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TECHNICAL MEMORANDUM

DETAILED ANALYSIS OF CAMS PROCEDURES FOR PHASE III USING GROUND-TRUTH INVENTORIES

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1. INTRODUCTION

Using the digitized ground-truth inventories developed during Phase III, detailed analyses of the Classification and Mensuration Subsystem (CAMS) classification procedure may be performed. The purpose of the CAMS procedure is to determine the small-grains proportion in a segment. All of the processings used in this study were passed to the aggregation system as good processings, although some were not used in the aggregations.

The CAMS classification procedure follows these steps:

a. Two sets of dots are labeled as wheat or nonwheat by the analysts.

b. Using one set of analyst-labeled dots (type 1 dots) as seed picture elements (pixels), all of the pixels in the segment are grouped into clusters on the basis of their spectral values.

c. Each of the clusters is labeled as wheat or nonwheat by the type 1 analyst-labeled dot closest to the mean of the cluster.

d. On the basis of the means and variances for each cluster, every pixel in the segment is classified as either wheat or nonwheat.

e. Using the second set of analyst-labeled dots (type 2 dots) as a random sample of the segment, the machine classification proportion is corrected for any bias introduced by the classification process.

The proportion of wheat in a segment can be estimated at four steps in the procedure:

a. The type 2 dots can be used as a random sample of the segments to determine a proportion.

b. At the machine clustering stage, a proportion can be determined using the analyst label for each cluster.

c. The machine classification proportion is calculated using the CAMS procedures.

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d. The bias-corrected machine proportion is calculated using CAMS procedures.

If the procedure is effective, the proportion estimate should improve at each step. The CAMS procedures will be evaluated by calculating the proportion of small grains at each of these four steps: type 2 dots as a random sample, machine clusters, machine classification, and bias-corrected machine classification.

The results of these studies will be given for three groups: winter wheat segments, spring wheat segments, and mixed wheat segments. The winter wheat segments were those located in Colorado, Kansas, Nebraska, Oklahoma, and Texas and the spring wheat segments were in Minnesota and North Dakota. All of the segments in Montana and South Dakota were grouped as mixed wheat although some of these segments were processed as winter or spring wheat.

When necessary to aggregate the pixels in a segment into small grains and non-small grains, winter wheat, spring wheat, barley, rye, flax, and oats were aggregated as small grains and all other crops were aggregated as nonsmall grains.

2. CAMS CLASSIFICATION RESULTS

Figures 1 through 4 show the errors in the estimates at each of the four stages in the CAMS procedure, using the last processing for each segment. The errors are plotted as a function of the true small-grains proportion for each segment. The general trend with all four of the estimates is an underestimation of the small-grains proportion, with the worst errors occurring for large small-grains proportions.

The mean error and standard deviation (SD) of the mean error were calculated to quantize the errors. The mean error gives a measure of the bias of the estimator, and the SD is a measure of the variability. The mean square error (MSE), a measure of the overall performance of the estimator, was also
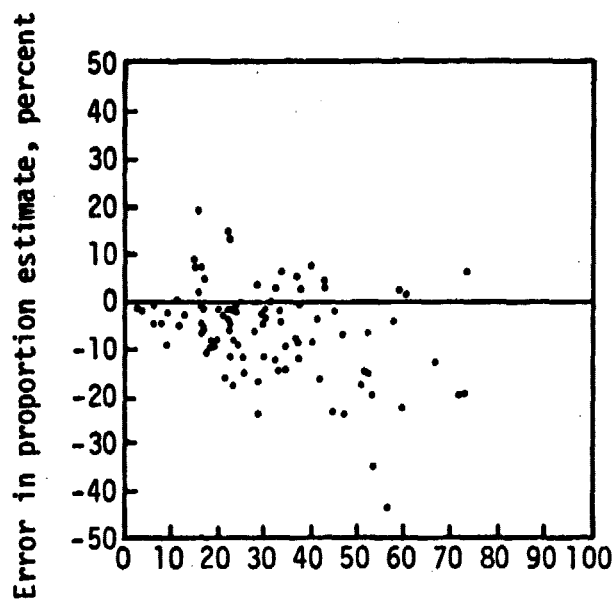
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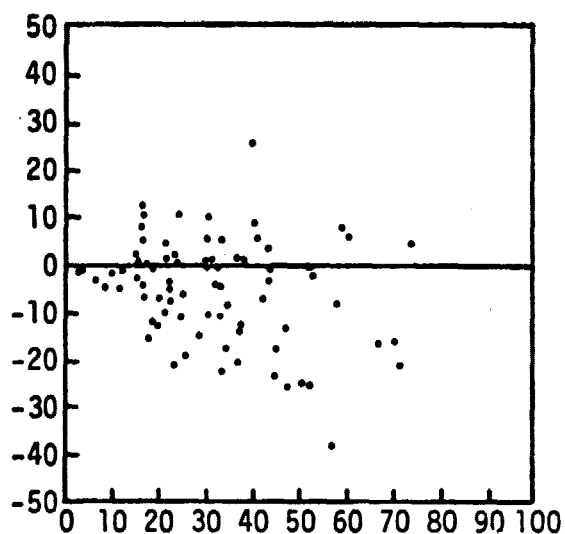Figure 1.— Analyst-labeled type 2
dots as random sample.

