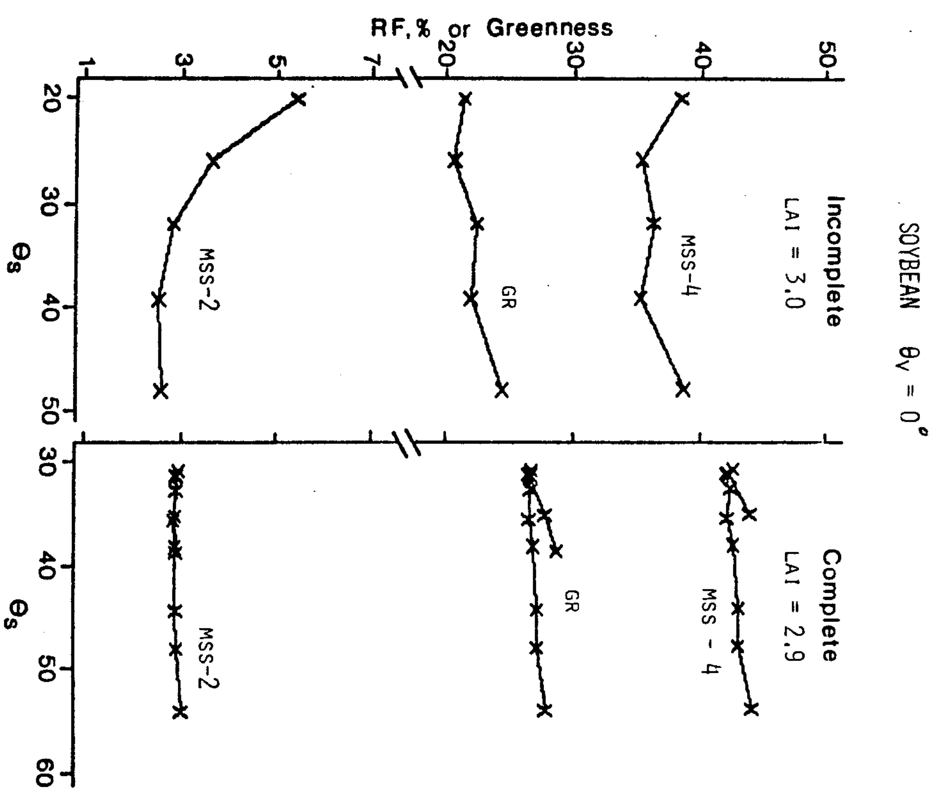


REFLECTANCE FACTOR AND GREENNESS AS A FUNCTION OF
SOLAR ZENITH ANGLE

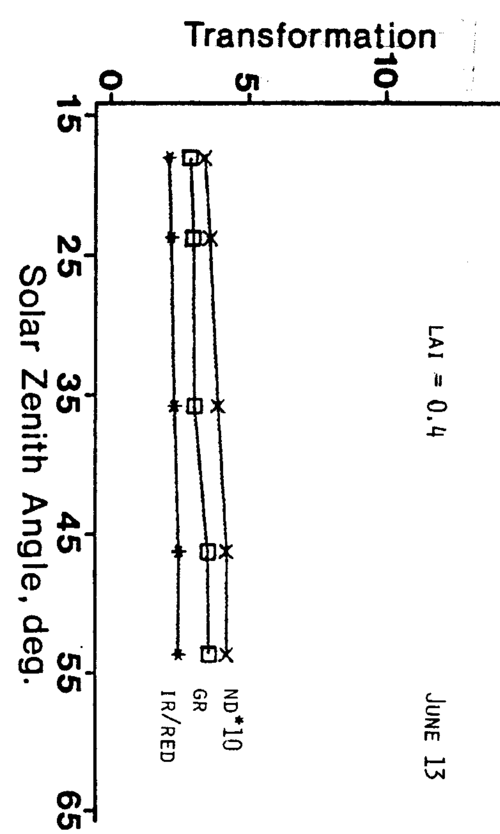
LINEAR TRANSFORMATIONS

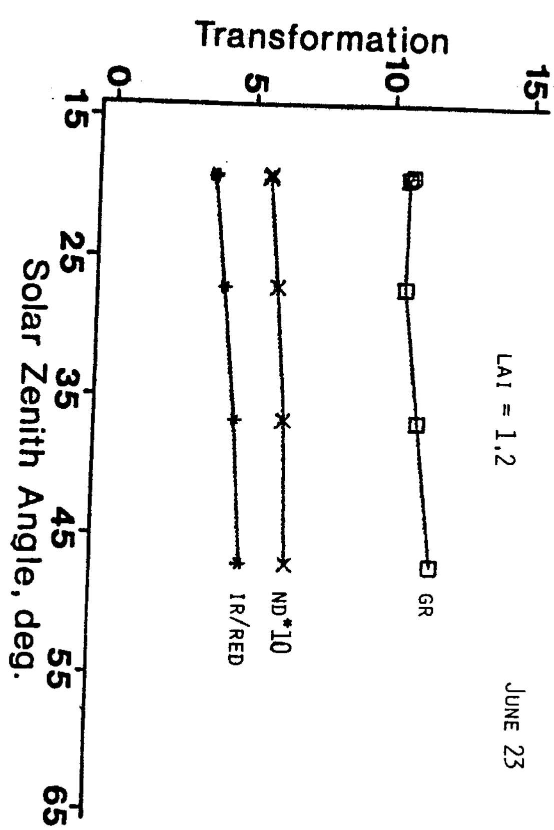
