Journal of Geography, Environment and Earth Science International

20(4): 1-20, 2019; Article no.JGEESI.48360
ISSN: 2454-7352

Evaluating Sampling Designs for Assessing the Accuracy of Cropland Extent Maps in Different Cropland Proportion Regions

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Authors' contributions

This work was carried out in collaboration between both authors. Authors KY and RGC designed the study. Author KY performed the statistical analysis and wrote the first draft of the manuscript. Author RGC managed the analyses of the study and edited the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2019/v20i430111
Editor(s):
(1) Dr. Iovine Giulio, CNR-IRPI (National Research Council – Institute of Research for the Geo-hydrologic Protection) of Cosenza, Italy.
Reviewers:
(1) Ahmed Saber Taha, Benha University, Egypt.
(2) Ngakan Ketut Acwin Dwijendra, University of Udayana, Indonesia.
Complete Peer review History: http://www.sdiarticle3.com/review-history/48360

Original Research Article

Received 11 January 2019
Accepted 15 April 2019
Published 23 April 2019

ABSTRACT

The GFSAD30m cropland extent map has been recently produced at a spatial resolution of 30m as a part of NASA MEaSUREs' Program Global Food Security Data Analysis (GFSAD) project. Accuracy assessment of this GFSAD30m cropland extent map was initially performed using an assessment strategy involving a simple random sampling (SRS) design and an optimum sample size of 250 for each of 72 different regions around the world. However, while statistically valid, this sampling design was not effective in regions of low cropland proportion (LCP) of less than 15% cropland area proportion (CAP).
The SRS sampling resulted in an insufficient number of samples for the rare cropland class due to low cropland distribution, proportion, and pattern. Therefore, given our objective of effectively assessing the cropland extent map in these LCP regions, the use of an alternate sampling design was necessary. A stratified random sampling design was applied using a predetermined minimum

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number of samples followed by a proportional distribution (i.e., SMPS) for different cropland proportion regions to achieve sufficient sample size of the rare cropland map class and appropriate accuracy measures.

The SRS and SMPS designs were compared at a common optimum sample size of 250 which was determined using a sample simulation analysis in ten different cropland proportion regions. The results demonstrate that the two sampling designs performed differently in the various cropland proportion regions and therefore, must be selected according to the cropland extent maps to be assessed.

Keywords: Accuracy assessment; Simple Random Sampling (SRS); Cropland Area Proportion (CAP); Low Cropland Proportion (LCP); Stratified Minimum Proportional Sampling (SMPS).

1. INTRODUCTION

The cropland regions of different continents distributed around the world exhibit different cropland proportions, cropping patterns, spatial extents, and heterogeneity due to their climatic, topographic, and ecological conditions. The cropland maps of various cropland proportion regions are important for cropland monitoring and modeling, cropland change analysis, resolving food security issues, and improving crop productivity in different continents [1]. To accomplish these objectives, cropland maps of various cropland regions have been generated continuously and effectively using remote sensing data at different spatial resolutions [1-4]. The GFSAD30m cropland extent map is one of the three GFSAD (Global Food Security Data Analysis) cropland extent maps (produced at 30, 250, and 1000 meter resolutions) which has been generated for various cropland proportion regions distributed around the world from satellite imagery and effective classification algorithms [5-18].

The accuracy assessment of the GFSAD30m cropland extent map was initially performed using an assessment strategy involving a simple random sampling (SRS) design and an optimum sample size of 250 for 72 cropland regions around the world [19]. The results of this accuracy assessment reported accuracy measures in the form of error matrices for each region (e.g., overall, user's, and producer's accuracy) [20]. However, while statistically valid, this sampling design was ineffective in regions of low cropland proportion (LCP) of less than 15% cropland area proportion (CAP). The SRS design resulted in an insufficient number of samples when the cropland class was rare due to low cropland distribution, proportion, and pattern [21]. As a result, the error matrices generated with such an insufficient distribution and allocation of samples for the rare cropland map class reported accuracy measures in the LCP regions that were not useful for our analysis [22-27]. Therefore, given our objective of effectively assessing the cropland extent maps in these LCP regions, the use of an alternate sampling design was desirable and necessary.

