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TECHNICAL MEMORANDUM

AN EVALUATION OF NATURAL STRATIFICATION AND SAMPLE ALLOCATION USED IN TRANSITION YEAR FOR THE U.S. GREAT PLAINS

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CONTENTS

TABLES

FIGURES

1. BACKGROUND

A new stratification of the U.S. Great Plains (USGP) was developed for use in the Transition Year (TY) sample design. This stratification, based on soil, climate, and agricultural characteristics, was considered more efficient than stratification based entirely on political subdivisions.

Soil characteristics were obtained from soil maps (refs. 1 and 2), and monthly average temperature and precipitation data obtained from the World Meteorological Organization were used to achieve the climatological classification of the area. The USGP was stratified into 27 agrophysical units (APU's) as shown in figure 1. Agriculture and nonagriculture areas for each APU were delineated, using full-frame color infrared images. Segments containing 5 percent or less agricultural area were defined as nonagriculture areas and were excluded from the sampling frame.

As the APU's are generally larger than Crop Reporting Districts, the new strata can be expected to be much less homogeneous than the counties which formed the basis of optimum sample allocation during Large Area Crop Inventory Experiment (LACIE) Phases I, II, and III. The questions of the extent to which strata homogeneity has been reduced and what benefits are derived from the new stratification approach thus arise. Besides leading to a natural stratification, the new approach is uniformly applicable in all countries and may provide a solution to the problem of optimum sample allocation in countries with no historical data at a lower political subdivision level.

The stratification was made more efficient for sampling by considering the new set of strata obtained by the intersection of APU's with political subdivisions in the country. As the state represents the size of a political subdivision for which historical crop information is likely to be available in a foreign country, the state was the political subdivision level considered for intersection with APU's in the USGP. The strata obtained by this

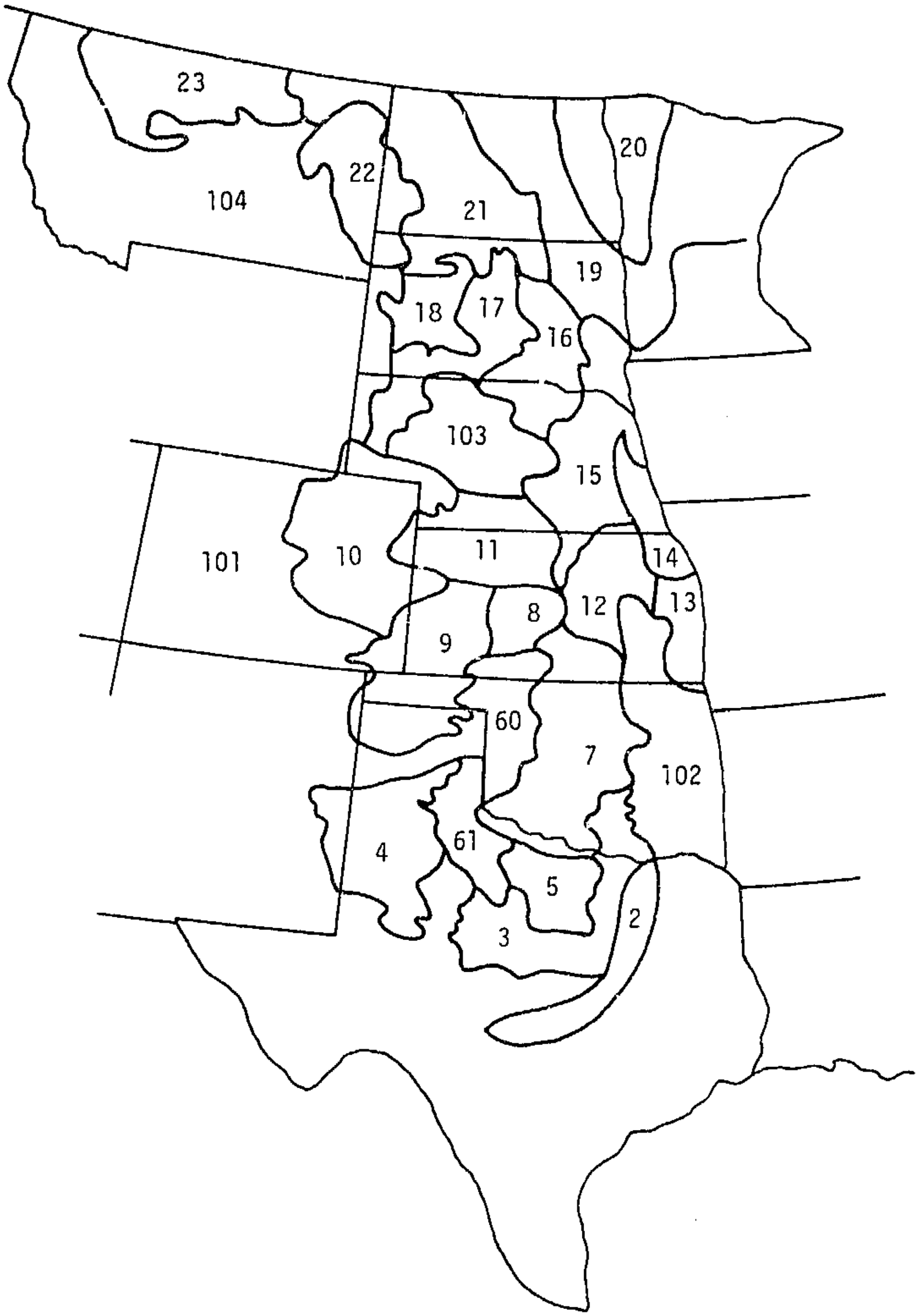

Figure 1.— APU stratification of USGP.

intersection were called refined strata and were assumed to be as homogeneous as the APU's containing them.

Sample allocation in the USGP was made first at the APU level, using Neyman's optimum allocation procedure (ref. 3), and then for the refined strata within an APU, using proportional allocation based on the size of the agricultural area. The APU agriculture density with respect to the sampling unit (a 5- by 6-nautical-mile-area segment) was used to estimate the within-APU variances for wheat or small grains and the historical wheat acreages for the APU's; both types of information were required to perform the sample allocation for the APU's. The historical wheat acreages for the APU's were obtained by aggregating such acreages for the refined strata, which were estimated by apportioning the state historical wheat acreage to its refined strata on the basis of agricultural size. The sample allocation was made to achieve a specified precision for the wheat production estimate with cost minimized. The procedure required input for APU yields and their likely prediction errors to determine the total sample size and its distribution for the APU's. The yield information was assessed in terms of potential yield and a somewhat ad hoc procedure based on soil suitability for wheat and climate was used to generate the data needed (ref. 4). Further details on the stratification, sample allocation, and acreage estimation procedures are available in reference 5.

An evaluation of the homogeneity of certain APU's in the USGP is reported in reference 6. This evaluation was made using the historical county data; it was concluded that APU's were generally not homogeneous with respect to wheat density. Apportionment was evaluated in this report and it was observed that although the apportioned estimate of refined strata historical wheat is not reliable, it has little effect by itself on the accuracy of the wheat acreage and production estimates. This conclusion and others stated in reference 6 reflect negatively on the new stratification as well as on the sample design, but as the evaluations conducted and discussed in this reference corresponded to only a part of the USGP, they cannot be regarded as conclusive for the entire USGP.

This memorandum reports an evaluation of the TY-sample design as developed for the entire USGP. This evaluation was carried out using the LACIE Phase III segment estimates, blind site data, and historical information.

2. EVALUATION STUDIES

Agriculture density played a major role in the development of TY-sample design. It was assumed that wheat acreage was uniformly distributed over the agricultural area in an APU and in a state. Accordingly, if an APU was agriculturally homogeneous, it was considered homogeneous with respect to wheat. Also, the historical wheat acreages for refined strata in a state could be determined from the state historical wheat by apportioning the state wheat figure by the ratio of agricultural areas of the refined strata of that of the state. It is therefore important to evaluate both the stratification and the sample allocation for the APU homogeneity and efficiency in sampling for wheat acreage estimation in the USGP.