GREENNES = -.0174*MMR1 - .0206*MMR2 - .0638 * MMR3 + .9403 MMR4
- .2147*MMR6 - .2550*MMR7

IR/RED = MMR4/MMR3

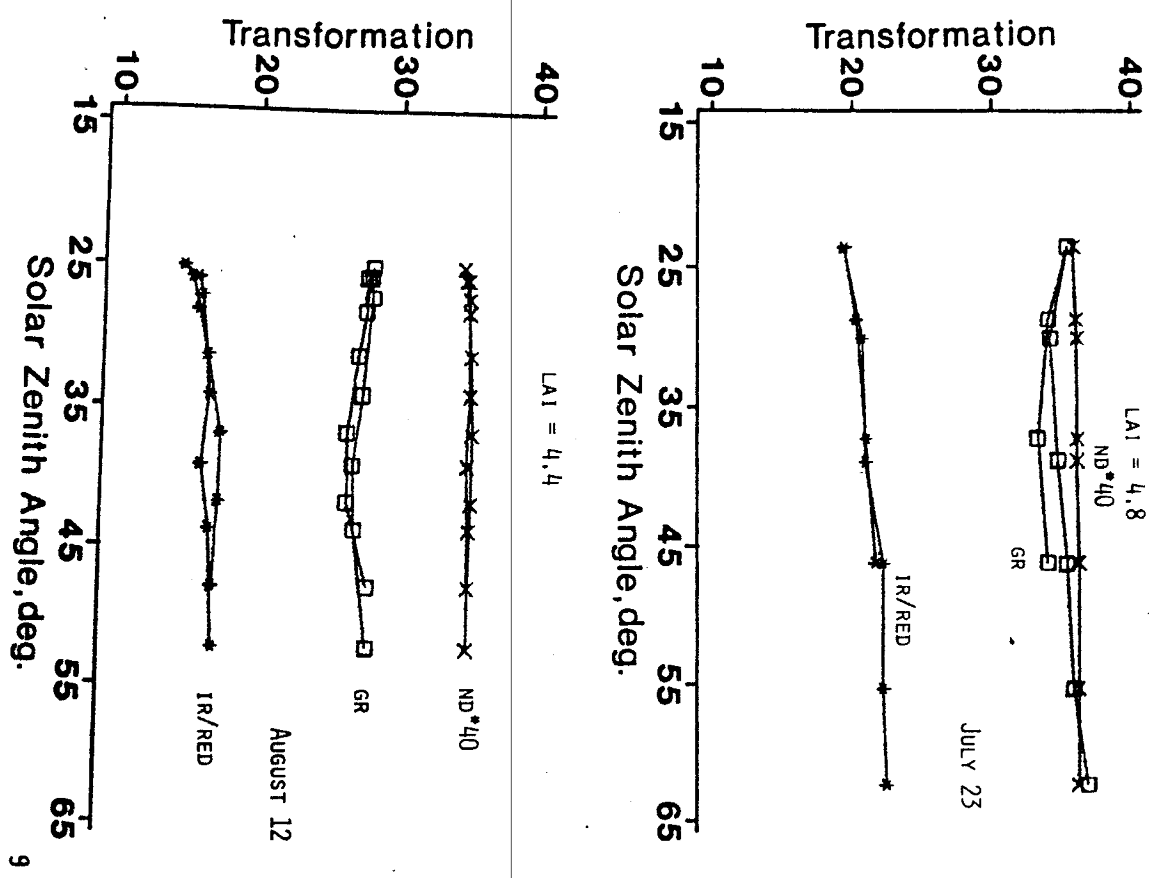
NORMALIZED DIFFERENCE (ND) = (MMR4 - MMR3)/(MMR4 + MMR3)