Many researchers have expressed opinions on using different sampling designs (e.g., simple random sampling, stratified, and systematic unaligned sampling) to be used for assessing thematic map accuracy [20-21,28-32]. While different sampling approaches have been studied for achieving appropriate accuracy results in different landscapes, their effective use still needs to be established for various cropland regions around the world [33]. Determination of the cropland area proportion (CAP) of various cropland regions aids in defining an effective sampling area for applying probability-based sampling designs characterized either by simple random or stratified protocols for selecting the samples [21]. The probability-based simple random sampling (SRS) design, while statistically valid, results in an insufficient sample size of the rare cropland map class because each sample area has equal probability of selection and there is not enough area covered by cropland in the LCP regions. Therefore, an alternate probability-based sampling design imposed within strata defined by the map classes combined with a predetermined minimum sample size is one method to provide sufficient samples and useful accuracy measures of these rare cropland maps [21,34].

A minimum of 50 samples for each map category has been recommended as sufficient to generate statistically valid and meaningful accuracy measures [20]. This predetermined minimum sample size of 50 can be allocated to each stratum or map class with additional samples allocated proportionally to the cropland and non-cropland area depending on the total sample size and the cropland regions to be assessed [34]. The literature suggested that a larger sample size be implemented for assessing cropland regions that have between 25-75% cropland and that a smaller sample size would be enough to efficiently assess the cropland maps in areas with very high or very low cropland proportion [33]. However, in most cropland assessments, mostly small samples sizes that are sparsely distributed have been used resulting in an ineffective assessment of the cropland extent maps of various cropland regions [4,35]. A larger sample size can achieve more appropriate and useful accuracy of the cropland extent maps [36]. However, even a larger total sample size can result in insufficient samples and ineffective accuracies of the rare cropland map class if the samples are not distributed effectively. Rather than selecting sample size and strategy by the map complexity, the cropland distribution and proportion of each cropland region must be carefully considered to choose an optimum sample size to efficiently assess the cropland extent maps. Therefore, an optimum sample size must be chosen using a sample simulation analysis based on a Monte Carlo method for an effective and useful assessment of the cropland extent maps of various cropland regions [19,37,38].

This paper evaluates two sampling designs to perform an effective assessment of the GFSAD30m cropland extent maps of the various cropland proportion regions. The first is the simple random sampling (SRS) approach. The second is an alternate sampling design which is primarily a stratified design using a predetermined minimum of 50 samples per strata and a proportional allocation of the remaining total samples (SMPS). The SRS and SMPS designs were evaluated by comparing summary plots and detailed error matrices of the sample size and accuracy measures of the rare cropland map class.

2. STUDY AREA

The study area comprises ten different cropland proportion regions selected from the 72 regions located around the world in which the GFSAD30m cropland extent map was initially assessed using the SRS design and an optimum sample size of 250 [19,39,40]. Five of these study sites were purposely selected from the Low Cropland Proportion (LCP) regions and the other five were randomly selected from rest of the 72 regions. The location of the ten selected cropland proportion regions for this study are depicted in Fig. 1.

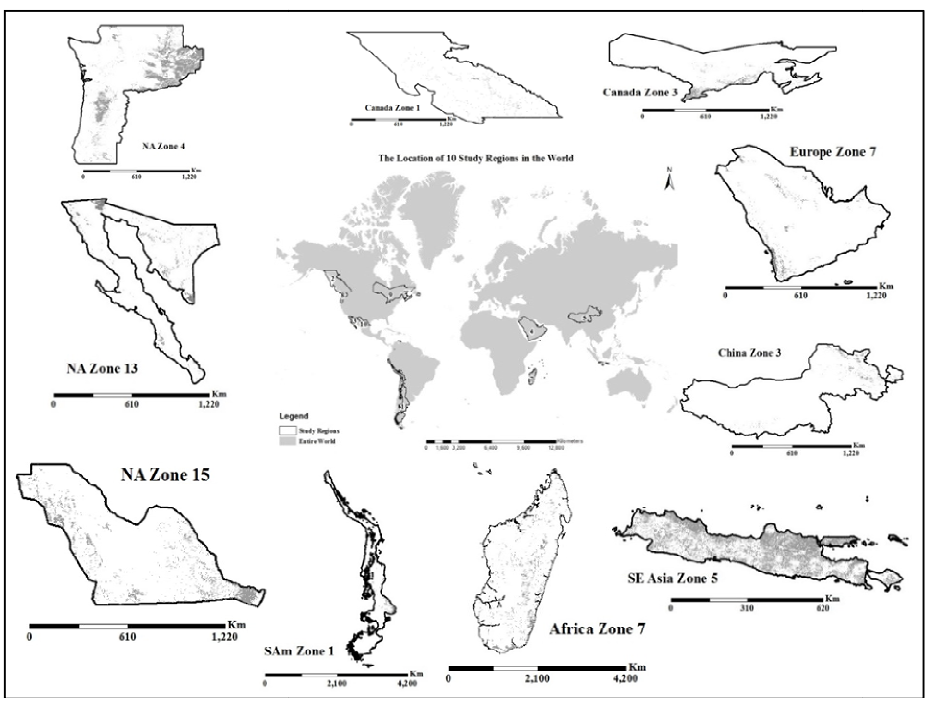

Fig. 1. The location of ten regions selected in the entire world with different crop proportions along with the distribution of cropland areas of GFSAD30m cropland map

3. MATERIALS AND METHODS

This section describes the datasets and methods that were used to evaluate two sampling designs with respect to the spatial distribution and allocation of samples for each map class of the cropland map in the ten selected regions.