In this report, APU homogeneity is evaluated by assessing (1) Are the within-refined-strata variances for each APU the same? and, if so, (2) Are the refined strata means equal? The wheat acreage proportion or percentage, rather than wheat acreage in a segment, is considered as a variable in this discussion. The Bartlett test of homogeneity (ref. 7) is used to answer the first question and Fisher's F-test (ref. 7) is used to answer the second question, regarding each APU containing two or more refined strata.

The χ^2-approximation is considered for the distribution of the Bartlett test statistic (ref. 7). The test is first made for the homogeneity of strata variances; if homogeneity is not confirmed, no further test is performed and the APU is regarded as heterogeneous. On the other hand, if there is no indication of heterogeneity, the F-test is conducted to assess the significance of the difference between refined strata means. APU's showing a significant difference between strata variances and/or means are regarded as nonhomogeneous.

The TY-sample allocation was based upon several assumptions and for it to be considered optimum, these assumptions must be satisified. In addition, input data in the allocation formula can make a significant difference if such data contain many inaccuracies and errors. This could easily happen for the TY-sample allocation because of the type of procedures used in generating data for the sampling frame, the strata variances, historical acreages, and yield potentials. Although all these issues should be addressed, at present the sample allocation is evaluated by considering a different (and hopefully more reliable) set of strata variances and historical acreages. The Classification And Mensuration Subsystem (CAMS) estimates of segment wheat proportions obtained during LACIE Phase III provide a data set of much better quality than those from Phase II used for TY-sample allocation; therefore, these segments estimates form the basis of the data used for estimating strata variances and evaluation of sample allocation. Considering the LACIE Phase III segments to be randomly distributed, a poststratification of the segment estimates is considered for this evaluation. Next, a new historical data set is prepared for the APU's by aggregating county historical wheat acreage data. A relative change in sample allocation caused by the use of aggregated county historical data versus the apportioned historical data for the APU's is assessed. There are several components to the evaluation issue being considered. These sub-issues were addressed as they arose during the evaluation work, and are discussed in the following sections.

3. DATA USED IN EVALUATION

For the 27 APU's across nine states, table I shows the primary data set used in the evaluation studies. The yield potential data (APU mean yields and variances), total area, and total number of segments are those used in the TY-sample allocation. Phase III CAMS estimates of segment wheat proportions are used to estimate the wheat proportion means and variances for the APU's. A total of 446 segment estimates were used for the USGP wheat acreage estimation during LACIE Phase III. These segments (i.e., segments for which CAMS estimates are available from Phase III) were poststratified and the first column under Phase III CAMS estimates (table I) gives the distribution of the segments for the APU's. No segment estimate was available for APU 5, and for APU's 103 and 2 only one segment estimate each was available. For the three APU's, variances could not be estimated directly; instead, the variances originally used in TY-sample allocation were substituted for these APU's in table I.

Another set of data from Phase III was used in the present evaluation; ground truth was collected for 132 LACIE segments, called blind sites,[1] for which CAMS estimates were also available. However, the two blind sites from Oklahoma (segment numbers 1244 and 1365) were excluded because of an abnormality encountered in estimating their wheat acreages. (A large underestimation was caused by unavailability of certain temporal acquisitions necessary to determine adequate crop signatures.) In addition, no CAMS estimates were available for 14 blind site segments. The distributions of 130 blind sites for the APU's are given in table II for winter wheat region and in table III for spring wheat regions; blind sites from the mixed wheat region are also included.

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[1]Blind site data are maintained by the Accuracy Assessment Group, Earth Observations Division, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration, and are available from Dr. Dave Pitts, Accuracy Assessment Manager.

TABLE I.- APU MEANS AND VARIANCES OF LACIE PHASE III ESTIMATES OF SEGMENT WHEAT PERCENTAGES, YIELDS, AND SIZE DATA

Serial no.	APU	Total area	Total no. segments	Phase III CAMS estimates			Yield potential[a]	
				No.	Mean	Variance	Yield, bu/ac	Variance
1	101	172 564	240	2	4.8	21.1	19.5	6.50
2	102	331 640	535	5	11.9	59.2	25.0	10.85
3	103	2 881	267	1	1.9	23.0[b]	32.0	16.10
4	104	726 012	830	10	5.0	19.5	27.0	12.35
5	2	191 737	247	1	10.8	34.6[b]	19.0	6.35
6	3	499 914	558	6	15.1	109.5	18.5	5.98
7	4	821 074	542	7	24.6	302.3	20.4	7.40
8	5	459 309	103	0	-	617.3[b]	19.5	6.73
9	60	2 038 530	308	17	21.1	152.4	24.5	10.48
10	61	435 269	208	2	17.5	38.7	21.0	7.85
11	7	5 936 170	659	39	41.5	284.8	26.0	11.60
12	8	1 374 943	192	12	29.7	103.1	28.0	13.10
13	9	3 300 970	637	31	26.9	222.5	25.0	10.85
14	10	2 915 632	780	28	22.4	147.2	25.5	11.23
15	11	3 119 556	721	35	19.5	82.2	31.5	15.73
16	12	1 821 461	298	21	23.6	232.8	34.0	17.60
17	13	498 283	266	9	12.5	45.4	32.0	16.10
18	14	561 259	289	11	13.2	76.6	40.0	22.10
19	15	1 112 428	992	21	6.8	86.5	36.0	19.10
20	16	721 415	596	19	4.6	9.9	27.5	12.73
21	17	640 344	322	6	8.9	54.9	28.5	13.48
22	18	235 822	205	3	4.9	7.6	22.5	8.98
23	19	5 621 096	1118	52	18.6	91.1	30.0	14.60
24	20	3 625 572	530	29	25.6	111.0	36.0	19.10
25	21	5 250 232	1229	56	15.1	73.0	26.0	11.60
26	22	733 494	275	16	7.8	19.8	24.0	10.10
27	23	2 583 687	548	7	8.5	29.8	26.5	11.98

[a]As used for the TY-sample allocation.

[b]Variance as originally used in TY-sample allocation.

TABLE II.— GROUND-TRUTH ACREAGES OF LACIE PHASE III BLIND SITES FOR WINTER WHEAT REGION

APU	No. of segments	Actual wheat acreage, %	
		Average	Variance
101	1	6.5	-
103	1	1.6	-
104	4	5.2	4.53
2	1	20.2	-
3	1	27.6	-
4	3	8.2	9.96
5	1	21.9	-
60	6	18.0	316.13
7	15	46.0	294.32
8	2	35.9	62.72
9	12	27.8	116.62
10	13	23.4	126.50
11	11	22.8	104.38
12	6	18.6	374.38
13	2	19.4	44.18
14	3	12.4	29.14
15	5	14.7	138.34
16	4	0.2	0.10
17	3	8.6	108.76
19	4	0.5	0.48
21	6	1.5	5.59
22	2	6.4	80.64
23	3	3.9	6.88

TABLE III.— GROUND-TRUTH ACREAGES OF LACIE PHASE III BLIND SITES FOR SPRING WHEAT REGION

APU	No. of segments	Actual wheat acreage, %	
		Average	Variance
104	3	3.7	34.09
15	2	6.2	56.18
16	4	5.8	15.75
17	2	0.2	0.12
19	19	19.1	142.55
20	11	31.7	197.73
21	22	17.6	128.03
22	2	3.7	24.50
23	3	13.4	221.22

4. NUMERICAL RESULTS

4.1 APU HOMOGENEITY EVALUATIONS

The average wheat proportions and the variance estimates for the refined strata are given in table IV. Computations are based on the CAMS estimates for the number of segments available for these refined strata (second column in table IV). For the APU having variance estimates available for two or more refined strata, the Bartlett statistic (ref. 7) was computed to test for the equality of refined strata variances. The computed statistics are given in the fifth column of table IV. Considering a 5-percent significance level for the test and a χ^2-approximation for the test statistics, it was found that APU's 15, 20, and 21 were nonhomogeneous with respect to their refined strata variability. APU 60 was also declared as nonhomogeneous when tested at the 10-percent significance level.