TRANSFORMATIONS AS A FUNCTION OF SOLAR ZENITH ANGLE
CORN CANOPY. VIEW ZENITH ANGLE = 0°





TRANSFORMATIONS AS A FUNCTION OF SOLAR ZENITH ANGLE FOR CORN CANOPY. VIEW ZENITH ANGLE = 0°



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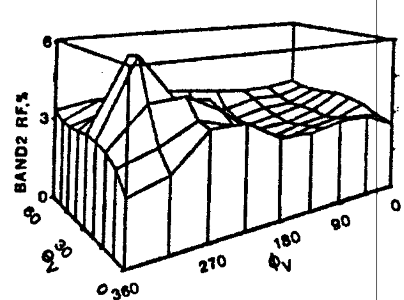
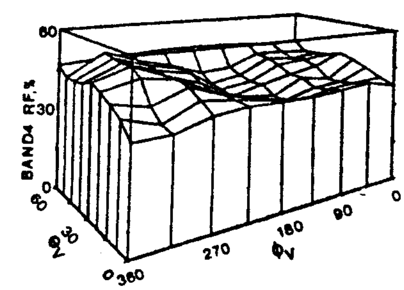
REFLECTANCE FACTOR AS A FUNCTION OF VIEW ZENITH (θ_V) AND VIEW AZIMUTH (ϕ_V) ANGLES FOR SOYBEANS CANOPIES

