

DK-2 Multiple Spectral Plotting

by

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I. Data Collection

During the summer of 1966, a DK-2 spectrophotometer having data-digitizing capability^{1/} was utilized to collect spectra from numerous plant and soil samples, primarily in the 0.5 - 2.6 μ m portion of the spectrum. The digitization feature of this instrument (a Datex encoder) allowed reflectance values to be recorded on computer punch cards at 10 μ m wavelength intervals. A limited number of spectra from various plant and soil samples have been collected since 1966, but since the instrument used did not have a digitization feature, the reflectance at only a few wavelengths has been digitized.

Most plant samples were obtained from field grown, rather than greenhouse grown materials, and represent many stages of maturity as well as many species, varieties, portions of the plant, and parts of the leaves. It is believed that all of the above factors affect spectral response. For most of the leaf samples, moisture content was also obtained using the formula:

$$\text{M.C. (in\%)} = \frac{\text{Fresh Leaf Weight} - \text{Dry Leaf Weight}}{\text{Fresh Leaf Weight}} \times 100$$

For about 10% of the samples, microscope slides were prepared of the leaf cross sections. Table 1 shows the number of spectra obtained for the various species and varieties, by date period.

^{1/} Mr. Charles Olson, School of Natural Resources, University of Michigan, is acknowledged for the loan of this instrument system, which is owned by the Office of Naval Research.

Soil spectra representing various soil types, moisture content, and condition of ped were also obtained. Since the soil samples had to be inserted in "sample holders" for the measurement, spectra of natural field conditions (such as crusted soil surfaces) could not be obtained. Table 2 shows the number of soil spectra obtained for the various soil types and conditions of soil samples.

These spectra, along with the necessary calibration data and the leaf cross sections, comprise the LARS DK-2 data collection. To facilitate the analysis of these data, they have been normalized to a full range of 0 to 100% reflectance, through the use of the calibration curves, and the normalized spectra are recorded on a data storage tape (Tape No. 50 in the LARS Tape Files). Header card information has been recorded in a coded format for each spectral curve. Printouts of this header code information are shown in Appendix A.

II. DK-2 Plot Program

A computer program, named "DK2PLT" has been designed to (1) read DK-2 data from the data storage tape, (2) sort the data into a maximum of 6 groups, according to sorting conditions specified by the user, (3) average the reflectance at each recorded wavelength interval, and (4) plot, on a single set of coordinates, a graph of the averaged spectral reflectance values for all groups, as well as frequency histograms of the moisture content data for each group. Figures 1-4 show examples of these computer printouts.

The types of parameters on which a researcher can sort include species, variety, plant part, leaf part, date, moisture content, type of measurement (reflectance or transmittance, from top or bottom of leaf), and if desired,

pigment or soil series name and field designation.^{2/} After establishing the experiment and deciding on the various sorting criteria, it is recommended that a DK-2 Plotter Program Data Card sheet (Fig. 5) be filled out, using the format shown below. Following this, the computer cards can be punched, and the program run on the LARS 360/67 computer.

^{2/} The sorting operation is designed such that all sorting conditions must be satisfied before a spectrum is accepted (i.e. condition 1 and condition 2, and.....condition n.) This system is usually sufficient for most researchers. However, it is possible to add more complex sorting operations to the program, through the use of separate subroutines which are specific for the individual researcher's requirements.

Card No. 1 (see Fig. 5)

- Col. 2 Number of sorting groups. Maximum = 6; recommended that you use 4 or less, so that spectra are not on top of each other.
- Col. 4 Wavelength interval on plot abscissa. Use 2, (unless you desire an elongated printout, in which case use 1).
- Col. 6 Request for listing of header card information for selected data. Use 0 (zero) or leave blank. (To suppress this listing, use 1. However, this is not recommended.)
- Col. 7-11 Symbols designated for each group. One character per group, adjacent columns (Col. 7 = Group 1, Col. 8 = Group 2, etc.). Any character on keypunch may be used.
- Col. 13-80 Comment regarding identification of materials selected for comparison (optional).

Card No. 2

- Col. 2 Number of sorting conditions (usually less than 5). (This number should be the same as the number of cards for the sorting criteria for each group, which must be the same for each group.)
- Col. 3-10 Highest serial number of interest. Punch decimal. Default = all spectra.
- Col. 11-20 Data tape number. Punch Decimal. Default = Tape 50.