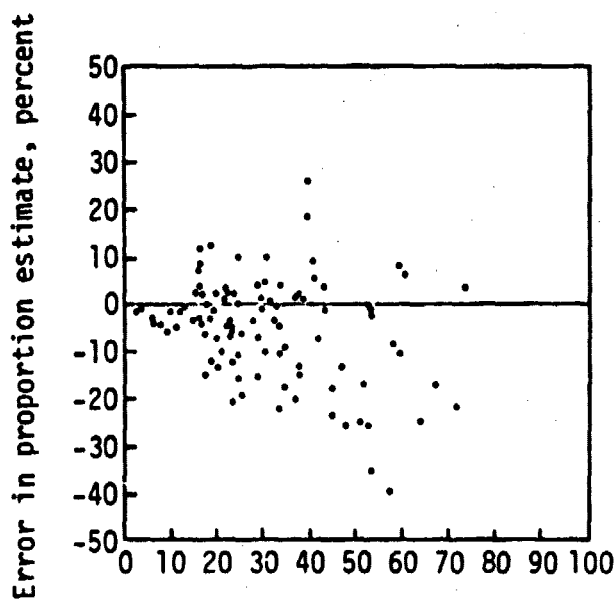Figure 2.— Machine clusters
with analyst labels.

Figure 3.— Machine
classification.
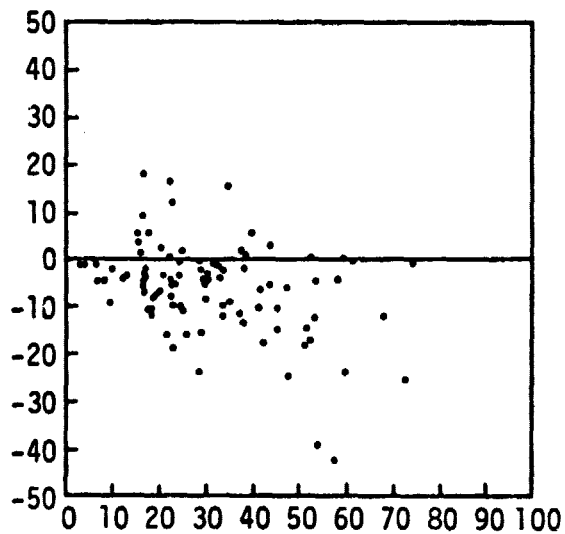
Figure 4.— Bias-corrected
machine classification.

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calculated. The mean error, SD, and MSE are shown in table 1; these results indicate that the estimate of small-grains proportion did not improve significantly from one step to the next. In all cases, the bias was approximately 6 percent with an SD of approximately 10 percent.

Another way of analyzing the procedure is to calculate the improvement (the difference in absolute value) in the error between any two steps. A positive improvement indicates that the error was less in the latter step than in the earlier step. The percentage of processings in which there was an improvement can also be calculated. If the step is effective, the percentage of processings improved should be greater than 50 percent, and the mean improvement should be greater than zero. These calculations for the CAMS results are shown in table 2. All of the comparisons indicate very little improvement in the error in any of the steps; overall, about half the processings improved, and half the processings became worse. The mean improvement was less than 0.5 percent.

In analyzing the differences between machine classification estimates and machine clustering estimates, the mean improvement was found to be 0.04 percent with an SD of the mean improvement of 0.46 percent. In performing a linear regression of the machine classification error against the machine clustering error, the slope was found to be 1.003 with an intercept of -0.185. The coefficient of determination for the regression was 0.9985. This result indicates that the classification results are essentially the same as the clustering results. A plot of the classification error as a function of clustering error is shown in figure 5. A pixel-level comparison was made between the classification results and the clustering results to investigate this relationship further. This comparison indicates that 96 percent of the pixels do not change their label from the clustering to the classification stage and that the average net change in pixel counts was only 0.3 percent, indicating that the classification is unnecessary.