Another source of variation is the difference in refined strata means. To test for the equality of refined strata means for an APU, F-statistics (ref. 7) were computed for the APU's which were not declared heterogeneous by the test procedure above. However, none of these APU's were found to contain refined strata with statistically significant difference in their means. Accordingly, the LACIE Phase III segment estimates show evidence of nonhomogeneity for APU's 60, 15, 20, and 21. Data evidence for nonhomogenity is not very strong for APU 60, the only APU from the pure winter wheat region falling in the category of nonhomogeneous APU's. For two of its refined strata, the variance estimates are based on two or three segments and hence are not very reliable. Data evidence is much more reliable and stronger in the case of APU's 15 and 21 in the mixed wheat region, and APU 20 in the pure spring wheat region.

4.2 EVALUATIONS BASED ON PHASE III BLIND SITE DATA

For APU's with two or more blind sites available for estimating wheat proportions by CAMS, table V lists sample means and variances computed for the ground-truth wheat percentages, the CAMS estimated wheat percentages, and the

TABLE IV.– TESTS OF HOMOGENEITY OF VARIANCES AND MEANS FOR REFINED STRATA IN EACH APU

Refined strata[a]	Number of CAMS segment estimates	Average wheat percentage	Variance estimate	Bartlett statistic	F-statistic
10108	1	8.0	-		
10148	1	1.5	-		
10220	4	14.2	43.6		
10240	1	2.7	-		
10248	0	-	-		
10331	1	1.9	-		
10346	0	-	-		
10430	10	5.0	19.5		
10431	0	-	-		
10446	0	-	-		
248	1	10.8	-		
340	0	-	-		
348	6	15.1	109.5		
448	7	24.6	302.3		
548	0	-	-		
6020	3	27.5	194.5		
6040	12	22.3	123.0		
6048	2	4.5	4.5		
				[b]4.76	-
6148	2	17.5	38.7		
720	16	42.8	279.4		
740	23	40.6	299.4		
748	0	-	-		
				.05	0.01
820	12	29.7	103.1		
908	4	17.6	69.9		
920	14	34.6	176.4		
940	6	21.4	272.8		
948	7	21.7	213.0		
				3.30	.35
1008	18	19.3	139.9		
1020	1	31.6	-		
1031	9	27.5	136.7		
				.003	.26
1108	0	-	-		
1120	24	22.9	55.2		
1131	11	12.3	67.6		
				.32	1.09

[a]Last two digits indicate state code (fig. 2).
[b]Significant at 10-percent level of significance.
[c]Significant at 5-percent level of significance.
[d]Significant at 1-percent level of significance.

TABLE IV.— Concluded.

Refined strata	Number of CAMS segment estimates	Average wheat percentage	Variance estimate	Bartlett statistic	F-statistic
1220	20	24.6	223.5		
1231	1	3.8	-		
1320	9	12.5	45.4		
1340	0	-	-		
1420	5	13.2	120.7		
1431	6	13.3	56.7		
				1.32	0
1520	0	-	-		
1527	13	1.4	6.3		
1531	8	15.7	90.6		
1546	0	-	-		
				[d]32.92	-
1631	0	-	-		
1646	19	4.6	9.9		
1731	2	16.5	33.6		
1746	4	5.1	22.2		
				.12	2.89
1846	3	4.9	7.6		
1927	12	10.9	24.9		
1938	29	24.7	53.4		
1946	11	10.8	42.6		
				4.55	1.75
2027	20	22.6	116.8		
2038	9	32.1	40.9		
2046	0	-	-		
				[c]5.76	-
2130	8	20.7	58.1		
2138	32	17.6	59.0		
2146	16	7.4	25.8		
				[c]7.09	-
2230	14	7.0	15.6		
2238	2	13.5	20.5		
2246	0	-	-		
				.06	2.06
2330	7	8.5	29.8		

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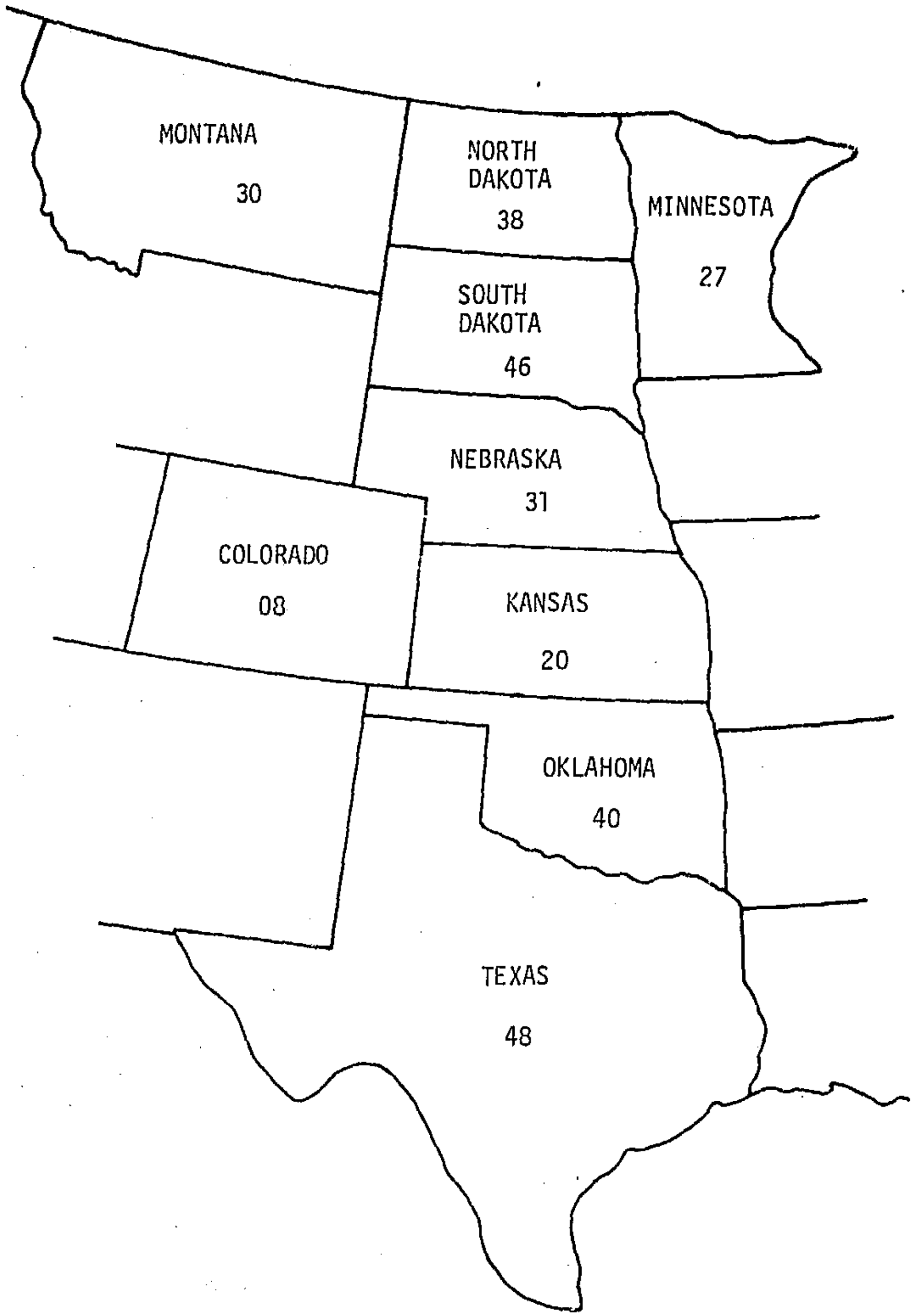

Figure 2.— USGP state codes.

