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Crop Area Estimates Using Ground-Gathered and LANDSAT Data

A Multitemporal Approach; Missouri 1979

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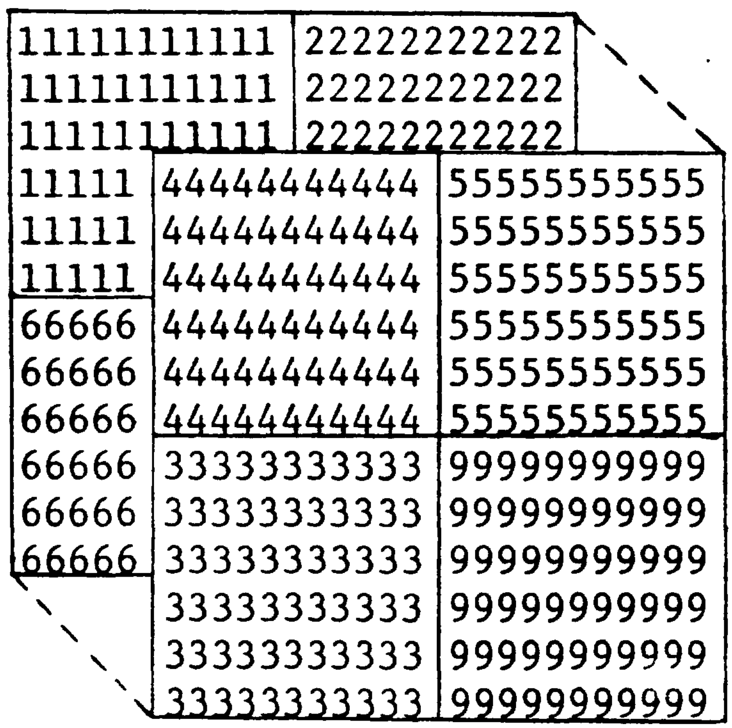

CROP AREA ESTIMATES USING GROUND-GATHERED AND LANDSAT DATA: A MULTITEMPORAL APPROACH, MISSOURI 1979. By JAMES W. MERGERSON, Statistical Research Division, Economics and Statistics Service, U.S. Department of Agriculture, Washington, D.C. 20250, ESS Staff Report No. AGESS810223, February 1981.

ABSTRACT

This report describes a comparative study in which a unitemporal approach for obtaining crop area estimates using ground-gathered and LANDSAT data was compared to a multitemporal approach. Four channel data were used for the unitemporal approach. Eight channel data consisting of four channels from each of two dates were used for the multitemporal approach. The multitemporal data set and the two corresponding unitemporal data sets were analyzed using various procedures. Results indicated that the use of multitemporal data can significantly improve the precision of crop area estimates for corn, soybeans, and winter wheat, obtained using the unitemporal approach.

This paper was prepared for limited distribution to the research community outside the U.S. Department of Agriculture

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CONTENTS

INTRODUCTION

The objectives of this project were to gain LANDSAT analysis experience using imagery from two different dates which cover the same land area in conjunction with ESS's conventionally gathered June Enumerative Survey (JES) ground data and to determine if this method can significantly improve the precision of crop area estimates obtained using single-date imagery in conjunction with ground data. The study area consisted of an eleven county region in Northwest and North Central Missouri.

For an explanation of general statistical methodology, ground data acquisition and processing, data processing systems hardware and software, or a general description of LANDSAT data, refer to the paper by Hanuschak, et.al.[1/]

This report, intended for those with some knowledge of remote sensing applications, will be useful to researchers considering the use of multi-date imagery in estimating crop areas.

LANDSAT DATA

Two scenes, with different dates, covering the same land area were selected for this project. Due to cloud cover only a portion of the scenes were analyzed. Additional information about the two scenes is provided in Table 1.