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TABLE 1.— CAMS CLASSIFICATION ERRORS

[Using final processing for each segment]

Source of classification result	Winter wheat				Spring wheat				Mixed wheat				All categories			
	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE
Type 2 dots as random sample	43	-6.4	10.3	146	26	-7.7	9.5	146	27	-5.4	9.2	110	96	-6.5	9.8	135
Machine clusters with type 2 labels	33	-5.6	11.7	163	21	-4.7	11.2	142	24	-5.8	9.3	118	78	-5.4	10.7	143
Machine classification	43	-5.7	10.3	135	26	-6.0	12.9	197	27	-5.8	9.1	111	96	-5.8	10.6	145
Bias-corrected machine classification	43	-6.6	9.9	140	26	-7.7	9.6	147	27	-5.4	8.4	97	96	-6.6	9.4	130

TABLE 2.— CAMS CLASSIFICATION IMPROVEMENT

[Using final processing for each segment]

| Classification sources compared	Winter wheat		Spring wheat		Mixed wheat		All categories	
	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement
Clusters vs. type 2 dots	55	0.4	43	-1.4	42	-0.9	47	-0.5
Machine classification vs. clusters	52	0.1	24	-0.2	38	0.0	40	0.0
Bias-corrected machine classification vs. machine classification	51	-0.3	58	1.9	52	0.5	53	0.5
Machine classification vs. type 2 dots	58	0.7	38	-1.3	48	0.1	50	0.0
Bias-corrected machine classification vs. type 2 dots	53	0.4	50	0.6	44	0.6	50	0.5
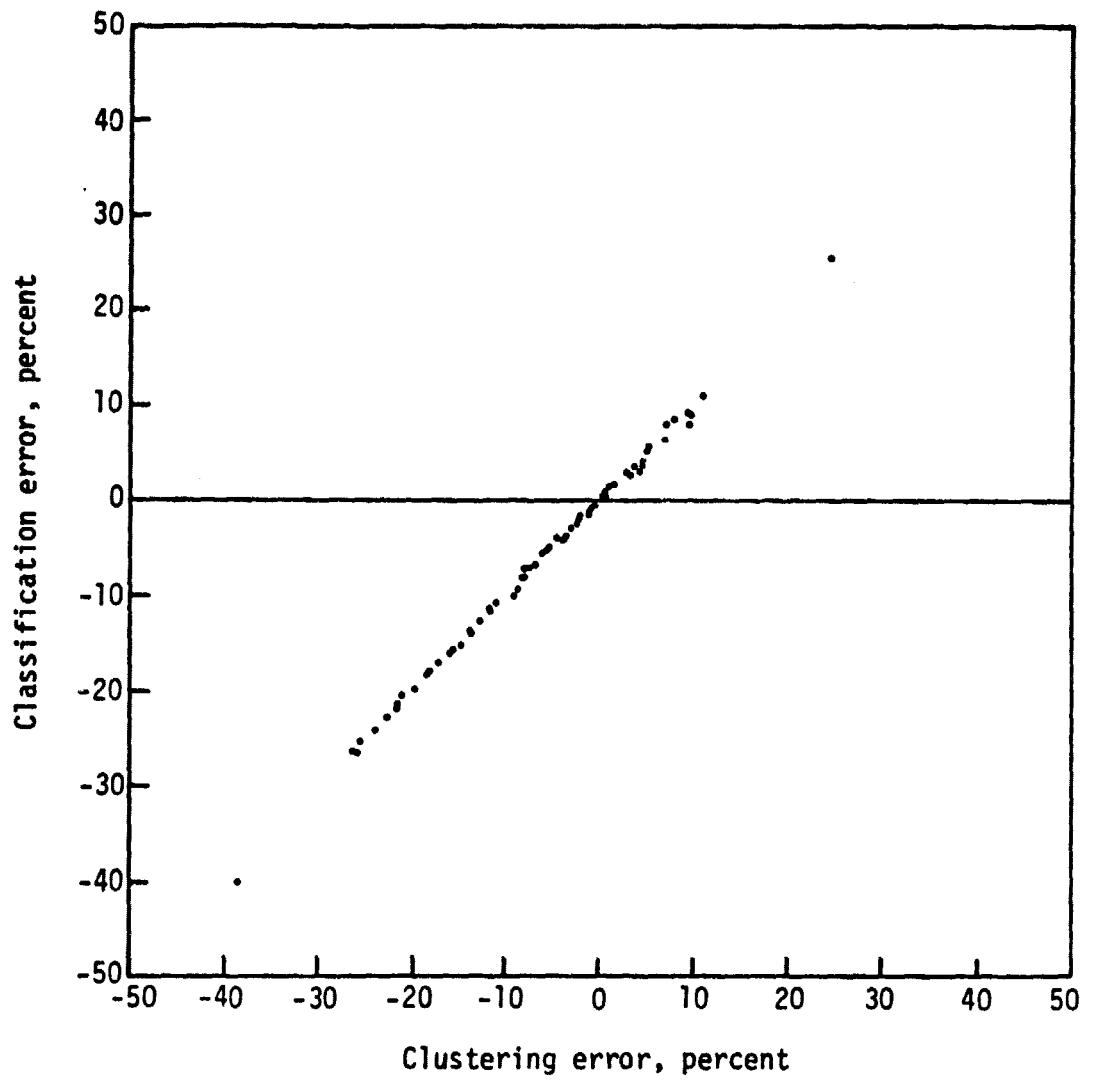
Figure 5.— Classification versus clusters.