TABLE V.— APU BLIND SITE DATA ANALYSIS

(a) Winter wheat

APU	No. of sites	CAMS estimate		Ground truth		Difference: ground truth - CAMS		Linear regression		
		Mean	Variance	Mean	Variance	Mean	Variance	Slope	Intercept	Residual
104	3	4.7	4.33	6.1	1.56	-1.47	1.86	0.47	3.96	1.25
60	4	25.3	271.94	23.2	415.55	2.05	58.55	1.16	-6.00	77.85
7	12	41.9	296.76	45.5	287.28	-3.56	14.65	0.96	5.26	15.58
8	2	34.2	136.12	35.9	62.72	-1.75	14.04	-	-	-
9	10	25.7	153.73	28.0	125.77	-2.34	33.19	0.80	7.45	30.50
10	12	21.5	116.96	24.2	128.87	-2.72	36.03	0.90	4.94	38.27
11	10	18.2	84.49	23.0	115.43	-4.79	20.87	1.06	3.70	23.14
12	6	19.4	211.79	18.6	374.30	0.75	53.55	1.26	-5.74	49.39
13	2	16.2	206.04	19.4	44.18	-3.25	59.40	-	-	-
14	2	8.4	5.12	12.8	57.24	-4.45	28.12	-	-	-
15	4	20.0	67.41	17.9	113.39	2.05	63.39	0.87	0.53	93.40
17	2	7.0	51.00	10.1	204.02	-3.05	51.00	-	-	-
Winter wheat region	77	22.6	236.80	24.5	269.60			.99	2.06	37.30

(b) Spring wheat

APU	No. of sites	CAMS estimate		Ground truth		Difference: ground truth - CAMS		Linear regression		
		Mean	Variance	Mean	Variance	Mean	Variance	Slope	Intercept	Residual
15	2	2.2	9.68	6.2	56.18	-4.00	19.22	-	-	-
16	3	4.2	12.04	5.2	21.28	-0.98	48.40	-.63	7.85	33.22
19	17	17.4	99.50	19.7	132.71	-2.25	46.38	0.93	3.41	49.01
20	9	28.0	47.66	35.0	157.53	-6.98	102.90	1.07	4.93	117.31
21	16	15.1	72.10	19.4	146.05	-4.37	54.46	1.14	2.34	56.94
23	3	8.0	76.00	13.4	221.22	-5.37	45.02	1.66	.09	23.99
Spring wheat region	51	16.4	112.60	20.4	187.90			1.09	2.456	55.40

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difference between the two. Considering only those APU's which have three or more blind sites with CAMS estimates, the ground-truth wheat percentages are linearly regressed on their CAMS estimates. Coefficients for the regression equations and the residual mean-square errors (MSE) are also listed in table V. Except for APU's 19, 20, and 21 in the spring wheat region, and for APU's 7, 9, 10, and 11 in the winter wheat region, the reliability of the regression equation is low.

Based on ground-truth variance estimates for the APU's mentioned above, no significant difference exists between the APU variances in the spring wheat region or between the APU variances in the winter wheat region. Although the variance estimate of APU 7 appears fairly high compared to others in the winter wheat region, it is not statistically significant. Thus, blind site data for these APU's as well as from the remaining ones should be pooled and combined to obtain one reliable regression equation for the winter wheat and one for the spring wheat region.

If y is the ground-truth wheat percent and x is its CAMS estimate for a segment, the two regression equations obtained by the least-square fit are

$$y = 2.06 + 0.991x \qquad (1)$$

for the winter wheat region with 77 data points, and

$$y = 2.46 + 1.09x \qquad (2)$$

for the spring wheat region with 51 data points. Their respective residual MSE are 37.3 and 55.4 (see table V).

Equations (1) and (2) should be regarded as calibration equations rather than regression equations. This distinction is necessary because the regression model assumes that the regressor (i.e., CAMS segment estimate) is error free, which is certainly not true.

The following conclusions are reached from the blind site data analysis given in table V:

a. APU variances computed from CAMS estimates are consistently smaller than those computed from the ground-truth segment wheat acreages for the spring wheat. Although a similar tendency of the APU variance underestimation from the use of CAMS estimates appears for the winter wheat, it is not consistent over APU's as in the case of spring wheat.

b. The regression of actual segment wheat percent on its CAMS estimate is significant.

These results suggest that the CAMS segment estimates can be improved by the use of calibration equations (1) and (2). Thus, besides the use of CAMS estimates which seem to underestimate the strata variances, segment wheat proportion estimates obtained from the calibration equations are used. It may be feasible to assess the impact of strata variance underestimation on the sample allocation.

The segment wheat percent is predicted or estimated corresponding to its CAMS estimate from the applicable calibration equation, resulting in a new set of segment estimates, referred as a "calibrated" data set. Another data set obtained by replacing the calibrated estimate for a segment by its ground-truth wheat percent (when available) is then prepared to assess the likely impact on sample allocation due to underestimation of strata variances from the CAMS segment estimates. This dat set will be referred as "mixed."

4.3 SAMPLE ALLOCATION EVALUATION

The optimum sample allocation results obtained using the LACIE Phase III segments data of CAMS estimates, calibrated values, and mixed figures are given in this section. The TY-sample allocation formula described in reference 5 is used. The optimum allocation formula is applied at the APU level and at the refined stratum level; the latter case is to evaluate the proportion allocation used previously during TY. As considered in TY, the present sample allocation is determined by considering the 5-percent coefficient of variation desired for the production estimate with a rate of 75-percent sample acquisition. The strata historical wheat acreages are obtained from the 1974 agriculture census data in two different ways, apportioned from the states and aggregated from county data, following the procedures described in section 3. The apportioned historical wheat acreages for strata are exactly those used for the TY-sample allocation.

4.3.1 ALLOCATION AT APU LEVEL

Table VI lists the total sample size and its allocation among the 27 APU's in the USGP for each of the cases discussed above. The original TY-sample allocation figures are also listed. These evaluations lead to the following conclusions:

a. The sample size determined by using the apportioned historical acreages is on the average about 13 percent smaller than that obtained by using the aggregated county historical acreages in each case.

b. Although the total sample size for the original allocation appears satisfactory (487 versus 451 with the CAMS estimates, 469 with the calibrated data, and 514 with the mixed data — an RD of less than 10 percent), both significant underallocation and overallocation are observed for the individual APU's. The APU's showing undersampling are 4, 60, 9, 10, 13, 17, and 20 and there is an oversampling for APU's 102, 2, 11, 14, 18, and 22. When compared with the sample allocation using aggregated county historical acreages, the original sample size is consistently on the low side (487 versus 518 with the CAMS estimates, 538 with the calibrated data, and 593 with the mixed data), and thus the underallocation for the TY-sample design may be as high as 20 percent. In addition to the APU's mentioned previously, two more APU's, 15 and 23, fall in the undersampling category; but APU 14 does not show any oversampling in this case. Thus, about 50 percent of the APU's are either undersampled or oversampled, according to the present evaluation.

c. When the sample sizes for the three cases of CAMS, calibrated, and mixed data are compared, the results (table VI) show that the total sample size