TABLE 1: LANDSAT Imagery, Missouri 1979

Path	Row	Date	Per Cent Cloud Cover	Scene ID
28	32	May 14	30	30435-16165
28	32	August 3	10	21654-16100

MULTITEMPORAL REGISTRATION AND DIGITAL DATA SET CREATION

Registration is the process of relating the LANDSAT row-column coordinates with map latitude-longitude coordinates by means of mathematical equations. A multitemporal LANDSAT digital data set consists of data from two different scenes taken at different dates but covering the same ground area. In creating a multitemporal digital data set, one of the original scenes is selected as the primary scene and the other as the secondary scene. The August 3 scene was selected as the primary scene and the May 14 scene was selected as the secondary scene.

Scene to map registration was performed using thirty four control points with an accuracy of 100 meters RMS (Root Mean Square Error) for the primary scene. The resulting precision calibration file was used in conjunction with the digitized segment files to predict the segment locations in the LANDSAT data. For each discrepancy between the predicted and actual location of a segment a local calibration was done. Segments were shifted as shown in Table 2.

TABLE 2: SEGMENT SHIFTS, MISSOURI 1979

SEGMENT	ROW SHIFT IN PIXELS	COLUMN SHIFT IN PIXELS
6015	0.0	-1.0
6034	0.0	-1.0
6035	-1.0	-1.0
6039	1.0	-2.0
6040	1.0	0.0
6044	0.0	1.0
6045	0.0	-2.0
6048	-1.0	-1.0
6049	-1.0	0.0
6053	-1.0	0.0
6058	-1.0	0.0
6059	-1.0	0.0
6060	-1.0	-2.0
6063	-1.0	0.0
6064	-2.0	0.0
6065	-1.0	0.0
6073	-1.0	0.0
6085	0.0	2.0
6093	4.0	2.0
6094	4.0	3.0
6095	-1.0	1.0
6098	1.0	-3.0
9016	-1.0	5.0
9017	-1.0	3.0
9036	1.0	-1.0
9037	0.0	-1.0
9041	1.0	-1.0
9047	-1.0	-0.5
9051	-1.0	-1.0
9052	-1.0	0.0
9057	0.0	-1.0
9061	-0.5	0.0
9062	-3.0	-2.0
9066	-1.0	1.0
9071	-1.0	1.0
9096	0.0	1.0

After registering the primary scene, a scene to scene overlay of the two scenes was performed with an accuracy of one-half pixel. This procedure consisted of selecting for each pixel in the primary scene the pixel in the secondary scene that most nearly represented the same area on the ground. The result was an eight channel data set; the first four channels for each pixel were from the primary scene and the second four channels were from the secondary scene.

For details concerning scene to map registration and scene to scene overlaying refer to the papers by Hanuschak, et.al. [1] and Ozga, et.al. [4].

ANALYSIS

The data was analyzed using various analysis procedures. These procedures will be referred to as MA1, MA2, MA3, MA4, UA1, UA2, UA3, and UA4 and will also have the extensions EP and PUR. MA indicates multitemporal analysis and UA indicates unitemporal analysis. EP indicates the use of equal probabilities and PUR indicates the use of prior probabilities proportional to unexpanded reported acres. Eight channel data was used for the multitemporal analysis. The multitemporal data set consisted of four channels from each of the two dates. Four channel data was used for the unitemporal analysis. Clustering was not performed for MA4, UA3, and UA4. May data was used for UA3 and August data was used for UA4. For MA3, UA1, and UA2, categories were automatically grouped and 95% pattern transmission was retained. For a description of the automatic grouping technique refer to the paper by Craig, et.al. [3]. May data was used for UA2 and August data was used for UA1. Clustering was performed using Bolt, Beranek, and Newman, Data Processing Facility in Cambridge, Mass. (BBN) for MA1 and the ILLIAC IV Computer in Sunnyvale, Calif. for MA2. The analysis procedures are summarized in Table 3.