3.1 Datasets

The ten selected study regions of the GFSAD30m cropland extent map which has been recently produced as a part of NASA MEaSUREs' (Making Earth System Data Records for Use in Research Environments) GFSAD project at 30m spatial resolution for the entire world were evaluated using two different sampling designs. Separate reference datasets were necessary and were collected using the two different sampling designs from Google Earth imagery and existing cropland maps (e.g., Cropland Data Layer of the United States) to assess the ten regional GFSAD30m cropland extent maps. The first reference dataset was collected as a part of an initial assessment of the GFSAD30m cropland map using the SRS sampling design and an optimum sample size of 250 for the 72 cropland regions around the world [19,39]. The second reference dataset was collected using an alternate sampling design (i.e., SMPS) and simulated sample sizes from 50 to 300 only for the ten study cropland regions.

3.2 Methods

This section describes the methodology for evaluating the initial SRS and the alternate SMPS designs for assessing the GFSAD30m cropland extent maps in four steps: (1) estimating cropland area proportion (CAP), (2) applying the sampling designs, (3) choosing an optimum sample size for the SMPS approach, and (4) generating appropriate accuracy measures for the ten study cropland regions (Fig. 2).

First, the Cropland Area Proportion (CAP) was estimated for each of the ten study regions using the GFSAD30m cropland extent map classes. The CAP of a region is defined as the percent of cropland area as compared to the total area of the region. The cropland regions with CAP from 0.9% (China Zone 3) to 43.2% (South East Asia Zone 5) were then grouped into five cropland probability classes from Class 1 to Class 5 as: (1) very low (0-1%), (2) low (>1-2%), (3) medium (>2-6%), (4) high (>6-15%), and (5) very high (>15%).

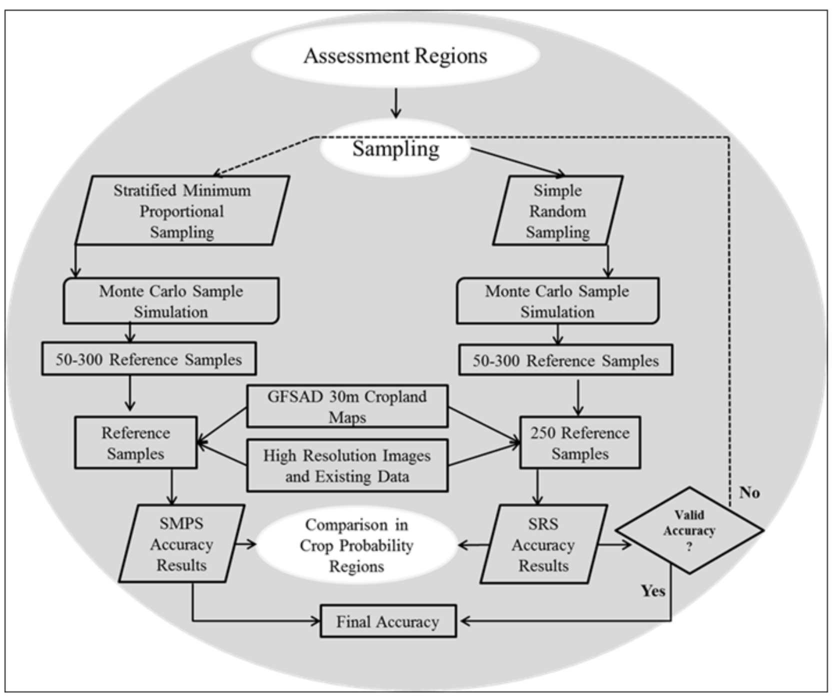

Fig. 2. The graphical work flow showing the steps involved to perform the assessment of cropland maps of different cropland regions

Table 1. The calculations of crop and no-crop samples for each sample simulation

Sample size	Cropland samples	No-cropland samples
50	25	25
100	50	50
150	50+ (CAP % of 50)	50+ (NCAP % of 50)
200	50+ (CAP % of 100)	50+ (NCAP % of 100)
250	50+ (CAP % of 150)	50+ (NCAP % of 150)
300	50+ (CAP % of 200)	50+ (NCAP % of 200)