INCOMPLETE CANOPY

$\theta_s = 26°$, $\phi_s = 138°$

LAI = 3.9

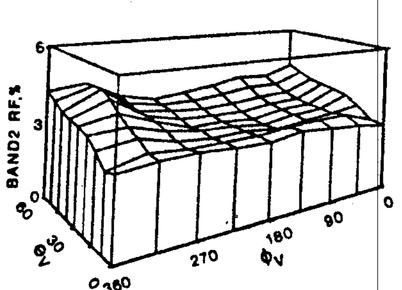


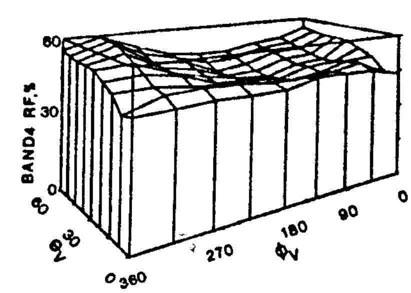


COMPLETE CANOPY

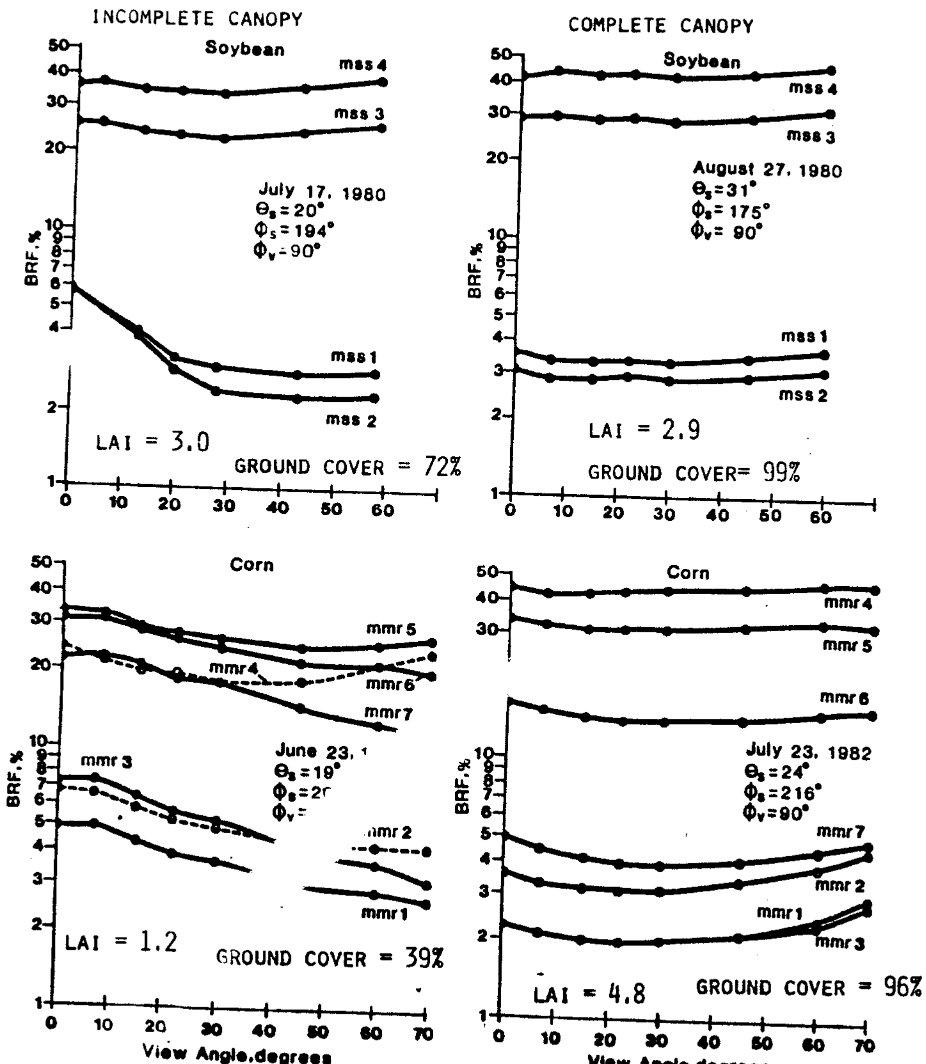
$\theta_s = 38°$, $\phi_s = 136°$

LAI = 2.9

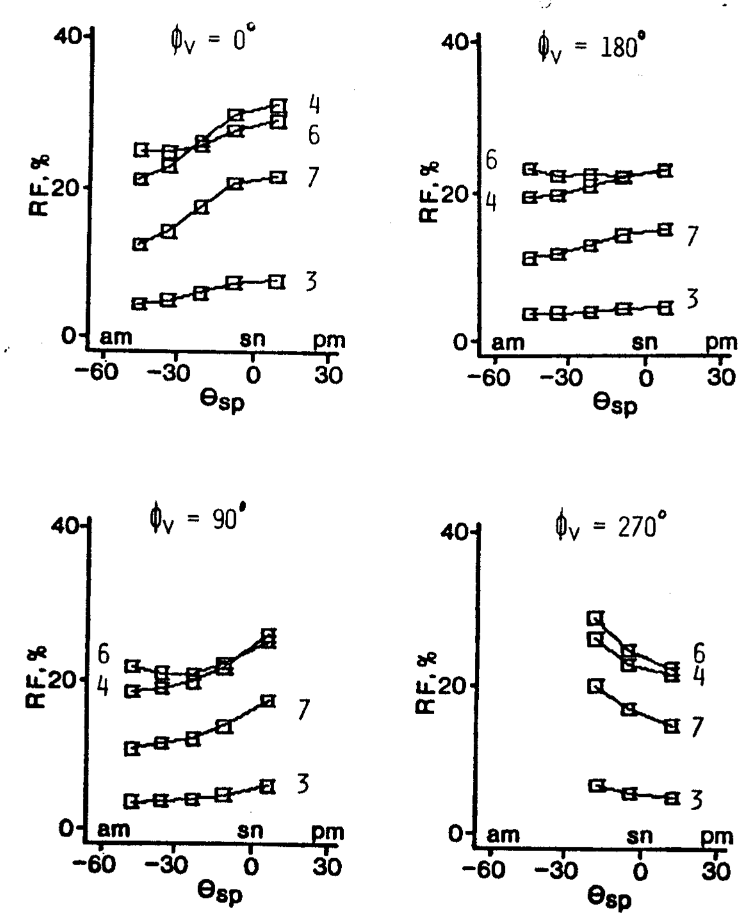