2.1 CAMS CLASSIFICATION RESULTS USING GROUND-TRUTH DOT LABELING

The bias and variability in the estimates produced by the CAMS procedure are caused by the procedure itself and by bad input data in the form of mislabeled type 1 and type 2 dots. If one could reprocess the segments using the true labels for the type 1 and type 2 dots, any bias or variability in the results would be due to the procedure itself, and not to bad input data.

Reprocessing all of the segments would be a big project; an easier way is to modify the CAMS results to reflect true dot labels instead of analyst labels. For the random-sample estimate using type 2 dots, it is a simple matter to replace the analyst labels with the true labels and recalculate the proportion. The clustering proportion is determined by aggregating the clusters on the basis of the analyst label for the dot closest to the mean of each cluster. The ground-truth clustering proportion can be determined by aggregating the clusters on the basis of the true dot label instead of the analyst dot label. It is not possible to reproduce the machine classification results using true labels, because means and variances of the clusters are used to classify the pixels. One does not have this information based on true labels. However, comparison of the classification results with the clustering results using analyst labels indicates that the results are identical. It can be assumed, therefore, that the classification results would be identical to the clustering result if true labels were used. The bias correction can be performed by comparing the ground-truth labels for type 2 dots with the label for the cluster in which the dot lies. The CAMS results can thus be reproduced by using ground-truth labels without reprocessing the segments.

The CAMS results using ground-truth labels for type 1 and type 2 dots are shown in figures 6 through 8, which can be compared with the actual CAMS results in figures 1 through 4. The scatter in the error is much less using ground-truth labels, and there is no underestimation for large small-grains proportions. The clustering estimates have more variability than the random sample and bias-corrected estimates. The mean error, SD, and MSE for the CAMS results using ground-truth labels are shown in table 3. As could be expected,
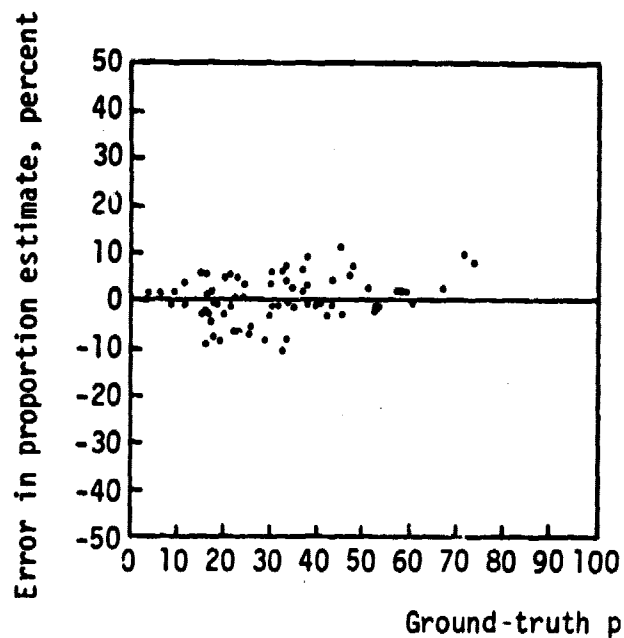
Figure 6.— Ground-truth
labeled type 2 dots.
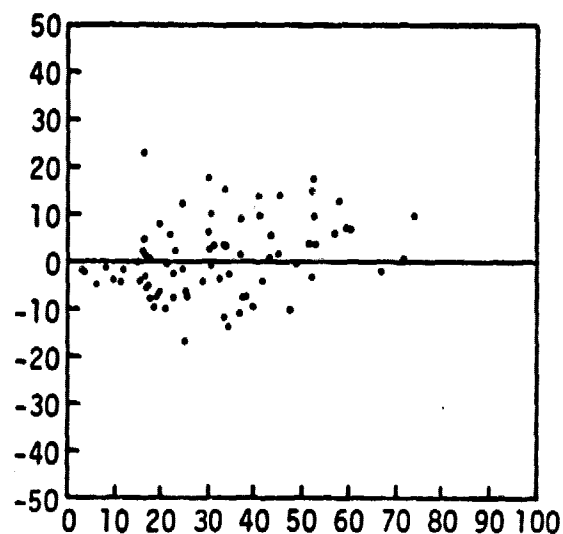
Figure 7.— Machine clusters
with ground-truth labels.