TABLE VI.— APU SAMPLE ALLOCATION

APU	No. of original sample segments	CAMS			Calibrated			Mixed		
		A[a]	C[b]	RD,[c] %	A	C	RD, %	A	C	RD, %
101*	-	3	3	0.0	3	3	0.0	1	2	-50.0
102	27	13	15	-13.3	14	16	-12.5	14	16	-12.5
103	4	4	5	-20.0	4	5	-20.0	4	5	-20.0
104	19	13	15	-13.3	13	15	-13.3	14	17	-17.6
2	9	4	4	0.0	4	4	0.0	4	4	0.0
3	18	14	16	-12.5	14	16	-12.5	15	18	-16.7
4	7	25	29	-13.8	25	29	-13.8	26	30	-13.3
5	7	6	7	-14.3	7	8	-12.5	7	8	-12.5
60	9	12	14	-14.3	12	14	-14.3	14	16	-12.5
61	3	4	4	0.0	4	4	0.0	4	4	0.0
7	37	38	43	-11.6	38	44	-13.6	39	45	-13.3
8	7	7	8	-12.5	7	8	-12.5	7	8	-12.5
9	21	31	36	-13.9	31	36	-13.9	32	36	-11.1
10	27	31	36	-13.9	32	37	-13.5	34	39	-12.8
11	35	27	31	-12.9	27	31	-12.9	29	34	-17.6
12	21	20	23	-13.0	20	23	-13.0	24	27	-11.1
13	11	7	9	-22.2	8	9	-11.1	6	7	-14.3
14	17	13	15	-13.3	13	15	-13.3	14	16	-12.5
15	40	43	50	-14.0	43	49	-12.2	42	48	-12.5
16	13	7	8	-12.5	8	9	-11.1	9	11	-18.2
17	7	9	10	-10.0	9	10	-10.0	11	13	-15.4
18	4	2	2	0.0	2	2	0.0	2	2	0.0
19	50	42	48	-12.5	46	54	-14.8	56	64	-12.5
20	25	26	30	-13.3	29	33	-12.1	35	40	-12.5
21	50	36	41	-14.6	40	46	-13.0	48	56	-14.3
22	8	4	4	0.0	4	5	-20.0	5	6	-16.7
23	11	10	12	-16.7	12	13	-7.7	18	21	-14.3
Total	487	451	518	-13.2	469	538	-12.8	514	593	-13.3

[a]A = Sample allocation for the case of apportioned historical wheat acreages.

[b]C = Sample allocation for the case of aggregated county historical wheat acreages.

[c]RD = Relative difference, $\frac{A - C}{C}$.

*Not included in the original allocation, and only the refined stratum in Colorado is considered for the other three cases.

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is approximately 3 percent higher for the calibrated case and 14 percent higher for the mixed data case than for the CAMS estimates case, a direct consequence of the underestimation of the refined strata variances shown by the blind site data analysis discussed earlier. Much larger differences are noted in the spring wheat APU's (e.g., sample size of 42 vs. 56 in APU 19, 26 vs. 35 in APU 20, 36 vs. 48 in APU 21 and 10 vs. 18 in APU 23) because of the significant underestimation of variances of APU's in the northern USGP.

The present sample allocations show that APU's 101, 103, 2, 61, 18, and 22 have been allocated five or less sample segments and thus at most three to four segments from an APU may be expected for data availability. The reliability of acreage estimates for these APU's will therefore be poor. One possible way to improve the reliability is to merge these marginal wheat-growing APU's into other contiguous yet similar APU's. Assessing the similarity in terms of APU wheat acreage variances and their potential yield (table 1), these APU's were merged or combined with others as follows: {2, 3, 5}, {4, 61}, {10, 101}, {11, 103} and {18, 22}.

For APU 101, only its refined strata in Colorado is merged with APU 10. The new stratification thus obtained for the USGP will be referred to as "merged APU's."

The sample allocation for each of the three data input cases discussed previously was performed. The results for the sample size are listed in table VII. Once again the new sample size figures, and hence evaluations, parallel those reached for the original APU stratification; for example,

a. There is no significant difference for the total sample size between the original sample allocation and the present allocation based on apportioned historical data, but about 50 percent of the APU's show either underallocation or overallocation.

TABLE VII.- MERGED APU SAMPLE ALLOCATION[a]

APU	No. of original sample segments	CAMS			Calibrated			Mixed		
		A	C	RD, %	A	C	RD, %	A	C	RD, %
102	27	14	16	-12.5	14	16	-12.5	15	17	-11.8
104	19	13	15	-13.3	14	16	-12.5	15	17	-11.8
{2, 3, 5}	34	22	26	-15.4	22	26	-15.4	22	26	-15.4
{4, 61}	10	32	37	-13.5	32	37	-13.5	33	39	-15.4
60	9	12	14	-14.3	12	15	-20.0	14	16	-12.5
7	37	39	45	-13.3	39	45	-13.3	40	47	-14.9
8	7	7	8	-12.5	7	9	-22.2	7	9	-22.2
9	21	32	37	-13.5	32	37	-13.5	32	37	-13.5
{10, 101}	27	42	50	-16.0	42	50	-16.0	45	54	-16.7
{11, 103}	39	37	42	-11.9	37	43	-14.0	41	47	-12.8
12	21	21	24	-12.5	21	24	-12.5	24	28	-14.3
13	11	8	9	-11.1	8	9	-11.1	6	7	-14.3
14	17	13	16	-18.8	14	16	-12.5	14	16	-12.5
15	40	44	51	-13.7	44	51	-13.7	43	50	-14.0
16	13	7	8	-12.5	8	9	-11.1	10	11	-9.1
17	7	9	10	-10.0	9	11	-18.2	11	13	-15.4
19	50	43	49	-12.2	48	55	-12.7	57	66	-13.6
20	25	27	31	-12.9	30	34	-11.8	36	41	-12.2
21	50	36	42	-14.3	41	47	-12.8	50	57	-12.3
{18, 22}	12	6	7	-14.3	7	8	-12.5	8	9	-11.1
23	11	11	12	-8.3	12	14	-14.3	19	22	-13.6
Total	487	475	549	-13.5	493	572	-13.8	542	629	-13.8

[a]Merging of APU's is primarily based upon statistical and contiguous considerations.

b. The relative difference of the sample size obtained for the case of apportionment to that in the case of aggregated county historical dat· is about -14 percent.

c. Approximately 14 percent more samples are needed for the mixed data case than for the CAMS estimates case.

In addition to the suggested merging of some APU's, it is also proposed to divide the APU's that are assessed heterogeneous by Bartlett's test (section 4.1). Considering the strata variance homogeneity and potential yield as the decision criterion, the following combinations of refined strata within APU's are obtained as new APU's: {1527, 1546}, {1531, 1520}, {1927}, {1938, 1946}, {2038, 2046}, {2027}, {2130, 2138}, {2146}. (See figs. 1 and 2 for APU and state codes.) Although desirable to split APU 60, it was kept intact to avoid having strata too small. This partition will be referred as "split and merged" APU stratification. Figure 3 shows the newly created APU's.

The sample allocation results (table VIII) show that the original total sample size is quite adequate unless it is compared with the sample size for the mixed data case with aggregated county historical acreages (487 vs. 584).

However, there are consistently significant underallocations and overallocations for some APU's, as follows:

Category	Split and merged APU's
Overallocation	102, 104, {2, 3, 5} 13, 14, {1527, 1546}, 16, 1927, {1938, 1946}, {2038, 2046}, {2130, 2138}, {18, 22}
Underallocation	{4, 61}, {60}, 9, {10, 101}, {1531, 1520}, 2027