All analysis was performed using EDITOR. EDITOR is an interactive data analysis system for processing LANDSAT data. For a description of EDITOR refer to the paper by Ozga, et.al. [2]. Several modifications were made to EDITOR to enable processing of eight channel data. The basic analysis steps for multitemporal data are almost the same as for unitemporal data. One difference is in the creation of the Multi-Window file. Since one eight-channel tape is created for the left side of the multitemporal window and a second eight-channel tape is created for the right side, two Multi-Window files are created and combined into one file. This file contains data for each window. A window is a rectangular array of pixels.

Table A2 gives the number of training pixels available after the elimination of boundary pixels and questionable field pixels. Signatures were created for covers having 150 or more training pixels. Table A4 gives the number of categories for each cover type by analysis procedure.

After creating statistics using various approaches all segment data was classified using the corresponding signatures. Boundary pixels were included

TABLE 3: ANALYSIS PROCEDURES

PROCEDURE	SEPARABILITY THRESHOLD	CLUSTERING PERFORMED ON	AUTOMATIC GROUPING	NUMBER OF CATEGORIES: CORN	DENSE WOODLAND	OTHER HAY	PERMANENT PASTURE	SOYBEANS	WINTER WHEAT	TOTAL
MA1	0.85	BBN	NO	6	4	4	12	10	2	38
MA2	NONE	ILLIAC	NO	6	4	4	12	10	2	38
MA3	NONE	ILLIAC	YES	8	8	8	17	14	5	60
MA4	NONE	NOT PERFORMED	NO	1	1	1	1	1	1	6
UA1	NONE	ILLIAC	YES	7	7	7	15	10	5	51
UA2	NONE	ILLIAC	YES	7	7	7	15	10	5	51
UA3	NONE	NOT PERFORMED	NO	1	1	1	1	1	1	6
UA4	NONE	NOT PERFORMED	NO	1	1	1	1	1	1	6

for each classification. Tables A5 thru A20 contains categorization results for each procedure.

A regression estimator with JES data as the dependent variable and LANDSAT classified pixels as the independent variable was used. For the purpose of estimating crop areas, ESS's evaluation criterion is not the percent of pixels classified correctly but is how precisely the crop area is estimated for the area of interest. Maximization of the R-square values minimizes the variance of the regression estimates. Thus, the major criterion used to compare the various procedures was the respective R-squares. Another measure for evaluation is relative efficiency (RE). The relative efficiency is the ratio of the variance of the direct expansion estimate to the variance of the regression estimate. Table 4 gives percent correct, R-square, and RE measures for the major crops in the analysis district by classifier.

Table 5 compares the best multitemporal results with the best unitemporal results.

SUMMARY AND CONCLUSIONS

A multitemporal data set and each of the two corresponding unitemporal data sets were analyzed using various procedures. Results indicate that the use of multitemporal data can significantly improve the precision of crop area estimates for corn, soybeans, and winter wheat. These results strongly suggest that the multitemporal approach be used when our objective is to estimate crop areas for both corn and soybeans at the analysis district level, if we are able to obtain cloud free imagery for two appropriate dates covering the same land area. A full state analysis using the multitemporal approach could entail additional complexity due to possible nonoverlap land area coverage of the multitemporal LANDSAT images due to clouds or satellite drift.

Registration and the creation of the multitemporal data set require an elapsed time of about four days. The analysis of multitemporal data requires about the same amount of time as the analysis of unitemporal data and the analysis steps are basically the same.

For future projects, in which the multitemporal approach will be used, scene to map registration could proceed after the acquisition of the secondary scenes. After the primary scenes are acquired scene to scene overlaying could then begin immediately.