Card No. 3

- Col. 1-80 Title card for Group 1.

Card No. 4 +

- Col. 1-10 Sorting criteria (see below)
- Col. 11-20 Relational operator (see below)
- Col. 21-30 Specific sorting parameters (see below)

Card No. N

- Col. 1-80 Title card for Group 2.

Card No. N +

- Col 1-10, Col. 11-20, Col. 21-30 - Sorting criteria, relational operator, and specific sorting parameter sequence for Group 2.

(Continue this sequence for remaining sorting groups, as shown on sheet in Fig. 5.)

III. Sorting code information

Columns 1-10 (must use decimal)

<u>Number Code</u>	<u>Sorting Criteria</u>
1.	Serial number
2.	Plant Species, or material (eg. soil)
3.	Plant Variety, or Soil Texture, or Misc. Expt.
4.	Portion of plant or soil description (Ped)
5.	Section of leaf or soil treatment (moisture)
6.	Year
7.	Month
8.	Day
9.	Moisture content x 10
10.	Pigment and material or soil series name
11.	Field number
12.	Type of measurement (reflectance, transmittance, top of leaf, bottom of leaf, etc.)

Columns 11-20 (must use decimal)

<u>Number Code</u>	<u>Relational Operator</u>
1.	< (less than)
2.	≤ (less than or equal to)
3.	= (equal to)
4.	≠ (not equal to)
5.	≥ (greater than or equal to)
6.	> (greater than)

Columns 21-30 (must use decimal)

Specific sorting parameters (only those used are shown)

<u>Number Code</u>	<u>Species or Material (2.0)</u>	<u>Number Code</u>	<u>Variety or Soil Texture Misc. Expt. (3.0)</u>
1.	Soybeans	0.	Amsoy
		1.	Harasoy 63
		2.	Wayne
		3.	Kent
		4.	Clark 63
		5.	Shelby
		9.	Unknown
2.	Corn	0.	5 x 29
		1.	5 x 9
		2.	Pioneer 3306 single cross
		3.	5 x 63
		9.	Unknown
3.	Oats	0.	Clinton 59
		1.	Putnam 61
		2.	Clintland 64
		3.	Tippecanoe
		4.	Clintford
		9.	Unknown
4.	Wheat	0.	Vermillion
		1.	Knox 62
		2.	Riley
		3.	LaPorte
		4.	Monon
		5.	Reed
		6.	Redcoat
		7.	Breeder's Wheat (7)
		8.	Breeder's composite (42W)
		9.	Unknown
5.	Soil	0.	Sandstone
		1.	Siltstone
		2.	Muck
		3.	Clay Mineral

(Continuation of specific sorting parameters, Cols. 21-30)

<u>Number Code</u>	<u>Species or Material (2.0)</u>	<u>Number Code</u>	<u>Soil Texture or Misc. Expt. (3.0)</u>
6.	Soil	0.	Silt
		1.	Clay
		2.	Sandy Loam
		3.	Silty clay
		4.	Clay loam
		5.	Loam
		6.	Sand
		7.	Loamy sand
		8.	Silt loam
		9.	Silty clay loam
7.	Clover	--	
8.	Sorghum	--	
9.	Other Materials	0.	Sudan Grass
		1.	Backing experiments
		2.	Whatman paper comparisons
		3.	Elm leaves
		4.	Turgidity (water lily)
		5.	Boiling water (water lily)
		6.	Sample cover or port experiment
		7.	Apple leaves
		8.	Weeds
		9.	Other

(Continuation of specific sorting parameters, Cols. 21-30)

<u>Number Code</u>	<u>Portion of Plant (4.0) or</u>	<u>Number Code</u>	<u>Soil Description (Ped) (4.0)</u>
0.	Base	1.	Natural Ped
4.	Middle	2.	Crushed sample
8.	Top	9.	Solid, rock
9.	Unknown		

Parts of Plant 0, 2, 4, 6, 7, 8 available

<u>Number Code</u>	<u>Section of Leaf (5.0)</u>	or	<u>Number Code</u>	<u>Soil Treatment (moisture) (5.0)</u>
0.	Base		1.	Oven dry
4.	Middle		2.	Air dry
8.	Tip		3.	Moist
9.	Unknown		4.	Saturated
			9.	Unknown