CAP: Cropland Area Proportion; NCAP: Non-Cropland Area Proportion

Second, the sampling designs were applied in each cropland region based on the following two protocols: (1) Simple Random Sampling (SRS) and (2) Stratified Minimum Proportional Sampling (SMPS) [34,41]. The SRS design was applied initially to assess the GFSAD30 cropland extent map for all 72 cropland regions around the world [39]. This sampling design resulted in a random distribution of samples in the cropland and non-cropland map classes based on the equal probability characteristic of random sampling. The cropland map class was rare in low cropland proportion regions and achieved insufficient sample size and ineffective accuracy measures (i.e., producer's and user's accuracies) with this design. Therefore, a second alternative sampling design (i.e., SMPS) was applied to ten randomly selected cropland regions. The SMPS design approach used a predetermined minimum sample size of 50 randomly distributed in each map class (i.e., strata) followed by a proportional distribution of the remaining total samples. This approach was adopted to provide sufficient samples and useful accuracy measures (i.e., user's and producer's accuracy) for the rare cropland map class in the LCP regions.

Third, a sample simulation analysis based on a Monte Carlo method was employed as in Yadav and Congalton [39] with sample sizes ranging from 50 to 300 to determine the optimum sample size. Table 1 shows the allocation of samples tested between 50 and 300 in increments of 50. Once the predetermined minimum sample size of 50 was reached (total samples more than 100) then the additional samples were allocated to each map class proportionally to the cropland and non-cropland area (i.e, CAP and NCAP) [34].

Finally, the accuracy measures of the cropland extent map classes were generated in each of the ten cropland regions at the determined optimum sample size for the two sampling designs. The accuracy measures (e.g., overall, producer's, and user's accuracy) were presented in the form of error matrices. The sample size and accuracy measures of the rare cropland map class achieved with different sampling designs at an optimum sample size were compared and evaluated for each cropland region (i.e., probability class from Class 1 to Class 5).

4. RESULTS

The results of the assessment of the cropland maps of different crop proportion regions describe the comparison of the two different sampling designs with respect to the distribution and allocation of reference samples for each map class and the accuracy measures in the following two sections:

The evaluation of the two sampling designs was performed by comparing the distribution and allocation of reference samples and accuracy measures of the rare cropland map class in each of the ten cropland proportion regions. The results are divided into (1) the grouping of the ten cropland regions into five probability classes, (2) the distribution and allocation of the reference samples, (3) the determination of optimum sample size for the SMPS design, and (4) the accuracy measures of the cropland extent map classes using SRS and SMPS designs.

4.1 Five Cropland Probability Classes

The grouping of cropland area proportion of the ten cropland regions resulted in five cropland probability classes in which the two sampling designs were applied, evaluated, and compared to achieve effective accuracy measures of the cropland map class. Table 2 presents the assigned cropland probability class of each region derived from the cropland and non-cropland area proportions (i.e., CAP and NCAP).

4.2 Distribution and Allocation of Reference Samples Using SRS and SMPS Designs

The SRS and SMPS sampling designs resulted in different distributions and allocation of reference samples of each map class in the ten cropland study regions. An example of the distribution of the 250 reference samples selected using the SRS and SMPS designs are presented for Canada Zone 3 (4.8% CAP) (Fig. 3). In addition to the distribution, the allocation of reference samples in the cropland and non-cropland map classes using the two different sampling designs is also presented for the ten cropland regions (Table 3). For example, in Table 3, Canada Zone 3 shows an allocation of 11 and 57 cropland reference samples at a sample size of 250 using SRS and SMPS designs, respectively.

4.3 The Optimum Sample Size for the SMPS Design

The determination of the optimal sample size for the SRS sampling was conducted using a sampling simulation analysis [39]. A sample size of 250 was selected. The optimal sample size for the SMPS design was determined by plotting the overall accuracy of the cropland extent maps at sample sizes from 50 to 300 for each of the ten cropland proportion regions (Fig. 4). The graphical representation shows a plateau in the

Table 2. Cropland and non-cropland area proportion and probability class of the various cropland regions