TABLE 4: CLASSIFIER EVALUATION

Cover Type	Classifier	Percent Correct	R^2	RE
Corn	MA1,PUR	67.00	0.8181	5.33
	MA1,EP	68.58	0.7821	4.44
	MA2,PUR	67.13	0.8188	5.35
	MA2,EP	69.97	0.7885	4.58
	MA3,PUR	67.07	0.7947	4.72
	MA3,EP	64.10	0.7983	4.80
	UA1,PUR	42.92	0.3721	1.54
	UA1,EP	49.62	0.1734	1.17
	UA4,PUR	48.61	0.3537	1.50
	UA4,EP	57.84	0.1704	1.17
	MA4,PUR	67.38	0.8055	4.98
	MA4,EP	72.12	0.7830	4.46
Soybeans	MA1,PUR	78.45	0.8559	6.72
	MA1,EP	73.75	0.8643	7.14
	MA2,PUR	77.78	0.8540	6.64
	MA2,EP	73.57	0.8644	7.15
	MA3,PUR	79.99	0.8625	7.04
	MA3,EP	75.08	0.8637	7.11
	UA1,PUR	74.39	0.7450	3.80
	UA1,EP	57.32	0.7194	3.45
	UA4,PUR	71.42	0.7285	3.57
	UA4,EP	73.02	0.7365	3.68
	MA4,PUR	80.33	0.8493	6.43
	MA4,EP	78.96	0.8478	6.37

Table 4: Continued

Winterwheat	MA1,PUR	32.96	0.4920	1.91
	MA1,EP	43.58	0.4353	1.72
	MA2,PUR	34.07	0.5247	2.04
	MA2,EP	46.68	0.4488	1.76
	MA3,PUR	38.72	0.6175	2.53
	MA3,EP	46.90	0.5550	2.18
	UA1,PUR	30.31	0.3864	1.58
	UA1,EP	44.03	0.3899	1.59
	UA2,PUR	9.07	0.1162	1.10
	UA2,EP	27.21	0.0159	0.98
	UA3,PUR	*	*	*
	UA3,EP	30.09	0.0001	0.97
	UA4,PUR	27.43	0.2159	1.24
	UA4,EP	46.68	0.1480	1.14
	MA4,PUR	31.86	0.3385	1.46
	MA4,EP	52.88	0.2443	1.28
Overall	MA1,PUR	67.03	-	-
	MA1,EP	63.02	-	-
	MA2,PUR	66.78	-	-
	MA2,EP	63.04	-	-
	MA3,PUR	68.34	-	-
	MA3,EP	63.30	-	-
	UA1,PUR	58.43	-	-
	UA1,EP	50.83	-	-
	UA2,PUR	54.44	-	-
	UA2,EP	44.85	-	-
	UA3,PUR	55.76	-	-
	UA3,EP	33.73	-	-
	UA4,PUR	58.54	-	-
	UA4,EP	48.03	-	-
	MA4,PUR	65.04	-	-
	MA4,EP	53.60	-	-

* No pixels classified as winterwheat

TABLE 5: MULTITEMPORAL vs UNITEMPORAL COMPARISONS

	Best % Correct Multitemporal	Best % Correct Unitemporal	Best R^2 Multitemporal	Best R^2 Unitemporal
Corn	72.12	57.84	0.8188	0.3721
Soybeans	80.33	74.39	0.8644	0.7450
Winterwheat	52.88	46.68	0.6175	0.3899
Overall	68.34	58.54	-	-

	Best Relative Efficiency Multitemporal	Best Relative Efficiency Unitemporal
Corn	5.35	1.54
Soybeans	7.15	3.80
Winterwheat	2.53	1.59
Overall	-	-

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APPENDIX A

TABLE A1: TABULATION OF SEGMENT DATA BY COVER TYPE

COVER TYPE	REPORTED AREA IN PIXELS
Alfalfa	130
Corn	1582
Dense Woodland	1136
Oats	67
Other Hay	964
Permanent Pasture	3984
Rye	41
Sorghum	12
Soybeans	3299
Unknown	18
Wasteland	1791
Winter Wheat	452
TOTAL	13476

TABLE A2: TABULATION OF USABLE TRAINING DATA

COVER TYPE	TRAINING PIXELS	PER CENT
Alfalfa	62	1.0
Corn	651	10.1
Wasteland	66	1.0
Winter Wheat	192	3.0
Sorghum	4	0.1
Permanent Pasture	2527	39.2
Oats	34	0.5
Rye	28	0.4
Soybeans	1773	27.5
Dense Woodland	514	8.0
Other Hay	592	9.2
TOTAL	6443	100.0