Pigment, Material, Moisture Content (wilted or normal) (10.0)

<u>Number Code</u>	<u>Material</u>	<u>Number Code</u>	<u>Color (Predominate Pigmentation)</u>
1.	Geranium	1.	Green (Chlorophyll)
2.	Col. as	2.	Red (Anthocyanin)
3.	Tuliptree Leaves	3.	Deep Red (Anthocyanin & Chlorophyll)
4.	Maple Leaves	4.	Yellow (Xanthophyll & Carotenoid)
5.	Elm Leaves	5.	White (no pigments)
6.	Apple Leaves	9.	Unknown
7.	Foxtail		
8.	Lamb's Quarters	<u>Number Code</u>	<u>Moisture Content (wilted or normal)</u>
9.	Pigweed		
10.	Corn (albino)	1.	Normal
99.	Unknown	2.	Wilted
		3.	Unknown

Soil Series Name (10.0)

<u>Number Code</u>	<u>Soil Series Name</u>
1.	Chalmers Loam
2.	Morocco Sandy Loam
3.	Raub Silt Loam
4.	Fincastle Silty Clay
5.	Miami Silt Loam
6.	Pembroke Clay Loam
7.	Kokomo Silty Clay Loam
8.	Martinsville Sand
9.	Princeton Sand
10.	Maurne Loamy Sand
11.	Chelsea Loamy Sand
12.	Maumee Loamy Sand
13.	Pembroke Clay
14.	Montgomery Clay
15.	Kaolinite Clay Mineral
16.	Bentonite Clay Mineral
17.	Muscovite Clay Mineral
18.	Carlisle Muck
19.	Unknown
99.	Princeton Silt

Field Number Explanation & former field numbers (11.0)

First Digit - Geographic Area

1. Greenhouse
2. Agronomy Farm
3. Sand Farm
4. Forest or Orchard
- . Miscellaneous
9. Unknown

Second and Third Digits - Field Number (numerical portion)

*Fourth Digit - Irrigation Treatment or Direction

1. Irrigated
2. Non-Irrigated
3. North
4. East
5. South
6. West
7. Unknown

*Except Agronomy Farm Field 31, fourth digit refers to A2=1, A3=2, B1=3, B2=4, B3=5, C1=6, C2=7, C4=8, C=3.

<u>Old Field Numbers</u> (Agronomy Farm)	<u>New Field Numbers</u> (Agronomy Farm)	<u>Old Field Numbers</u> (Agronomy Farm)	<u>New Field Numbers</u> (Agronomy Farm)
2	2029	4B	2043
3	2039	6A	2065
4	2049	6B	2063
5	2059	7A	2075
7	2079	7B	2073
13	2139	16E	2164
16	2169	42E	2424
22	2229	44E	2444
23	2239	62E	2624
33	2339	3W	2036
40	2409	16W	2166
41	2419	23W	2236
51	2519	24W	2246
61	2619	33W	2336
62	2629	41W	2416
63	2639	42W	2426
2B	2023	62W	2626
3A	2035	54S	2545
3B	2033	55S	2555
4A	2045	53N	2533
		3M	2039
		41M	2419

Old Field Numbers
(Agronomy Farm)

31A2
31A3
31B1
31B2
31B3
31C1
31C2
31C4

New Field Numbers
(agronomy Farm)

2311
2312
2313
2314
2315
2316
2317
2318

(Sand Farm)

4N
SF2I
SF3I
SF4I
SF6I
SF7I
SF2N
SF3N
SF4N
SF6N
SF7N
SF31

(Sand Farm)

3043
3021
3031
3041
3061
3071
3022
3032
3042
3062
3072
3319

<u>Number Code</u>	<u>Type of measurement</u> (12.0)
0.	Total reflectance from top (ventral) side of leaf (5° angle)
1.	Total reflectance from bottom (dorsal) side of leaf (5° angle)
2.	Transmittance, radiation entering from top side of leaf (5° angle)
3.	Transmittance, radiation entering from bottom side of leaf (5° angle)
4.	Total reflectance of soil or rock sample, or from top side of leaf (perpendicular)

IV. Examples

Figure 5 shows the DK-2 Plotter Program Data Sheet filled out for a sorting sequence to compare green soybeans, air dried clay and air dried sandy loam soils. The prepared data deck is shown in Figure 6. This deck was used to obtain Figures 1 and 2.