Ground-truth proportion, percent

Ground-truth proportion, percent
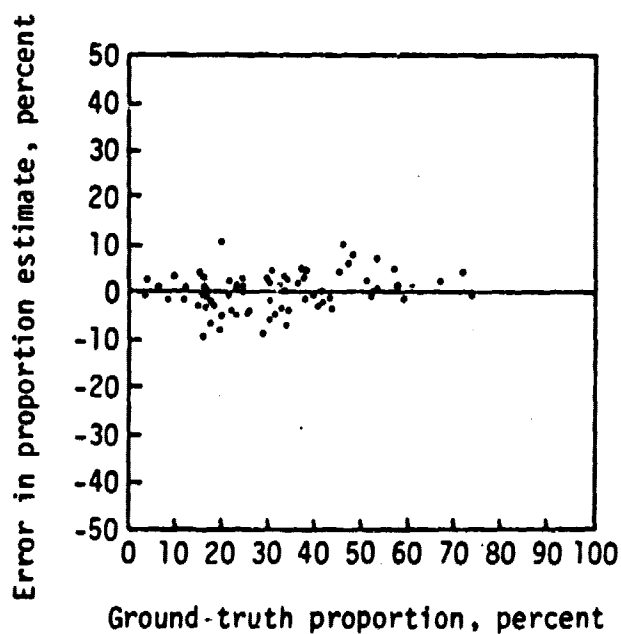
Figure 8.— Bias-corrected
machine clusters.

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TABLE 3.— CAMS CLASSIFICATION ERRORS FOR GROUND-TRUTH DOT LABELS

[Using final processing for each segment]

Source of classification result	Winter wheat				Spring wheat				Mixed wheat				All categories			
	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE	No. of processings	Mean error	SD	MSE
Type 2 dots as random sample	31	-1.1	5.0	26	20	1.0	4.2	18	24	1.4	4.7	21	75	-0.1	4.7	24
Machine clusters (machine classification)	31	0.0	8.2	64	20	4.1	8.0	78	24	-2.4	6.5	46	75	0.4	7.9	62
Bias-corrected machine classification	31	-1.2	3.8	16	20	0.9	3.8	15	24	0.9	4.3	19	75	0.1	4.1	16

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the clustering estimates have a great deal more variability than the random sample or bias-corrected estimates. The bias of the clustering estimate was less than 0.5 percent, indicating that the classification is essentially unbiased. The clustering does increase the variability significantly. The bias correction reduces the errors to about the same level as for the random sample.

Table 4 shows the relative improvement between the three estimates. Clustering made the estimate worse for 71 percent of the segments. The bias-corrected estimate was better than the random sample for 57 percent of the processings, but the mean improvement was only 0.5 percent.

The results using ground-truth dot labels indicate that the 6-percent negative bias and about half of the variability are due to analyst dot-labeling errors. The procedure is capable of producing an unbiased estimate with an SD of about 4 percent.

2.2 ANALYST DOT-LABELING ACCURACY

Because analyst dot-labeling errors are so important, the analyst labeling accuracy was studied in detail. The labeling accuracy was determined for 7677 type 1 dots and 12 037 type 2 dots. The dots used in this study were from all processings for each segment; classification results presented in previous sections were for only the last processing for each segment.

Tables 5 and 6 show the analyst dot-labeling accuracy for type 1 and type 2 dots. The analysts labeled small-grains dots correctly about 61 percent of the time; the labeling accuracy for nonsmall grains was about 93 percent.

In the strip-fallow categories, the dots were labeled as small grains about 42 percent of the time. Because strip-fallow categories are half small grains and half nonsmall grains, the strip-fallow dots should be labeled as small grains 50 percent of the time. Therefore, the labeling accuracy for strip-fallow categories is really 85 percent, which is better than the 61-percent labeling accuracy for small grains.

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TABLE 4.— IMPROVEMENT IN CAMS CLASSIFICATION FOR GROUND-TRUTH DOT LABELS

[Using final processing for each segment]

Classification sources compared	Winter wheat		Spring wheat		Mixed wheat		All categories	
	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement	Processings improved, %	Mean improvement
Clusters (classification) vs. type 2 dots	35	-2.2	5	-4.6	42	-1.4	29	-2.6
Bias-corrected clusters vs. clusters	68	2.9	75	4.8	58	1.9	67	3.1
Bias-corrected clusters vs. type 2 dots	55	0.8	65	0.2	54	0.5	57	0.5

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TABLE 5.— ANALYST DOT-LABELING ACCURACY FOR PHASE III PROCESSING — TYPE 1 DOTS