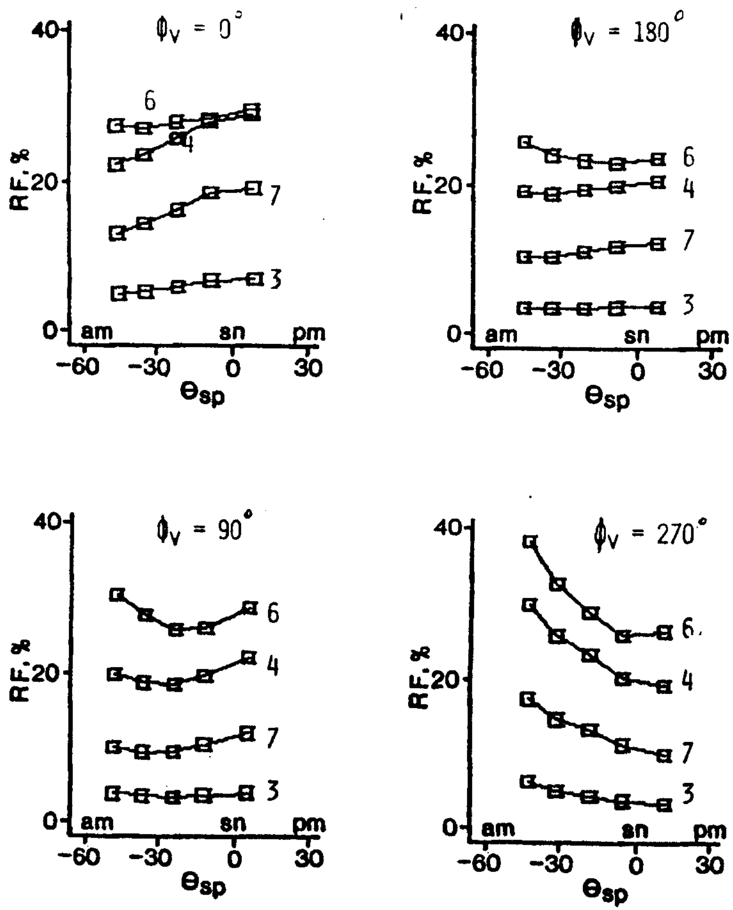
REFLECTANCE FACTOR AS A FUNCTION OF VIEW ZENITH ANGLE



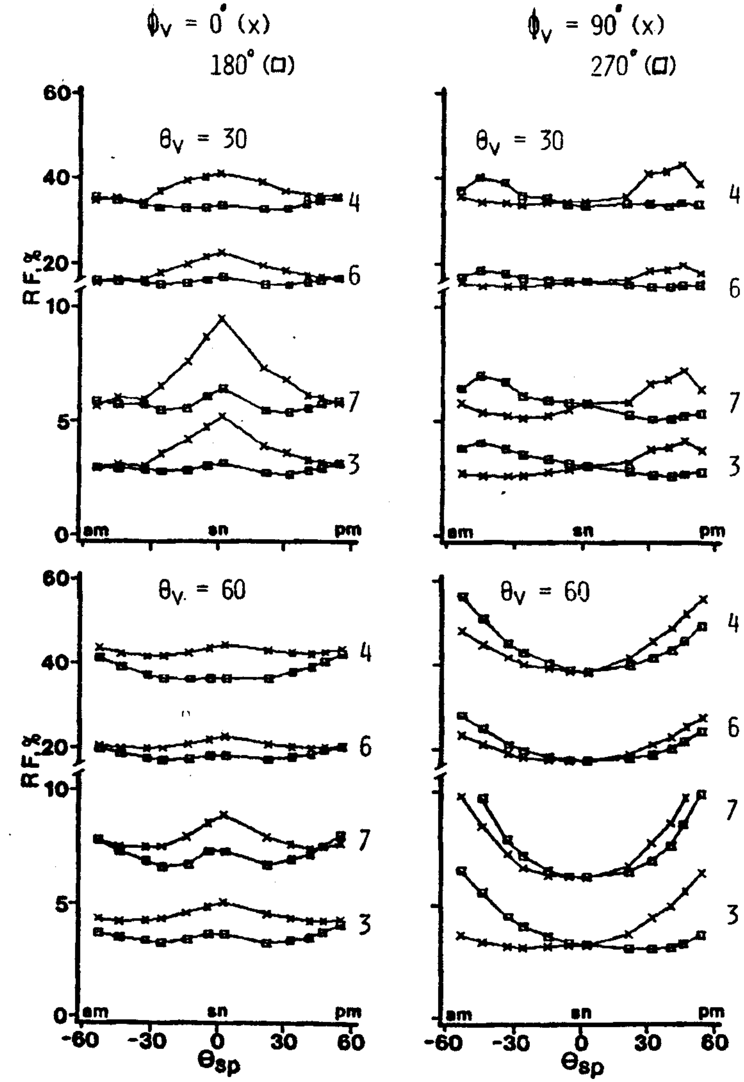
REFLECTANCE FACTOR FOR BARNES MMR BANDS AS A FUNCTION OF PROJECTED SOLAR ANGLE FOR CORN CANOPY
JUNE 23
(LAI = 1.2)
$\theta_v = 30$