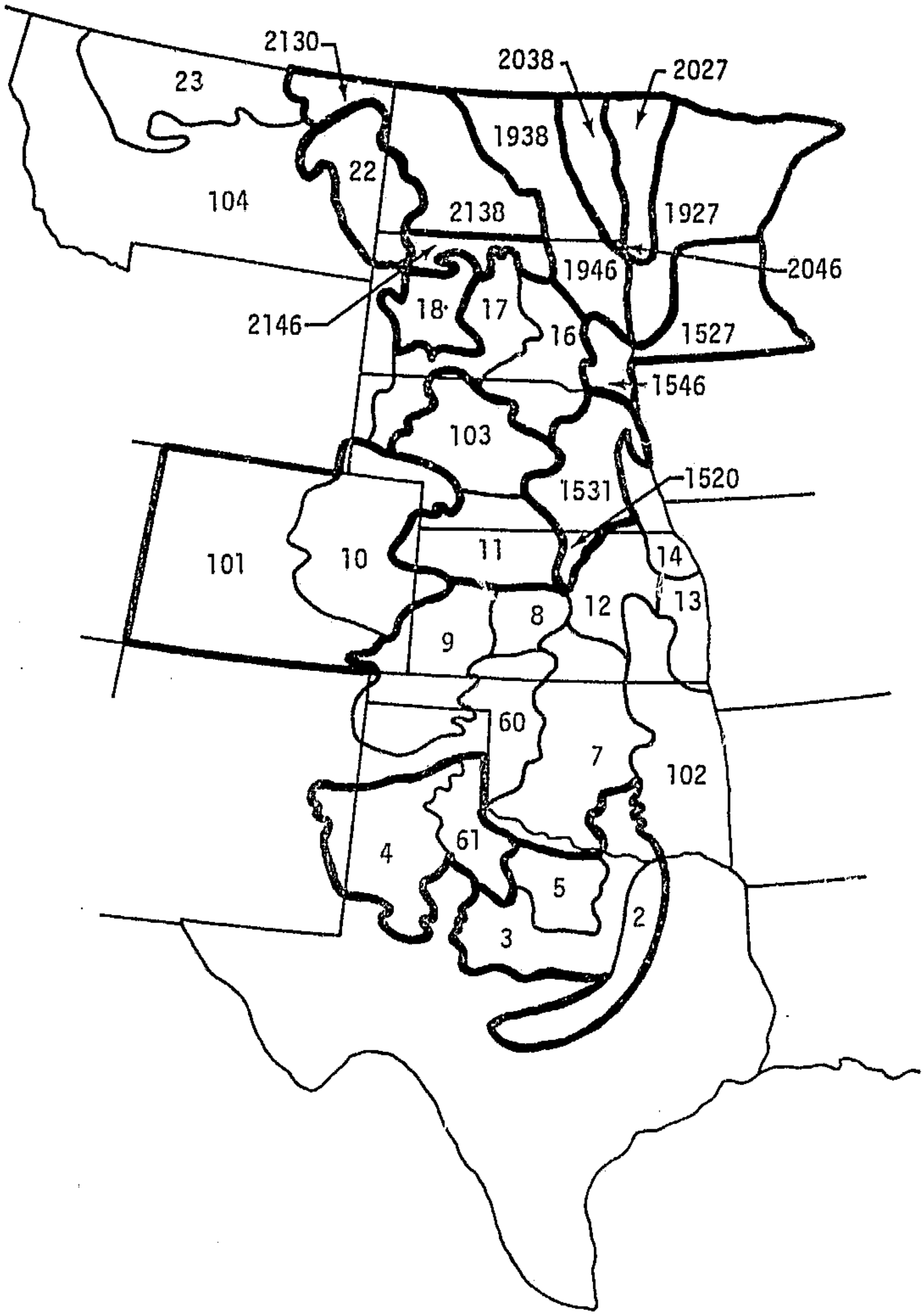

Figure 3.— A split and merged APU stratification of USGP.

TABLE VIII.- SPLIT AND MERGED APU SAMPLE ALLOCATION

APU	No. of original sample segments	CAMS			Calibrated			Mixed		
		A	C	RD, %	A	C	RD, %	A	C	RD, %
102	27	13	15	-13.3	13	15	-13.3	14	16	-12.5
104	19	12	14	-14.3	13	15	-13.3	14	17	-17.6
{2, 3, 5}	34	21	24	-12.5	21	24	-12.5	21	25	-16.0
{4, 61}	10	30	35	-14.3	30	35	-14.3	32	37	-13.5
60	9	12	14	-14.3	12	14	-14.3	14	16	-12.5
7	37	36	42	-14.3	37	42	-11.9	39	45	-13.3
8	7	7	8	-12.5	7	8	-12.5	7	8	-12.5
9	21	30	35	-14.3	30	35	-14.3	31	36	-13.9
{10, 101}	27	39	47	-17.0	40	47	-14.9	43	52	-17.3
{11, 103}	39	35	40	-12.5	35	40	-12.5	39	45	-13.3
12	21	19	22	-13.6	20	23	-13.0	23	27	-14.8
13	11	7	8	-12.5	7	8	-12.5	6	7	-14.3
14	17	13	15	-13.3	13	15	-13.3	13	15	-13.3
{1531, 1520}	23	27	31	-12.9	27	31	-12.9	31	36	-13.9
{1527, 1546}	17	4	5	-20.0	5	5	0	5	5	0
16	13	6	7	-14.3	7	8	-12.5	9	11	-18.2
17	7	9	10	-10.0	9	10	-10.0	11	13	-15.4
1927	8	6	7	-14.3	7	8	-12.5	9	11	-13.9
{1938, 1946}	42	29	33	-12.1	32	37	-13.5	39	46	-15.2
2027	9	14	16	-12.5	16	18	-11.1	21	24	-12.5
{2038, 2046}	16	7	8	-12.5	8	9	-11.1	8	10	-20.0
{2130, 2138}	46	25	29	-13.8	28	32	-12.5	38	6	-13.6
2146	4	4	4	0	4	5	-20.0	5	6	-16.7
{18, 22}	12	6	7	-14.3	7	8	-12.5	8	9	-11.1
23	11	10	12	-16.7	11	13	-15.4	18	21	-14.3
Total	487	421	488	-13.7	439	505	-13.1	499	584	-14.6

Note that the split APU {1527, 1546}, shows overallocation, whereas the other part of APU 15, {1520, 1531} shows underallocation. Similarly, the two parts of the original APU 20 fall in both categories of allocation.

The results of comparisons between different cases of data utilization are parallel with those obtained and discussed previously for the original APU or merged APU stratification. On the other hand, on a case-by-case basis, the present sample sizes for the original APU stratification are consistently higher than those for the split and merged APU stratification. It may therefore be concluded that the latter stratification is more efficient than the original. Accordingly, had the TY-sample allocation performed optimally with respect to the split and merged APU stratification, the original sample size might have been smaller than 487. Although this would help in eliminating overallocation for some APU's, the underallocation would become a larger problem.

Based upon physical considerations (e.g., soil and topography), it seemed that APU homogeneity could not be extended to certain merged APU's. It was therefore decided not to merge APU's 61 and 4, 103 and 11, and 18 and 22. With this modification, the only cases of merged APU's remaining are {2, 3, 5} and {10, 101}. This stratification will be referred as "modified merged APU's."

Sample allocation was performed for this new stratification; results given in table IX show that the figures lie between those obtained for the original and the merged APU's stratifications. Conclusions are again parallel with those derived in the other two cases:

a. No significant difference in the total sample size, but sample sizes of 50 percent of the APU's are affected considerably

b. Underallocation by 13 percent with the use of apportioned historical data in sample allocation

TABLE IX.— MODIFIED MERGED APU SAMPLE ALLOCATION

APU	No. of original sample segments	CAMS			Calibrated			Mixed		
		A	C	RD, %	A	C	RD, %	A	C	RD, %
102	27	14	16	-12.5	14	16	-12.5	14	17	-17.6
103	4	4	5	-20.0	4	5	-20.0	4	5	-20.0
104	19	13	15	-13.3	13	15	-13.3	15	17	-11.8
{2, 3, 5}	34	22	25	-12.0	22	25	-12.0	22	25	-12.0
4	7	25	29	-13.8	25	29	-13.8	26	30	-13.3
60	9	12	14	-14.3	12	14	-14.3	14	16	-12.5
61	3	4	4	0	4	4	0	4	4	0
7	37	38	44	-13.6	38	44	-13.6	40	46	-13.0
8	7	7	8	-12.5	7	8	-12.5	7	9	-22.2
9	21	31	36	-13.9	31	36	-13.9	32	37	-13.5
{10, 101}	27	41	49	-16.3	41	49	-16.3	44	53	-17.0
11	35	27	31	-12.9	27	31	-12.9	30	34	-11.8
12	21	20	23	-13.0	20	24	-16.7	24	27	-11.1
13	11	8	9	-11.1	8	9	-11.1	6	7	-14.3
14	17	13	15	-13.3	13	15	-13.3	14	16	-12.5
15	40	44	50	-12.0	43	50	-14.0	42	49	-14.3
16	13	7	8	-12.5	8	9	-11.1	10	11	-9.1
17	7	9	10	-10.0	9	10	-10.0	11	13	-15.4
18	4	2	2	0	2	2	0	2	2	0
19	50	42	48	-12.5	47	54	-13.0	56	65	-13.8
20	25	26	30	-13.3	29	34	-14.7	35	41	-14.6
21	50	36	41	-12.2	40	46	-13.0	49	56	-12.5
22	8	4	4	0	4	5	-20.0	5	6	-16.7
23	11	10	12	-16.7	12	13	-7.7	18	21	-14.3
Total	487	459	528	-13.1	473	547	-13.5	524	607	-13.7

c. Sample size for the mixed data case higher than that for the CAMS estimates case by 15 percent