Classification	Winter wheat		Spring wheat		Mixed wheat		All categories	
	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %
Small grains								
Winter wheat	483	61			75	57	558	61
Spring wheat			432	73	140	63	572	70
Barley			187	75	139	38	326	60
Flax			21	24	17	6	38	16
Oats	25	28	152	⋅⋅	227	71	404	58
Total small grains	508	60	792	67	598	58	1898	62
Strip-fallow small grains[a]								
Winter wheat	48	35			107	46	155	43
Spring wheat			51	37	45	47	96	42
Barley					21	21	21	24
Total strip-fallow small grains	48	35	51	37	173	43	272	41
Nonsmall grains								
Alfalfa	49	90	106	90	151	79	306	85
Beans	19	95					19	95
Corn	159	98	193	95	225	92	577	94
Sunflower			104	98			104	98
Sudan grass	10	90			12	100	22	95
Sorghum	178	92			26	100	204	93
Soybeans and guar	40	100	96	100	11	82	137	99
Sugar beets			27	93	14	100	41	95
Grass	47	98	67	94	125	90	239	93
Hay	25	88	63	89	116	83	204	85
Pasture	933	97	354	92	1218	96	2505	96
Trees	27	85	42	88	41	100	110	92
Cotton	32	97					32	97
Water	27	100	80	100	86	100	193	100
Nonagricultural	37	100	40	98	39	97	116	98
Homestead	51	98	22	91	45	69	118	86
Idle cropland — stubble	13	85			12	92	25	88
Idle cropland — cover crop	10	90					10	90
Idle cropland — residue	33	94			16	100	49	96
Idle cropland — fallow	190	95	139	94	167	93	496	94
Total nonsmall grains	1880	96	1323	94	2304	93	5507	94

[a]The percent correctly labeled for strip-fallow assumes that small grains is the correct label.

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TABLE 6.— ANALYST DOT-LABELING ACCURACY FOR PHASE III PROCESSING — TYPE 2 DOTS

Classification	Winter wheat		Spring wheat		Mixed wheat		All categories	
	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %	No. of dots	Correctly labeled, %
Small grains								
Winter wheat	712	61			149	55	861	60
Spring wheat			738	68	217	56	955	66
Barley	.		282	70	210	40	492	57
Rye					16	38	16	38
Flax			27	11	23	30	50	20
Oats	32	19	281	59	440	59	753	58
Total small grains	744	59	1328	66	1055	53	3127	60
Strip-fallow small grains[a]								
Winter wheat	86	36			179	54	277	47
Spring wheat			75	32	107	41	182	37
Barley					69	38	69	38
Total strip-fallow small grains	86	36	75	32	355	47	528	43
Nonsmall grains								
Alfalfa	53	81	159	89	264	78	476	82
Beans			11	91			11	91
Corn	220	97	228	93	366	92	814	94
Sunflower			170	94	29	93	199	94
Sudan grass	14	86	10	100	11	100	35	94
Sorghum	291	95			55	95	346	95
Soybeans and guar	51	82	105	94			156	90
Sugar beets			41	93			41	93
Grass	65	86	120	88	217	89	402	88
Hay	53	98	76	89	188	90	317	91
Pasture	1271	96	478	95	1993	93	3742	95
Trees	46	96	77	81	95	96	218	90
Cotton	57	81					57	81
Millet					14	79	14	79
Water	3ᶠ	100	95	100	86	100	217	100
Nonagricultural	58	97	55	93	69	100	182	97
Homestead	68	96	48	60	84	85	200	83
Idle cropland — stubble	22	91			11	91	33	91
Idle cropland — cover crop	10	90	12	100			22	95
Idle cropland — residue	25	100			44	95	69	97
Idle cropland — fallow	343	91	244	81	244	94	831	89
Total nonsmall grains	2683	94	1929	90	3770	92	8382	92

[a]The percent correctly labeled for strip-fallow assumes that small grains is the correct label.

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These results are consistent with the underestimation of the small-grains proportion by the CAMS procedure. The analyst does a good job of labeling nonsmall-grains pixels, but mislabels many of the small-grains pixels.

The accuracy for labeling type 1 dots is slightly better than for type 2 dots, probably because type 1 dots are not labeled if they fall on field boundaries, whereas type 2 dots are labeled regardless of where they fall.

The CAMS procedure allows the analyst to change the labels of type 2 dots after the machine classification has been performed. Table 7 shows a comparison of the proportion errors for those segments in which type 2 dot labels were changed. There was an overall improvement in the errors when the relabeled dots were used, but in the mixed wheat segments, the errors became worse. To investigate this problem further, the improvement in dot labeling accuracy was calculated for those processings where dot labels were changed; the results of these calculations are shown in table 8. The overall improvement in labeling small-grains dots was 4 percent. In the strip-fallow and nonsmall-grains categories, the improvement was 1 percent; in the mixed wheat segments, the small-grains accuracy went down by 2 percent and the nonsmall-grains accuracy went up by 3 percent. The less accurate labeling of small grains coupled with the more accurate labeling of nonsmall-grains caused the increased proportion errors observed in the mixed wheat segment.