Reflectance Factor for Barnes MMR Bands as a Function of Projected Solar Angle For Corn Canopy
June 23
(LAI = 1.2)
θ_V = 60

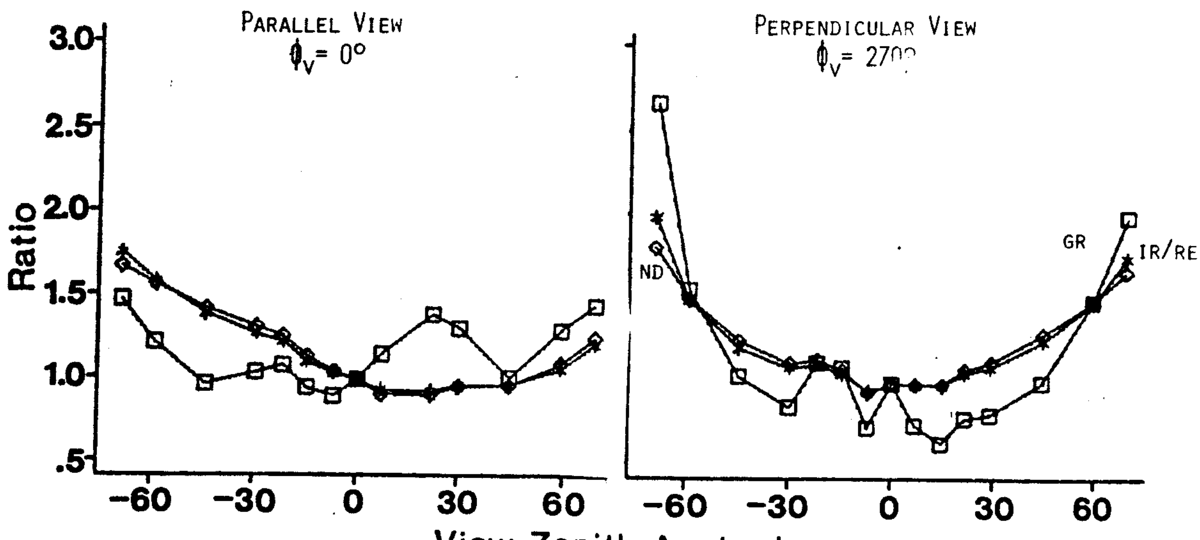


Reflectance Factor for Barnes MMR Bands as a Function of Projected Solar Angle For Corn Canopy
September 4
(LAI = 4.0)



Transformations as a Function of View Zentth Angle for Corn Canopy

Measurements were made at noon
June 13
(LAI = 0.4)



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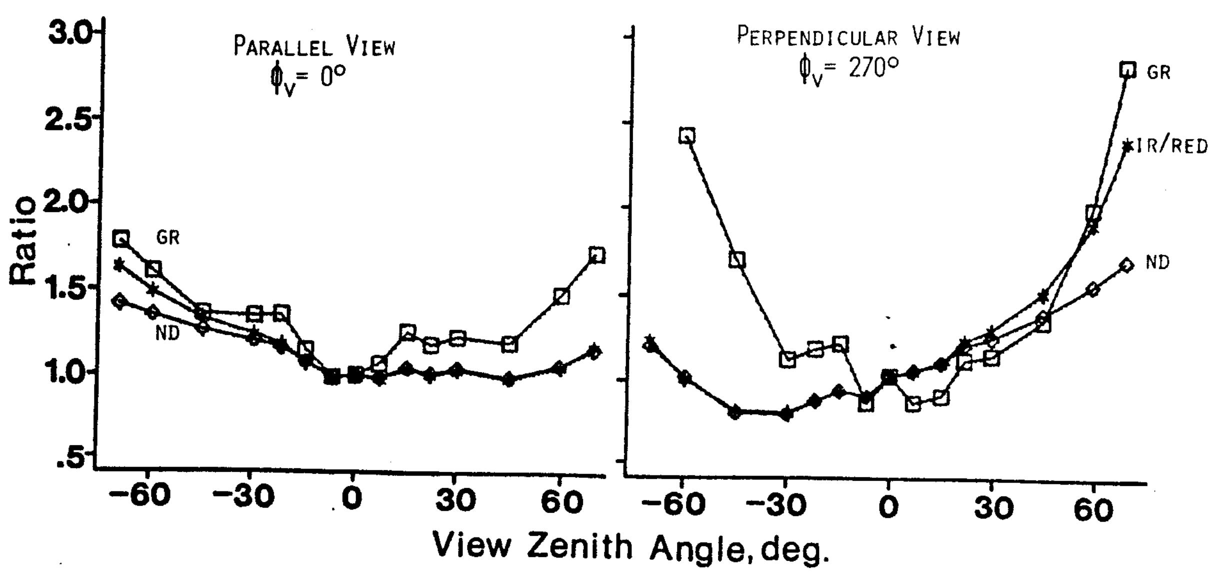
Transformations as a Function of View Zenith Angle for Corn Canopy