A DK-2 Plotter Program Data Card Sheet prepared to allow a comparison of averaged spectra for 4 moisture content groups of corn leaves is shown in Figure 7. The data deck is shown in Figure 8. The results obtained were shown in Figures 3 and 4.

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Figure 2. Averaged Spectra of Green Soybean Leaves and Air Dried Clay and Air Dried Sandy Loam Soils.

Figure 3. Histograms of Moisture Contents for Data Used to Compute Spectral Averages Shown in Figure 4.

Figure 4. Plotting of Averaged Corn Spectra in 4 Moisture Groups.

Figure 5. "DK-2 Plotter Program Data Sheet", Filled Out to Obtain Results Shown in Figures 1 and 2.

Figure 6. Data Deck Prepared From "DK-2 Plotter Program Data Sheet" shown in Figure 5.

Figure 7. "DK-2 Plotter Program Data Sheet", Filled Out to Obtain Results Shown in Figures 3 and 4.

Figure 8. Data Deck Prepared from "DK-2 Plotter Program Data Sheet" Shown in Figure 7.

Table 1. DK-2 Spectra Obtained on Plant Leaves

Crop Species and Variety	Early June	June Flight	Early July	July Flight	Early August	September Flight	Late Sept.-Oct.	Total
	6/17-6/24	6/27-7/01	7/05	7/20-7/30	8/01-8/05	9/11-9/15	9/21-10/07	
Soybeans								155
Amsoy	---	---	---	58	29	68	---	134
Harasoy 63	---	30	---	71	28	5	---	11
Wayne	---	---	---	---	---	11	---	7
Kent	---	---	---	---	---	7	---	3
Clark 63	---	---	---	---	---	3	---	3
Shelby	---	---	---	---	---	3	---	182
Other	6	14	---	---	102	---	---	---
Total	6	44	---	129	219	97	---	495
Corn								95
PF SX 29	---	30	---	39	---	26	---	183
PF SX 9	---	59	---	84	---	34	6	202
Pio 3306	---	83	---	83	---	36	---	10
SX 63	---	---	---	---	---	10	---	236
Other	183	---	---	33	---	2	18	---
Total	183	172	---	239	---	108	24	720
Oats								78
Tippecanoe	---	78	---	---	---	---	---	59
Clintford	---	59	---	---	---	---	---	---
Total	---	137	---	---	---	---	---	137
Wheat								28
Vermillion	28	---	---	---	---	---	---	27
Knox 62	27	---	---	---	---	---	---	36
Riley	26	10	---	---	---	---	---	28
LaPorte	28	---	---	---	---	---	---	66
Monon	26	15	20	---	---	---	---	31
Reed	31	---	---	---	---	---	---	23
Redcoat	23	---	---	---	---	---	---	36
Breeder's Wheat	---	36	---	---	---	---	---	36
Breeder's Composite	---	36	---	---	---	---	---	28
Other	---	---	28	---	---	---	---	---
Total	189	97	53	---	---	---	---	339
Sorghum	---	20	---	57	---	20	---	97
Sundangrass	---	20	---	50	---	15	---	85
Miscellaneous	56	15	18	47	---	---	116	252
GRAND TOTAL	434	505	71	522	219	240	140	2131