2.3 ANALYSIS OF CLUSTERING EFFECTIVENESS

In the CAMS results using ground-truth dot labels, clustering increased the variability of the estimate from 4 to 7 percent. To investigate this problem, the cluster purity was calculated for all clusters of all processings. A histogram of cluster purity is given in figure 9. The number of clusters with a given small-grains proportion is plotted as a function of the small-grains proportion within the cluster. Ideally, this histogram would show a maximum value near zero purity to reflect clustering of nonsmall grains, a second maximum near 100-percent purity to reflect clustering of small grains, and a minimum near 50 percent. The results for procedure 1 clustering show

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TABLE 7.— IMPROVEMENT IN CAMS CLASSIFICATION RESULTS

[Relabeled type 2 dots]

Source of classification result	Winter wheat				Spring wheat				Mixed wheat				All categories			
	Mean error	SD	Processing improved, %	Mean improvement	Mean error	SD	Processing improved, %	Mean improvement	Mean error	SD	Processing improved, %	Mean improvement	Mean error	SD	Processing improved, %	Mean improvement
Type 2 dots																
Original	-5.9	9.1	50	0.0	-10.6	9.2	80	3.2	-3.1	9.7	43	-1.7	-6.7	9.6	58	0.6
Relabeled	-4.7	9.8			-7.4	8.2			-6.8	10.1			-6.3	9.2		
Bias correction																
Original	-6.9	8.8	57	1.1	-10.2	7.8	73	3.1	-2.9	8.7	43	-0.6	-6.7	8.8	58	1.3
Relabeled	-5.8	8.8			-7.0	7.7			-6.5	8.2			-6.5	8.1		

TABLE 8.— IMPROVEMENT IN ANALYST DOT-LABELING ACCURACY FOR PHASE III PROCESSING

[Relabeled type 2 dots]

Classification	Winter wheat			Spring wheat			Mixed wheat			All categories		
	No. of dots	Original correct, %	Improvement, %	No. of dots	Original correct, %	Improvement, %	No. of dots	Original correct, %	Improvement, %	No. of dots	Original correct, %	Improvement, %
Small grains												
Winter wheat	218	58	+10				27	5?	-15	245	53	+8
Spring wheat				218	69	+5	48	50	-2	266	65	+4
Barley				82	54	+3	51	53	-8	133	53	0
Flax				8	0	0	6	67	-17	14	29	-8
Oats	4	25	-25	67	66	+7	118	68	+2	189	66	+4
Total small grains	222	58	+10	375	63	+5	250	60	-2	847	61	+4
Strip-fallow small grains												
Winter wheat	30	50	+3	23	22	+17	51	45	-8	81	43	0
Spring wheat				1	0	0	69	45	0	92	43	0
Barley							32	38	+3	33	39	0
Total strip-fallow small grains	30	50	+3	24	22	+17	152	43	-2	206	42	+1
Nonsmall grains												
Alfalfa	10	70	+10	34	94	0	72	79	+10	116	83	+7
Corn	67	99	-3	39	90	0	93	96	+2	199	95	0
Sunflower	6	100	-17	47	96	+2	6	83	0	53	94	+2
Sudan grass	77	94	-1	4	100	0	4	100	0	14	100	-7
Sorghum	30	87	-4	16	94	-7	7	100	0	84	94	0
Soybeans and guar	2	100	0	10	100	0	1	100	0	1	100	0
Sugar beets										12	100	0
Grass	22	91	0	38	87	-5	40	88	+2	100	88	-1
Hay	13	92	0	16	88	-7	48	88	+2	77	88	0
Pasture	263	97	0	136	97	-1	583	94	+2	982	95	+2
Trees	5	80	+7	20	95	-5	23	91	+9	48	92	+2
Cotton	48	81	0							48	81	+7
Water	3	100	0	30	100	0	5	100	0	38	100	0
Nonagricultural	4	75	+25	20	95	0	5	100	0	29	93	+4
Homestead	24	88	+4	9	56	-23	14	93	-7	47	83	-4
Idle cropland — stubble	7	100	0	5	100	0	1	100	0	7	100	0
Idle cropland — cover							3	100	0	6	100	0
Idle cropland — residue	8	100	0							11	100	0
Idle cropland — fallow	108	92	+1	66	79	+3	60	95	0	234	89	+1
Total nonsmall grains	697	93	+1	490	92	-1	965	92	+3	2106	93	+1

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Figure 9.— Histogram of cluster purity.

Small grains cluster purity: ground-truth small grains proportion in clusters, percent