Measurements were made in the afternoon
June 13
(LAI = 0.4)



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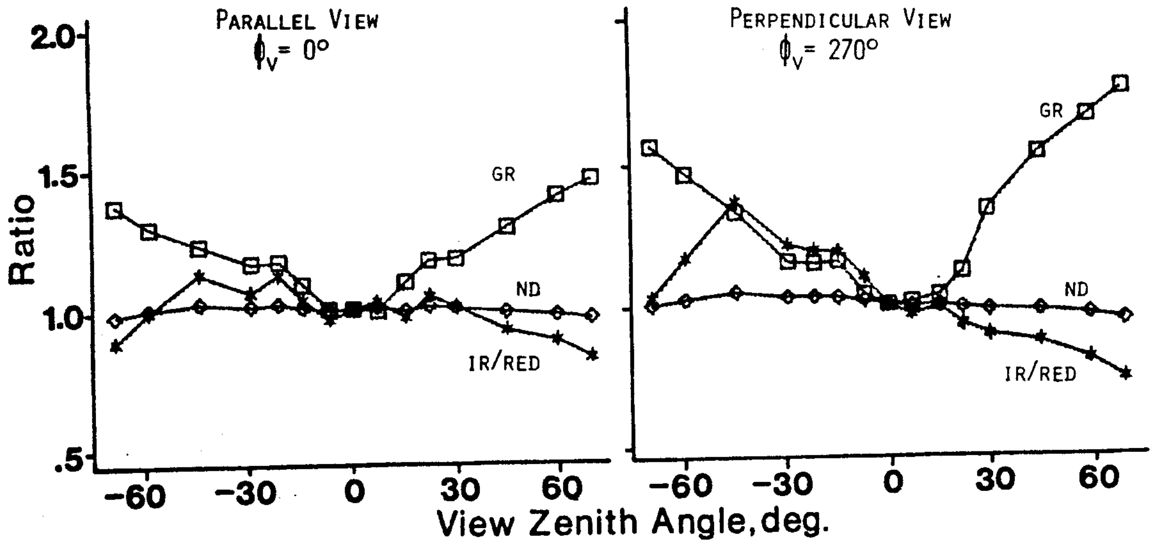
Transformations as a Function of View Zenith Angle for Corn Canopy

Measurements were made at noon

September 4

(LAI = 4.0)