Table 2. DK-2 Spectra Obtained on Soils

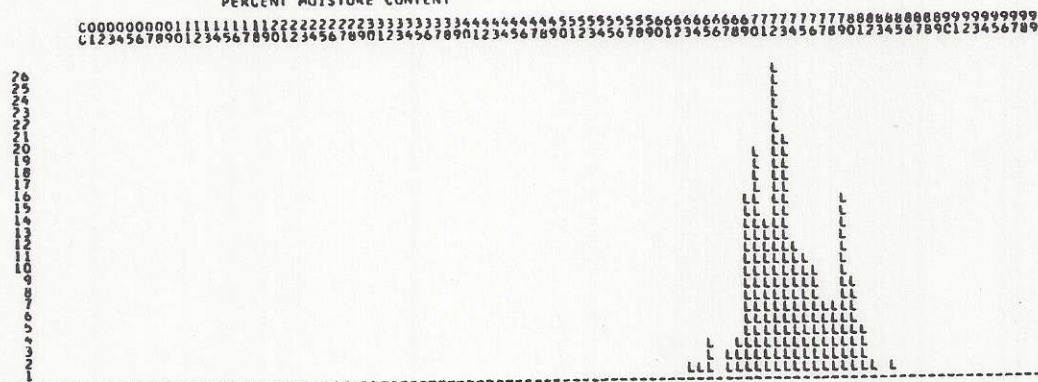
Textural Class	Soil Type & Horizon	Treatments		
		Natural Ped		Crushed Samples Air Dry
		Air Dry	Saturated	
Sand	Chelsea (A _p)	21 ^a	5	5 ^b
Loamy Sand	Maumee (A _p)	7	5	--
Sandy Loam	Martinsville (A ₂)	5	5	--
	Morocco (A _p)	7	5	5
Loam	Chalmers (A _p)	5	5	--
Silt Loam	Miami (A _p)	5	5	--
	Fincastle (A _p)	3	5	3
	Raub (A _p)	5	5	5
Silt	Princeton (C)	--	--	5
Silty Clay	Kokomo (A ₁)	5	5	--
Clay Loam	Montgomery (A ₁)	5	--	5
	Pembroke (B ₁)	5	5	5
Muck	Carlisle (A _p)	5	--	--
Clay Minerals	Bentonite	5	--	--
	Kaolinite	--	--	5
	Muscovite	--	--	5
Sandstone		13	--	--

^a In addition, 26 Natural Ped samples were obtained in a moist condition.

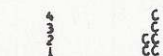
^b In addition, 3 Crushed samples were obtained in a moist condition.

UK-2 PLOTTER PROGRAM

CLASS 1 (L) 174 SAMPLES GREEN SOYBEAN LEAVES
PERCENT MOISTURE CONTENT



PERCENT HISTOGRAM: CONVENT



PERCENT HUMIDITY CONTENT

0000000000111111111122222222223333333333444444444455555555556666666666777777777788888888889999999999
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789

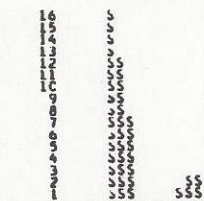


Figure 1. Histograms of Moisture Contents for Data Used to Compute Spectral Averages Shown in Figure 2.