TABLE A3: ANALYSIS DISTRICT DESCRIPTION

COUNTIES CONTAINED	NUMBER OF SEGMENTS
Caldwell	3
Daviess	5
De-Kalb *	1
Gentry *	1
Grundy	3
Harrison *	4
Linn	5
Livingston	5
Mercer *	1
Putnam *	1
Sullivan *	4
TOTAL	33

* Counties partially contained

TABLE A4: NUMBER OF CATEGORIES BY COVER TYPE AND ANALYSIS PROCEDURES

	ANALYSIS PROCEDURE							
	MA1	MA2	MA3	UA1	UA2	MA4	UA3	UA4
COVER TYPE	NUMBER OF CATEGORIES							
Corn	6	6	8	7	7	1	1	1
Dense Woodland	4	4	8	7	7	1	1	1
Other Hay	4	4	8	7	7	1	1	1
Permanent Pasture	12	12	17	15	15	1	1	1
Soybeans	10	10	14	10	10	1	1	1
Winter Wheat	2	2	5	5	5	1	1	1
TOTAL	38	38	60	51	51	6	6	6

TABLE A5: CLASSIFIER PERFORMANCE - MA1, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	67.00	23.58	1060	0	216	217	49	40	1502
WINTER WHEAT	32.96	42.91	6	149	147	63	14	73	452
PERMANENT PASTURE	76.10	35.14	85	47	3032	312	229	279	3984
SOYBEANS	78.45	22.95	128	17	426	2588	44	96	3299
DENSE WOODLAND	44.54	42.24	76	8	403	90	506	53	1136
OTHER HAY	32.99	62.98	32	40	451	89	34	318	964
TOTAL			1387	261	4675	3359	876	859	11417

OVERALL PERFORMANCE = 67.03 percent correct

TABLE A6: CLASSIFIER PERFORMANCE - MA1, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	68.58	27.18	1085	1	205	206	63	22	1582
WINTER WHEAT	43.58	61.14	7	197	90	64	23	71	452
PERMANENT PASTURE	63.76	35.99	114	165	2540	341	487	337	3984
SOYBEANS	73.75	24.53	157	33	538	2433	68	70	3299
DENSE WOODLAND	54.84	53.19	102	23	256	86	623	46	1136
OTHER HAY	35.06	61.76	38	88	339	94	67	338	964
TOTAL			1503	507	3968	3224	1331	884	11417

OVERALL PERFORMANCE = 63.20 percent correct

TABLE A7: CLASSIFIER PERFORMANCE - MA2, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	67.13	24.36	1062	1	206	229	52	32	1582
WINTER WHEAT	34.07	43.80	6	154	138	62	21	71	452
PERMANENT PASTURE	75.05	35.56	96	53	2990	299	263	283	3984
SOYBEANS	77.78	22.69	124	17	463	2566	46	83	3299
DENSE WOODLAND	47.45	43.74	81	11	374	91	539	40	1136
OTHER HAY	32.47	61.92	35	38	469	72	37	313	964
TOTAL			1404	274	4640	3319	958	822	11417

OVERALL PERFORMANCE = 66.78 percent correct

TABLE A8: CLASSIFIER PERFORMANCE - MA2, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	69.97	28.86	1107	1	179	200	65	30	1582
WINTER WHEAT	46.68	60.71	6	211	83	60	23	69	452
PERMANENT PASTURE	62.20	35.38	132	167	2478	316	508	383	3984
SOYBEANS	73.57	23.22	158	37	512	2427	58	107	3299
DENSE WOODLAND	55.99	53.06	114	25	233	82	636	46	1136
OTHER HAY	35.06	65.26	39	96	350	76	65	338	964
TOTAL			1556	537	3835	3161	1355	973	11417