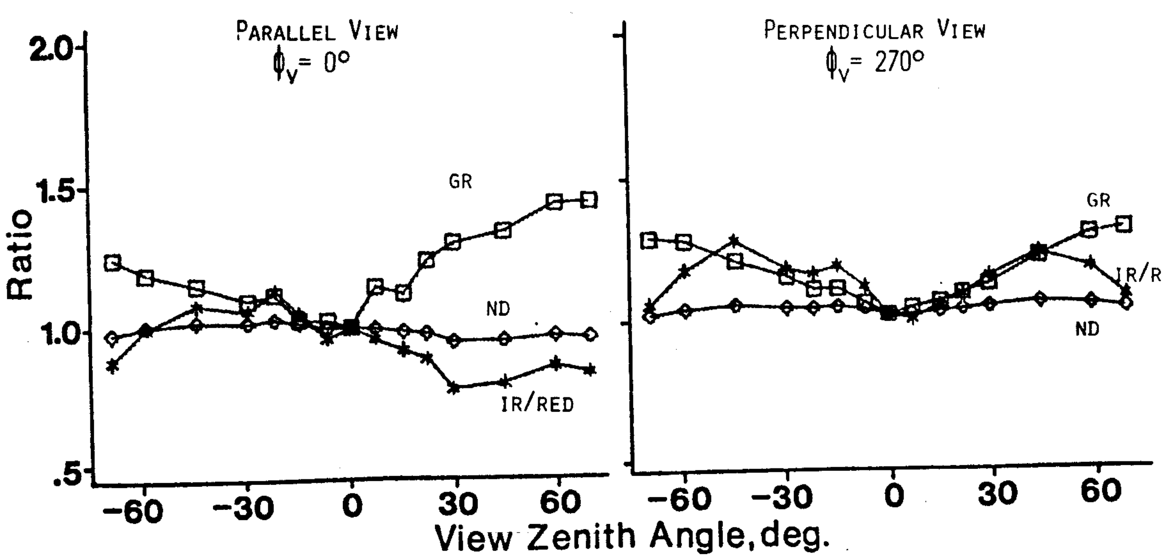


Transformations as a Function of View Zenith Angle for Corn Canopy

Measurements were made in the morning

September 4

(LAI = 4.0)



SOME COMMENTS

- THE 3 TRANSFORMATIONS AS A FUNCTION OF SOLAR ZENITH ANGLE ARE SIMILAR FOR CORN CANOPIES WITH LAIs <1.5.

- THE NORMALIZED DIFFERENCE CHANGES LITTLE WITH SOLAR ZENITH ANGLE FOR CORN CANOPIES WITH LAIs >4.

- THE V[illegible]TIONS IN THE TRANSFORMATION AS A FUNCTION OF VIEW ZENITH ANGLE A[illegible] SIMILAR FOR CORN CANOPIES WITH LAIs <1.

- THE NORMALIZED DIFFERENCE CHANGES LITTLE WITH VIEW ZENITH ANGLE (PROBABLY IS SATURATED) FOR CORN CANOPIES WITH LAIs >4.

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3. Paw U, K.T., and C.S.T. Daughtry. A new method of the estimation of diffusive resistance of leaves. AES Journal Paper 9828. (Submitted to Agricultural Meteorology.)

4. Seubert, C.E., C.S.T. Daughtry, D.A. Holt, and M.F. Baumgardner. Aggregating of available soil water holding capacity for crop yield models. AES Journal Paper 9287. (Submitted to Agronomy Journal.)

5.. Vanderbilt, V.C. Measuring plant canopy structure. (Submitted to Photogrammetric Engineering and Remote Sensing.)

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2. Batista, G.T., M.M. Hixson, and M.E. Bauer. 1982. Corn and soybean Landsat MSS performance as a function of scene characteristics. Proc. 8th Intl. Symp. on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, IN, July 7-9, 1982, pp. 178-188.

3. Biehl, L.L., M.E. Bauer, B.F. Robinson, C.S.T. Daughtry, L.S. Silva, and D.E. Pitts. 1982. A crops and soils data base for scene radiation research. Proc. 8th Intl. Symp. on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, IN, July 7-9, 1982, pp.169-177.

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2. Bauer, M.E., and Staff. 1983. Remote sensing of agricultural crops and soils. NAS9-16528 Annual Technical Summary for June 1, 1982-Mar. 31, 1983. SR-P3-04399 and LARS Contract Report 022183 (in press).

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2. Marshall, D.S. 1982. Epidiemology and multispectral sensing of leaf rust of wheat. Ph.D. thesis. Dept. of Botany and Plant Pathology, Purdue University, West Lafayette, In.

3. Ranson, K.J. 1983. A study of the angular reflectance characteristics of corn and soybean canopies. Ph.D. thesis. Dept. of Agronomy, Purdue University, West Lafayette, IN.

4. Ward, J.P. 1982. Effects of management practices on the reflectance of corn and soybean canopies. M.S. thesis. Dept. of Agronomy, Purdue University, West Lafayette, IN.

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2. Bauer, M.E., contributing author. 1983. Remote sensing applications in agriculture. Chapter 33 In R. N. Colwell (ed.), Manual of Remote Sensing, 2nd ed., American Society of Photogrammetry, Falls Church, VA.

3. Robinson, B.F., and D.P. DeWitt. 1983. Non-imaging sensors. Chapter 7 In R. N. Colwell (ed.), Manual of Remote Sensing, 2nd ed., American Society of Photogrammetry, Falls Church, VA.