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DK-2 PLOTTER PROGRAM

AVERAGED SPECTRAL REFLECTANCE FOR DK-2 DATA

(L)... 174 SAMPLES GREEN SOYBEAN LEAVES
(C)... 6 SAMPLES CLAY SOIL, AIR DRY
(S)... 40 SAMPLES LOAMY SAND SOIL, AIR DRY

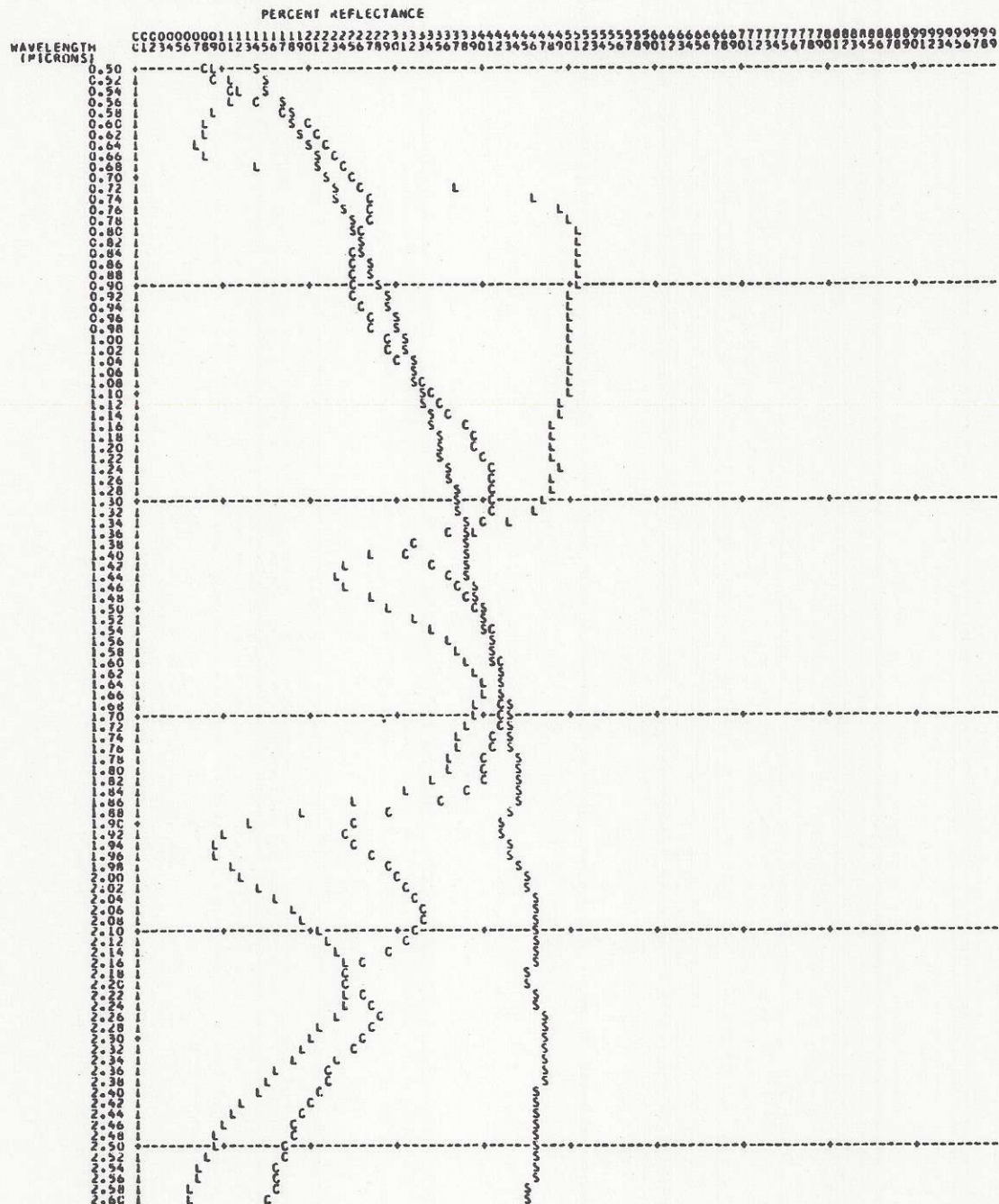


Figure 2. Averaged Spectra of Green Soybean Leaves and Air Dried Clay and Air Dried Sandy Loam Soils.

OK-2 PLCTTEN PROGRAM

HISTOGRAMS OF MCISTURE CONTENT (DK-2 DATA)

Figure 3. Histograms of Moisture Contents for Data Used to Compute Spectral Averages Shown in Figure 4.

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DK-2 PLCTER PROGRAM

AVERAGED SPECTRAL REFLECTANCE FOR DK-2 DATA

(1).... 9 SAMPLES CORN: 0.1 - 40.0 PERCENT MOISTURE CONTENT, VAR SK9, TOP OF PLANT, MID LEAF
(2).... 5 SAMPLES CORN: 40.1 - 55.0 PERCENT MOISTURE CONTENT
(3).... 20 SAMPLES CORN: 55.1 - 65.0 PERCENT MOISTURE CONTENT
(4).... 147 SAMPLES CORN: 65.1 - 99.9 PERCENT MOISTURE CONTENT