Next, considering the proposed split of APU's for the modified merged APU stratification, the optimum allocation was performed (table X). The sample sizes for individual APU's were parallel with those obtained in the preceding two cases and the total sample size was smaller by about 7 percent than obtained for the split and merged APU stratification and by about 11 to 15 percent than those in the case of merged APU stratification. Compared to the TY sample size of 487, except for the case of mixed data with aggregated county historical acreages, the sample sizes were lower, suggesting an overallocation during TY. Significant underallocation and overallocation were again observed for about half of the APU's. However, this stratification suffers from having several small APU's which are allocated only a few sample segments each. When it becomes critical to use only the strata sample data for its acreage estimation, this stratification may not merit as much consideration as the merged or the split and merged APU stratification.

The total sample sizes are plotted in figure 4 for the various data input cases corresponding to the original, merged, and split and merged APU stratification. As might be expected, the sample sizes for the calibrated data case are only slightly higher than the corresponding ones for the CAMS estimates case. However, use of the mixed data makes a significant difference in sample sizes and shows that the sample allocation is considerably affected due to underestimation of strata variance resulting from the CAMS segment estimates. The sample sizes obtained using the aggregated county historical acreages for strata are consistently higher than the corresponding ones in the case of apportioned historical acreages for the strata.

It follows from the above results that both the use of apportionment for determining APU historical acreages and of CAMS segments estimates for the APU variance estimation would lead to a smaller sample size for the sample allocation when performed at the APU level. As both these factors were part of the

TABLE X.— SPLIT AND MODIFIED MERGED APU SAMPLE ALLOCATION

APU	Original sample segments	CAMS			Calibrated			Mixed		
		A	C	RD, %	A	C	RD, %	A	C	RD, %
102	27	12	14		13	15		14	16	
103	4	4	4		4	5		4	5	
104	19	12	14		12	14		14	16	
{2, 3, 5}	34	20	23		20	23		20	24	
4	8	23	27		24	27		25	29	
60	9	11	13		11	13		13	15	
61	3	3	4		3	4		4	4	
7	37	35	41		35	41		37	43	
8	7	7	8		7	8		7	8	
9	21	29	33		29	34		30	35	
{10, 101}	27	38	45		38	45		42	50	
11	35	25	29		25	29		28	32	
12	21	19	22		19	22		22	26	
13	11	7	8		7	8		6	7	
14	17	12	14		12	14		13	15	
{1531, 1520}	23	26	30		26	30		30	35	
{1527, 1546}	17	4	5		5	5		6	7	
16	13	6	7		7	8		9	10	
17	7	8	10		8	10		11	12	
18	3	2	2		2	2		2	2	
{1927, 1946}	14	12	14		13	15		20	24	
1938	36	14	17		16	18		16	19	
2027	9	14	16		15	17		20	23	
{2038, 2046}	16	7	8		7	9		8	9	
{2130, 2138}	46	24	28		27	31		36	42	
2146	4	4	4		4	5		5	6	
22	8	4	4		4	4		5	5	
23	11	10	11		11	12		17	20	
Total	487	392	455	-13.8	404	468	-13.7	464	539	-13.9

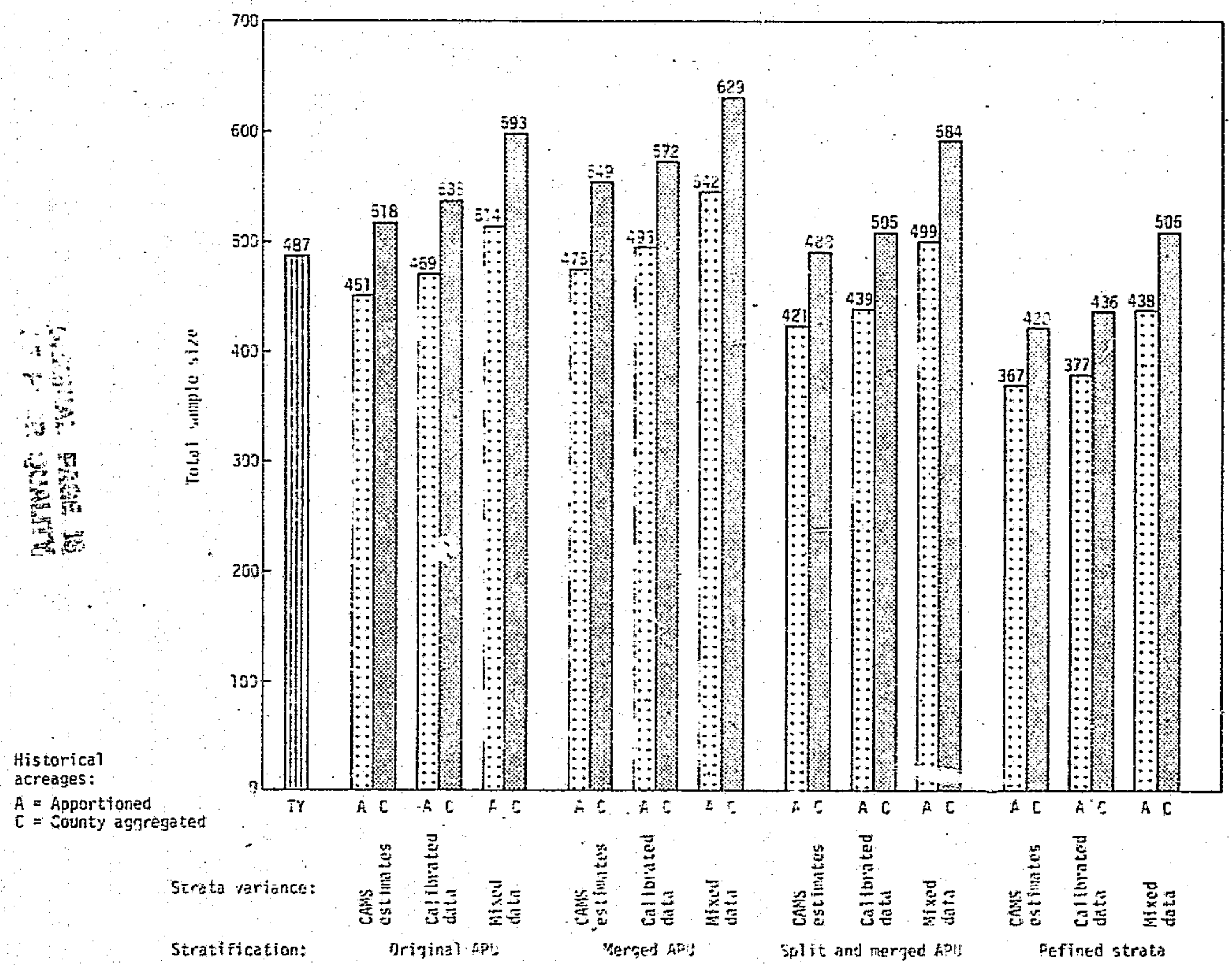

Figure 4.— Optimum sample sizes for various stratifications using different data inputs.

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allocation procedure for the TY-sample design, it is concluded that there may be an underallocation as high as 20 percent for the sample segments in the USGP during TY.