OVERALL PERFORMANCE = 63.04 percent correct

TABLE A9: CLASSIFIER PERFORMANCE - MA3, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	67.07	23.23	1061	1	205	244	41	30	1582
WINTER WHEAT	38.72	39.45	4	175	150	52	15	56	452
PERMANENT PASTURE	75.83	33.58	93	49	3021	315	229	277	3984
SOYBEANS	79.99	23.73	125	25	394	2639	38	78	3299
DENSE WOODLAND	48.24	39.58	68	13	357	118	548	32	1136
OTHER HAY	37.14	56.92	31	26	421	92	36	358	964
TOTAL			1382	289	4548	3460	907	831	11417

OVERALL PERFORMANCE = 68.34 percent correct

TABLE A10: CLASSIFIER PERFORMANCE - MA3, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	64.10	23.01	1014	3	185	224	83	73	1582
WINTER WHEAT	46.90	54.51	6	212	91	58	26	59	452
PERMANENT PASTURE	61.02	33.47	89	139	2431	373	476	476	3984
SOYBEANS	75.08	25.48	118	42	434	2477	74	154	3299
DENSE WOODLAND	58.36	52.44	66	15	232	90	663	70	1136
OTHER HAY	44.16	65.93	24	55	281	102	72	430	964
TOTAL			1317	466	3654	3324	1394	1262	11417

OVERALL PERFORMANCE = 63.30 percent correct

TABLE A11: CLASSIFIER PERFORMANCE - UA1, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	42.92	46.95	679	5	480	197	209	12	1582
WINTER WHEAT	30.31	42.19	3	137	208	70	2	32	452
PERMANENT PASTURE	72.72	44.53	243	36	2897	481	140	187	3984
SOYBEANS	74.39	29.08	91	20	638	2454	34	62	3299
DENSE WOODLAND	33.89	50.70	211	9	379	128	385	24	1136
OTHER HAY	12.34	72.71	53	30	621	130	11	119	964
TOTAL			1280	237	5223	3460	781	436	11417

OVERALL PERFORMANCE = 58.43 percent correct

TABLE A12: CLASSIFIER PERFORMANCE - UA1, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	49.62	57.52	785	15	264	154	325	39	1582
WINTER WHEAT	44.03	67.16	16	199	146	37	12	42	452
PERMANENT PASTURE	57.18	45.57	506	186	2278	295	348	371	3984
SOYBEANS	57.32	24.84	172	99	762	1891	112	263	3299
DENSE WOODLAND	40.67	64.68	272	18	260	73	462	51	1136
OTHER HAY	19.50	80.29	97	89	475	66	49	188	964
TOTAL			1848	606	4185	2516	1308	954	11417

OVERALL PERFORMANCE = 50.83 percent correct

TABLE A13: CLASSIFIER PERFORMANCE - UA2, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	18.08	57.94	286	3	250	1016	13	14	1582
WINTER WHEAT	9.07	65.83	7	41	289	51	26	38	452
PERMANENT PASTURE	77.18	43.62	64	44	3075	389	214	198	3984
SOYBEANS	71.60	42.11	291	2	582	2362	24	38	3299
DENSE WOODLAND	23.94	53.26	19	6	650	155	272	34	1136
OTHER HAY	18.57	64.27	13	24	608	107	33	179	964
TOTAL			680	120	5454	4080	582	501	11417

OVERALL PERFORMANCE = 54.44 percent correct

TABLE A14: CLASSIFIER PERFORMANCE - UA2, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	39.76	63.22	629	17	208	609	75	44	1582
WINTER WHEAT	27.21	84.98	22	123	137	38	86	46	452
PERMANENT PASTURE	47.92	41.96	140	384	1909	328	822	401	3984
SOYBEANS	50.71	41.38	848	74	457	1673	156	91	3299
DENSE WOODLAND	49.12	70.08	43	101	253	112	558	69	1136
OTHER HAY	23.76	73.98	28	120	325	94	168	229	964
TOTAL			1710	819	3289	2854	1865	880	11417