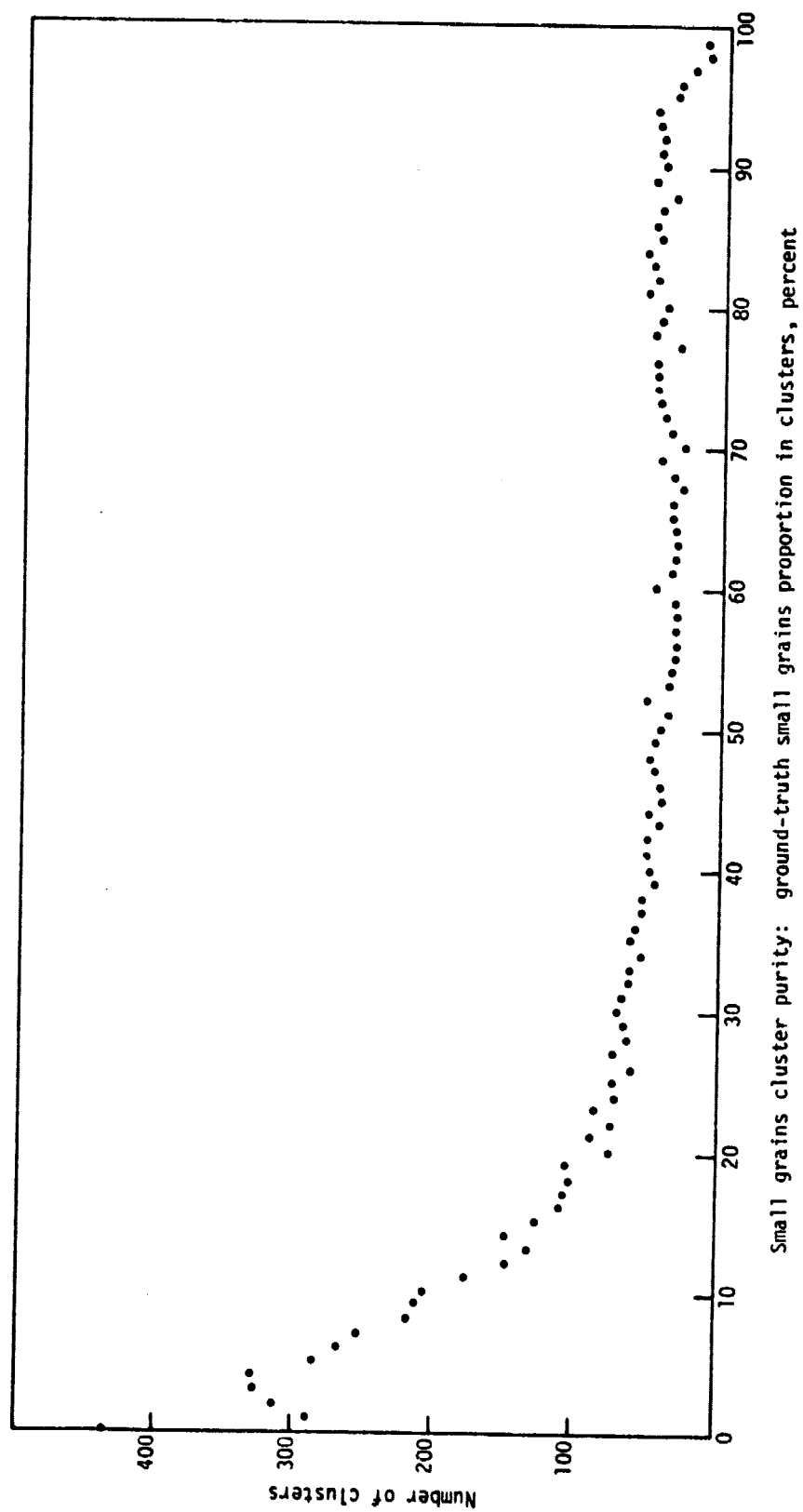Number of clusters

a large number of pure nonsmall-grains clusters, but there are very few pure small-grains clusters. These results show that the clustering does not separate the small grains from the nonsmall grains.

Each cluster is labeled by the dot closest to the cluster mean. If a small-- grains cluster is defined as a cluster with more than 50 percent small grains, the labeling logic correctly labels the small-grains cluster 70 percent of the time, based on the analyst dot labels. The nonsmall-grains clusters are labeled correctly 91 percent of the time. If ground-truth labels are used instead of the analyst labels, the small-grains clusters were labeled correctly 80 percent of the time, while the nonsmall-grains clusters were correctly labeled 83 percent of the time. This indicates that the labeling logic is nearly as effective on small-grains clusters as on nonsmall-grains clusters.

3. CONCLUSIONS

Based on these studies, the following conclusions are reached:

a. The CAMS proportion estimates have a bias of -6 percent with a standard deviation of 10 percent.

b. The -6 percent bias and half of the standard deviation are caused by analyst dot-labeling errors.

c. If the dot labeling were completely accurate, the proportion estimates would be unbiased with a standard deviation of 4 percent.

d. The proportions based on the type 2 dots as a random sample produce as good an estimate as the final bias-corrected result.

e. The proportion estimate produced by the machine classification is identical to the estimate produced by clustering; therefore, machine classification is nonproductive.

f. The -6 percent bias is due to the analysts' labeling nonsmall-grains dots quite well, while mislabeling a large portion of the small-grains dots.

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g. Relabeling the type 2 dots improved the proportion estimates overall, but produced worse estimates in mixed wheat states.

h. Machine clustering does not effectively separate small grains from the nonsmall grains (corn, soybeans, grasses, trees, etc.).

i. The greatest improvement in results would be produced by improving the analyst dot-labeling accuracy.

j. A significant improvement in results would be produced with better clustering.