4.3.2 ALLOCATION AT THE REFINED STRATA LEVEL

To evaluate the proportional allocation employed at the refined strata level for the TY-sample design, the optimum sample allocation was performed for the refined strata using the data sets described previously. If less than two CAMS estimate were available for a refined stratum, it was merged with other refined strata in its APU and the APU variance estimate was used for each of the merged refined strata. Again considering different types of data to compute refined strata historical acreages and variances, the sample allocation was evaluated in each case; results are given in table XI.

A comparison between the TY allocation and the optimum allocations shows that the TY has an higher sample size and hence is inefficient as compared to the optimum allocations obtained using the CAMS estimates data (33 percent), the calibrated data (29 percent), and the mixed data (11 percent), for the case of apportioned wheat acreages for the refined strata. Differences in sample sizes are smaller for the county aggreated wheat acreages. Other conclusions are similar to those made previously for the APU-level sample allocation. Use of apportionment data leads to underallocation by about 13 percent. The refined strata showing significant sample overallocation and underallocation are as follows:

Type	Refined strata[1]
Overallocation	10220, 10240, 10430, 248, 340, 1120, 1320, 1420, 1520, 1527, 1646, 1938, 2038, 2138, and 2230
Underallocation	10108, 348, 448, 948, 1031,[2] 1131,[2] 1531, 2027

[1]The last two digits refer to a state code number (see fig. 2).

[2]Applies only to the case of aggregated county historical acreages for refined strata.

TABLE XI.— SAMPLE ALLOCATION FOR REFINED STRATA

Refined stratum	Original allocation	Optimum allocation								
		CAMS			Calibrated			Mixed		
		A	C	RD, %	A	C	RD, %	A	C	RD, %
10108	-	3	3		3	3		1	2	
10142[a]	-	-	-		-	-		-	-	
10225	9	2	3		2	3		3	3	
10240	10	3	4		3	4		3	4	
10245	8	6	7		6	7		7	8	
10338	4	4	4		4	4		5	6	
10346	0	0	0		0	0		0	0	
10430	12	11	12		11	11		12	14	
10438	1	0	0		0	0		0	0	
10446	0	1	1		1	1		1	1	
508	9	3	4		3	4		4	4	
530	9	1	1		1	1		1	1	
538	9	12	14		12	14		14	15	
548	8	23	26		22	26		24	28	
[illegible]	7	6	7		6	7		6	7	
6020	2	3	4		3	4		3	4	
6030	7	6	7		6	7		7	9	
6046	6	0	0		0	0		0	0	
6148	3	3	4		3	4		3	4	
720	11	11	13		11	13		12	14	
740	26	22	25		22	26		23	27	
743	0	1	1		1	1		1	2	
820	7	6	7		6	7		7	8	
909	4	3	3		3	3		4	5	
925	10	10	12		10	12		11	12	
940	5	5	5		5	5		4	5	
943	2	7	8		7	8		8	9	
1008	22	20	23		20	23		21	24	
1020	0	1	1		1	1		1	1	
1031	5	7	8		7	8		9	10	
1108	2	2	2		2	2		2	3	
1120	27	11	12		11	12		13	15	
1131	6	8	10		8	10		8	10	
1220	21	18	20		18	21		21	25	
1231	0	0	0		0	0		0	0	
1320	11	6	7		6	7		5	6	
1330	0	0	0		0	0		0	0	
1420	13	8	9		8	9		8	10	
1431	4	5	6		5	6		5	6	
1520	4	1	1		1	1		1	1	
1527	14	3	3		3	4		4	5	
1531	19	24	27		24	27		28	32	
1546	1	4	4		4	4		4	4	
1631	2	1	1		1	2		2	2	
1646	11	5	6		5	6		7	8	
1731	2	2	2		2	2		3	3	
1746	5	4	4		4	4		7	8	
1846	3	1	2		2	2		2	2	
1927	8	6	6		6	7		9	10	
1938	36	14	16		15	18		16	18	
1946	6	6	7		7	8		11	12	
2027	9	13	15		15	17		19	22	
2038	16	6	7		7	8		8	9	
2046	0	0	0		0	0		0	0	
2130	6	4	4		4	5		8	10	
2138	40	20	23		22	25		25	29	
2146	4	3	4		4	4		5	6	
2230	7	2	3		2	3		3	4	
2238	1	1	1		1	1		1	1	
2246	0	0	0		0	0		0	0	
2310	11	9	11		10	12		17	19	
Total	487	367	420	-12.6	377	436	-13.5	438	506	-13.4

[a]Not considered in the allocation.

These results for overallocation and underallocation are obtained irrespective of the total optimum sample size. For example, although the total sample size in the case of mixed data with aggregated county historical acreages for refined strata exceeds the TY total sample size (this happens only in one case), the conclusions for the individual refined strata regarding underallocation or overallocation are the same as in the remaining cases.

Considering the refined strata by states, these results suggests that there was overallocation in Kansas and North Dakota, and underallocation in Colorado, Nebraska, and Texas during TY. The underallocation in Colorado is partly due to noncoverage of APU 101 in the TY-sample allocation.

Figure 4 also shows the optimum sample sizes obtained for the refined strata level. These sample size results are smaller than those obtained for the various APU stratifications. Although the implication is that the refined strata level stratification is more efficient than any one of the APU level, it has the drawback of having allocated few or no sample segments to some refined strata.

5. SUMMARY AND CONCLUSIONS

The natural stratification and sample allocation used for the TY-sample design were examined. LACIE Phase III data were employed to test the APU homogeneity and to evaluate the optimum sample allocation when performed at both the APU level and the refined strata level. The effect of apportionment on the sample allocation was assessed by determining the relative change in sample size caused by use of the aggregated county historical wheat acreages in place of apportioned historical wheat acreages for the refined strata and APU's. The evaluations lead to the following conclusions:

a. APU's 15, 19, 20, and 21 are heterogeneous for wheat density and therefore must be further split to achieve a better stratification and more efficient sample allocation. The following split of the APU's is proposed.

APU	Refined strata forming split APU's
15	{1527, 1546} and {1531, 1520}
19	{1938, 1946} and {1927}
20	{2038, 2046} and {2027}
21	{2130, 2138} and {2146}

b. When the APU's that are either small in size or have marginal wheat are merged with adjoining similar APU's, there is no significant increase in sample size.

c. A more efficient stratification for sample allocation is achieved by merging and or splitting APU's; see table VIII.

d. The total sample size for TY sampling seems adequate; however, the strata sample allocation is far from satisfactory. There is significant over- or underallocation of samples, affecting the sample allocation for about 50 percent of the APU's.

e. There is inadequate representation in sampling from some states. Colorado, Nebraska, Texas show an undersampling whereas Kansas and North Dakota have an oversampling during TY. The undersampling in Colorado is partly due to noncoverage of one of its refined stratum. Lack of full coverage generally results in a biased estimate.

f. When performed at the refined strata level, the optimum allocation leads to a saving of approximately one-third of the sample size obtained when it is performed at the APU level. However, the former may not be desirable because few or no sample segments are allocated for some refined strata. Optimum sample allocation performed with the split and merged stratification is recommended.

g. Use of apportioned historical data versus the aggregated county historical data (which are more accurate figures for the refined strata and APU's) leads to a smaller sample size by about 13 to 15 percent. This suggests that apportionment based on agriculture density tends to mask the underlying variability, and therefore its averaging effect leads to underallocation of sample segments for the wheat production estimation.

h. A similar averaging effect takes place when CAMS segment estimates are used in estimating the strata variances and then assessing the optimum sample size. This approach (i.e., use of CAMS segment estimates for strata variance determination) may lead to undersampling by as much as 20 percent.

It is apparent that natural stratification is the first necessary step toward developing an efficient sample design for crop assessment of a large area. Natural stratification should be modified and updated to be applicable to specific crop types for an optimum sample design. Further, apportionment should not be based purely on agricultural density. Use of the historical data in estimation of the strata crop acreages can be avoided by developing a stratification which is efficient yet does not contain strata too small, either in total size or in crop size.

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