OVERALL PERFORMANCE = 44.85 percent correct

TABLE A15: CLASSIFIER PERFORMANCE - MA4, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	67.38	21.39	1066	0	196	267	46	7	1582
WINTER WHEAT	31.86	46.86	5	144	199	60	9	35	452
PERMANENT PASTURE	67.55	37.81	73	47	2691	352	504	317	3984
SOYBEANS	80.33	24.72	127	15	430	2650	44	33	3299
DENSE WOODLAND	56.87	50.23	56	12	295	103	646	24	1136
OTHER HAY	23.76	64.50	29	53	516	88	49	229	964
TOTAL			1356	271	4327	3520	1298	645	11417

OVERALL PERFORMANCE = 65.04 percent correct

TABLE A16: CLASSIFIER PERFORMANCE - MA4, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	72.12	28.69	1141	10	65	229	84	53	1582
WINTER WHEAT	52.88	74.05	6	239	46	64	25	72	452
PERMANENT PASTURE	22.64	33.33	125	400	902	336	914	1307	3984
SOYBEANS	78.96	23.65	206	55	176	2605	77	180	3299
DENSE WOODLAND	65.67	61.80	80	51	85	94	746	80	1136
OTHER HAY	50.14	77.69	42	166	79	84	107	486	964
TOTAL			1600	921	1353	3412	1953	2178	11417

OVERALL PERFORMANCE = 53.60 percent correct

TABLE A17: CLASSIFIER PERFORMANCE - UA3, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	5.37	59.72	85	199	1275	18	5	1582
PERMANENT PASTURE	71.36	39.29	9	2843	467	475	190	3984
SOYBEANS	79.18	43.66	109	515	2612	45	18	3299
DENSE WOODLAND	37.15	60.26	4	532	170	422	8	1136
OTHER HAY	15.77	59.25	4	594	112	102	152	964
TOTAL			211	4683	4636	1062	373	10965

OVERALL PERFORMANCE = 55.76 percent correct

TABLE A18: CLASSIFIER PERFORMANCE - UA3, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	NUMBER OF PIXELS CLASSIFIED INTO: CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
CORN	56.83	69.42	899	29	46	497	78	33	1582
WINTER WHEAT	30.09	91.65	37	136	67	32	119	61	452
PERMANENT PASTURE	16.42	35.69	245	985	654	282	1060	758	3984
SOYBEANS	35.22	45.78	1612	97	142	1162	174	112	3299
DENSE WOODLAND	61.36	70.68	79	156	52	108	697	44	1136
OTHER HAY	31.43	76.89	68	226	56	62	249	303	964
TOTAL			2940	1629	1017	2143	2377	1311	11417

OVERALL PERFORMANCE = 33.73 percent correct

TABLE A19: CLASSIFIER PERFORMANCE - UA4, PUR

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	48.61	47.51	769	4	517	164	128	0	1582
WINTER WHEAT	27.43	52.12	6	124	250	63	0	9	452
PERMANENT PASTURE	78.69	46.90	269	60	3135	395	116	9	3984
SOYBEANS	71.42	26.05	81	12	820	2356	17	13	3299
DENSE WOODLAND	25.35	48.20	288	17	437	101	288	5	1136
OTHER HAY	1.14	76.60	52	42	745	107	7	11	964
TOTAL			1465	259	5904	3186	556	47	11417