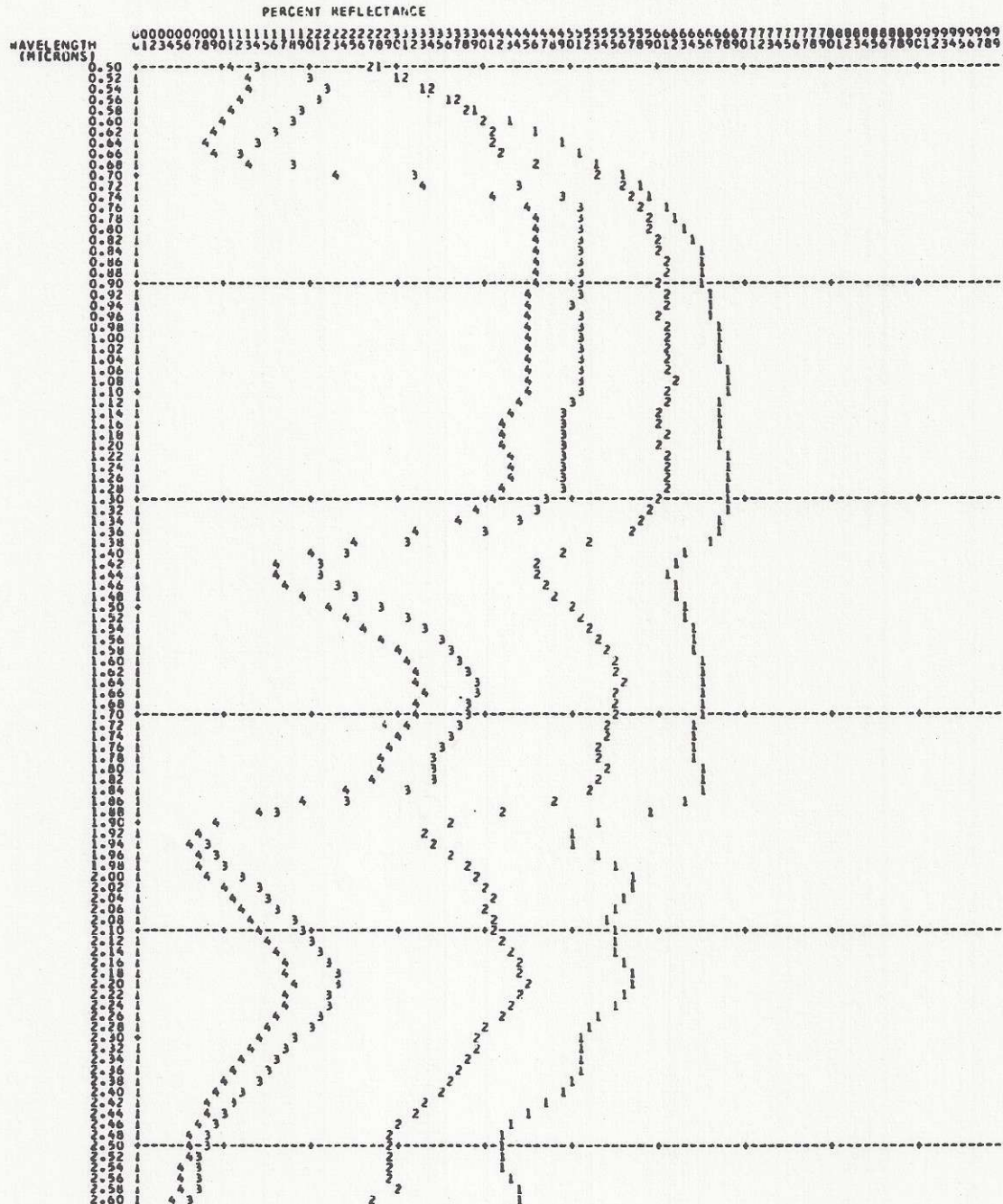


Figure 4. Plotting of Averaged Corn Spectra in 4 Moisture Groups.

DK-2 Plotter Program Data Cards

Card Number	Column													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	X	3	X	2	X	0	L	C	S			X	X	(Demonstration deck,
1 (cont)	showing soybean leaves, clay soil, and loamy sand soil)													
2	X	4												
Title	Green Soybean Leaves													
Sort 1	2.0 (Species)				3.0 (Equal to)				1.0 (Soybeans)					
Sort 2	7.0 (Month)				2.0 (Less than or Equal to)				7.0 (July)					
Sort 3	9.0 (Moisture Content)				6.0 (Greater than)				1.0 (0.1% x 10)					
Sort 4	9.0 (Moisture Content)				1.0 (Less than)				999.0 (99.9% x 10)					
Sort 5														
Title	Clay Soil, Air Dry													
Sort 1	2.0 (Material)				3.0 (Equal to)				6.0 (Soil)					
Sort 2	3.0 (Soil Texture)				3.0 (Equal to)				1.0 (Clay)					
Sort 3	4.0 (Soil Description)				3.0 (Equal to)				1.0 (Natural Ped)					
Sort 4	5.0 (Soil Treatment)				3.0 (Equal to)				2.0 (Air Dry)					
Sort 5														
Title	Loamy Sand Soil, Air Dry													
Sort 1	2.0 (Material)				3.0 (Equal to)				6.0 (Soil)					
Sort 2	3.0 (Soil Texture)				3.0 (Equal to)				7.0 (Loamy Sand)					
Sort 3	4.0 (Soil Description)				3.0 (Equal to)				1.0 (Natural Ped)					
Sort 4	5.0 (Soil Treatment)				3.0 (Equal to)				2.0 (Air Dry)					
Sort 5														
Title														
Sort 1														
Sort 2														
Sort 3														
Sort 4														
Sort 5														
Title														
Sort 1														
Sort 2														
Sort 3														
Sort 4														
Sort 5														

Figure 5. "DK-2 Plotter Program Data Sheet", Filled Out to Obtain Results Shown in Figures 1 and 2.