OVERALL PERFORMANCE = 58.54 percent correct

TABLE A20: CLASSIFIER PERFORMANCE - UA4, EP

COVER TYPE	PERCENT CORRECT	PERCENT COMMISSION ERROR	CORN	WINTER WHEAT	PERMANENT PASTURE	SOYBEANS	DENSE WOODLAND	OTHER HAY	TOTAL
			NUMBER OF PIXELS CLASSIFIED INTO						
CORN	57.84	57.48	915	18	135	176	292	46	1582
WINTER WHEAT	46.68	75.94	12	211	37	66	9	117	452
PERMANENT PASTURE	30.32	40.73	606	375	1208	430	393	972	3984
SOYBEANS	73.02	27.09	162	59	303	2409	96	270	3299
DENSE WOODLAND	38.91	65.17	347	48	124	102	442	73	1136
OTHER HAY	31.02	83.17	110	166	231	121	37	299	964
TOTAL			2152	877	2038	3304	1269	1777	11417

OVERALL PERFORMANCE = 48.03 percent correct

APPENDIX B

Testing Hypotheses Between Two Values of R^2

In performing this test I made use of the distribution of t, where

$$t = \frac{\sqrt{(n-3)(1+r_{um})} \cdot (r_{yu} - r_{ym})}{\sqrt{2D}}$$

and D is the determinant of

$$\begin{vmatrix} 1 & r_{yu} & r_{um} \\ r_{yu} & 1 & r_{ym} \\ r_{um} & r_{ym} & 1 \end{vmatrix}$$

with n - 3 degrees of freedom.

r_{yu} - coefficient of correlation between reported area and number of pixels classified into a given cover type using an unitemporal procedure

r_{ym} - coefficient of correlation between reported area and number of pixels classified into a given cover type using a multitemporal procedure

r_{um} - coefficient of correlation between number of pixels classified into a given cover type using an unitemporal procedure and number of pixels classified into a given cover type using a multitemporal procedure

Results of MA3,PUR vs UA1,PUR are as follows:

COVER TYPE	CALCULATED t-value	
CORN	-5.39	Significant ($p<0.001$)
SOYBEANS	-3.53	Significant ($p<0.005$)
WINTERWHEAT	-3.36	Significant ($p<0.005$)

APPENDIX C

Statistical comparison of classification results using one-factor Analysis of Variance and Newman-Keuls Range Test

Similar analysis procedures were performed for MA3,PUR, MA3,EP, UA1,PUR, and UA1,EP. The statistical procedures for testing the classification results are outlined below.

I. Apply arcsin transformation to overall percent correct for each classification

CLASSIFICATION	OVERALL PERCENT CORRECT	TRANSFORMED VALUE (DEGREES)
(1) MA3,PUR	68.34	55.76
(2) MA3,EP	63.30	52.71
(3) UA1,PUR	58.43	49.85
(4) UA1,EP	50.83	45.48

II. Calculate sum of square

$$SS = [(55.76)^2 + (52.71)^2 + (49.85)^2 + (45.48)^2]/1 -$$

$$[(55.76 + 52.71 + 49.85 + 45.48)^2/4]$$

$$= 57.36$$

III. Calculate mean square

$$MS = 57.36/3 = 19.12$$

IV. Calculate F test and determine if significant

$F = 19.12/[821/13476] = 313.84$ (significant)

$F_{3,\infty} = 2.60$

(95%)

V. Arrange transformed percents in descending order

(1)	(2)	(3)	(4)
55.76	52.71	49.85	45.48

VI. Calculate standard error

$$SE = \sqrt{(821/13476)/1} = 0.247$$

VII. Prepare a table of differences

(1-4)	(1-3)	(1-2)
10.28	5.91	3.05
(2-4)	(2-3)	
7.23	2.86	
(3-4)		
4.37		

VIII. Prepare a list of least significant ranges

$R_4 = 3.633\ (0.247) = 0.90$

$R_3 = 3.314\ (0.247) = 0.82$

$R_2 = 2.772\ (0.247) = 0.68$

(95%)

IX. Compare

(1-4)	10.28 vs 0.90 ∴ significant
(1-3)	5.91 vs 0.82 ∴ significant
(2-4)	7.23 vs 0.82 ∴ significant
(1-2)	3.05 vs 0.68 ∴ significant
(2-3)	2.86 vs 0.68 ∴ significant
(3-4)	4.37 vs 0.68 ∴ significant