[illegible]

Figure 6. Data Deck Prepared from "DK-2 Plotter Program Data Sheet" shown in Figure 5.

DK-2 Plotter Program Data Cards

Card Number	Column													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	X	4	X	2	X	0	1	2	3	4		X	X	(Demonstration deck)
1 (cont)	corn spectra in four moisture content groupings													
2	X	4												
Title	Corn, 0.1-40.0 Percent Moisture Content, Var 5X9 Top of Plant Mid Leaf													
Sort 1	2.0	(Species)			3.0	(Equal to)			2.0	(Corn)				
Sort 2	3.0	(Variety)			3.0	(Equal to)			1.0	(5X9)				
Sort 3	9.0	(Moisture Content)			5.0	(Greater than or Equal to)			1.0	(0.1% X 10)				
Sort 4	9.0	(Moisture Content)			2.0	(Less than or Equal to)			400.0	(40.0% X 10)				
Sort 5														
Title	Corn, 40.1 - 53.0 Percent Moisture Content													
Sort 1	2.0	(Species)			3.0	(Equal to)			2.0	(Corn)				
Sort 2	3.0	(Variety)			3.0	(Equal to)			1.0	(5X9)				
Sort 3	9.0	(Moisture Content)			5.0	(Greater than or Equal to)			401.0	(40.1% X 10)				
Sort 4	9.0	(Moisture Content)			2.0	(Less than or Equal to)			530.0	(53.0% X 10)				
Sort 5														
Title	Corn, 53.1 - 65.0 Percent Moisture Content													
Sort 1	2.0	(Species)			3.0	(Equal to)			2.0	(Corn)				
Sort 2	3.0	(Variety)			3.0	(Equal to)			1.0	(5X9)				
Sort 3	9.0	(Moisture Content)			5.0	(Greater than or Equal to)			531.0	(53.1% X 10)				
Sort 4	9.0	(Moisture Content)			2.0	(Less than or Equal to)			650.0	(65.0% X 10)				
Sort 5														
Title	Corn, 65.1 - 99.9 Percent Moisture Content													
Sort 1	2.0	(Species)			3.0	(Equal to)			2.0	(Corn)				
Sort 2	3.0	(Variety)			3.0	(Equal to)			1.0	(5X9)				
Sort 3	9.0	(Moisture Content)			5.0	(Greater than or Equal to)			650.0	(65.0% X 10)				
Sort 4	9.0	(Moisture Content)			2.0	(Less than or Equal to)			999.0	(99.9% X 10)				
Sort 5														
Title														
Sort 1														
Sort 2														
Sort 3														
Sort 4														
Sort 5														

Figure 7. "DK-2 Plotter Program Data Sheet", Filled Out to Obtain Results Shown in Figures 3 and 4.

3.0	2.0	999.0
-----	-----	-------

9.0 5.0 550.0

3.0 3.0 1.0

2.0 3.0 2.0

CORN, 65.1 - 99.9 PERCENT MOISTURE CONTENT

9.0	2.0	650.0
-----	-----	-------

2.0	5.0	531.0
-----	-----	-------

3.0 3.0 1.0

2.0 3.0 2.0

CORN, 53.1 - 65.0 PERCENT MOISTURE CONTENT

9.0	2.0	530.0
-----	-----	-------

9.0	5.0	401.0
-----	-----	-------

3.0	3.0	1.0
-----	-----	-----

2.0 3.0 2.0

CORN, 40.1 - 53.0 PERCENT MOISTURE CONTENT

9.8	2.0	400.0
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9.0 5.0 1.0

3.0 3.0 1.0

2.0 3.0 2.0

CORN, 0.1 - 40.0 PERCENT MOISTURE CONTENT, VAR SKS, TOP OF PLANT, MID LEAF

4

4 2 01234

[illegible]

Figure 8. Data Deck Prepared from "DK-2 Plotter Program Data Sheet" shown in Figure 7.