	Zones	CAP%	NCAP%	Probability class
1	South America Zone 1	1.85	98.15	Class 2 (1-2%)
2	Canada Zone 1	0.99	99.01	Class 1 (0-1%)
3	North America Zone 13	4.19	95.81	Class 3 (2-6%)
4	Europe Zone 7	1.90	98.10	Class 2 (1-2%)
5	China Zone 3	0.90	99.10	Class 1 (0-1%)
6	South East-Asia Zone 5	43.2	56.8	Class 5 (>15%)
7	Africa Zone 7	5.65	94.35	Class 3 (2-6%)
8	North America Zone 4	14.85	85.15	Class 4 (6-15%)
9	Canada Zone 3	4.8	95.2	Class 3 (2-6%)
10	North America Zone 15	9.88	90.12	Class 4 (6-15%)

Class 1: Very Low; Class 2: Low; Class 3: Medium; Class 4: High; Class 5: Very High

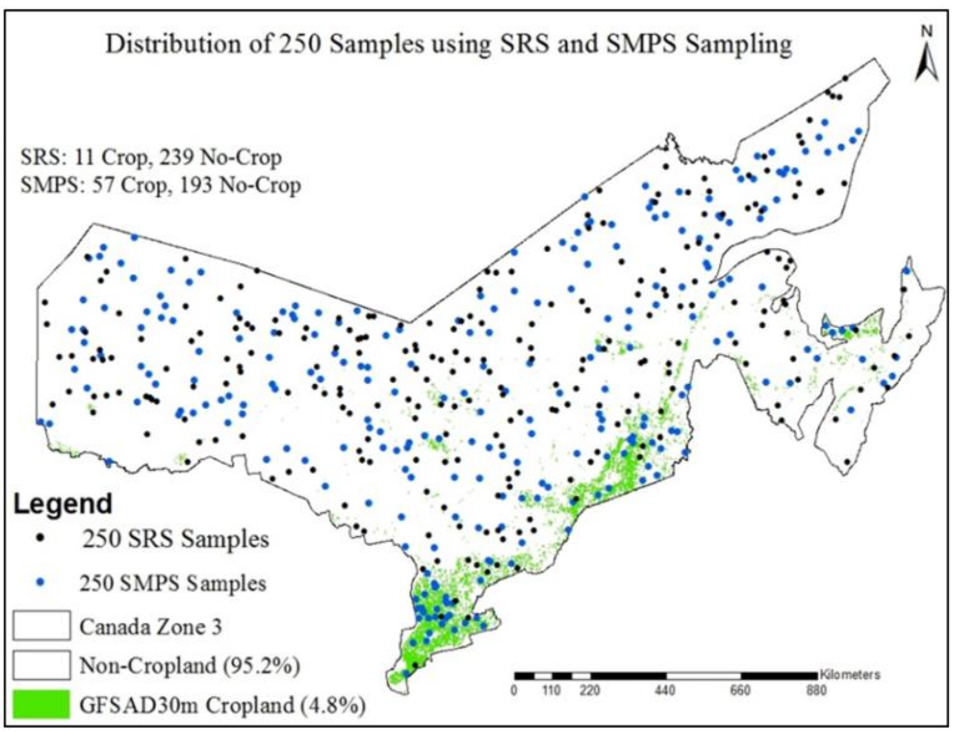

Fig. 3. The distribution of 250 reference samples using SRS and SMPS designs in the Canada Zone 3

Table 3. The allocation of cropland and non-cropland reference samples using SRS and SMPS designs

Region	CAP%	SMPS 50		SMPS 100		SMPS 150		SMPS 200		SMPS 250		SMPS 300		SRS 250	
		C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
SAm Zone 1	1.85	25	25	50	50	51	99	52	148	**53**	197	54	246	**8**	242
Canada Zone 1	0.99	25	25	50	50	50	100	51	149	**51**	199	52	248	**5**	245
NA Zone 13	4.19	25	25	50	50	52	98	54	146	**56**	194	58	242	**11**	238
Europe Zone 7	1.90	25	25	50	50	51	99	52	148	**53**	197	54	246	**8**	242
China Zone 3	0.90	25	25	50	50	50	100	51	149	**51**	199	52	248	**4**	345
SE Asia Zone 5	43.2	25	25	50	50	72	78	93	107	115	135	136	164	116	134
Africa Zone 7	5.65	25	25	50	50	53	97	56	144	**58**	192	61	239	**17**	233
NA Zone 4	14.85	25	25	50	50	57	93	65	135	**72**	178	80	220	**11**	238
Canada Zone 3	4.8	25	25	50	50	52	98	55	145	**57**	193	60	240	**11**	239
NA Zone 15	9.88	25	25	50	50	55	95	60	140	**65**	185	70	230	**24**	223

SRS: Simple Random Sampling, SMPS: Stratified, Minimum, Proportional Sampling, C: Cropland; NC: No-Cropland; SAm: South America; NA: North America; SE Asia: South East Asia

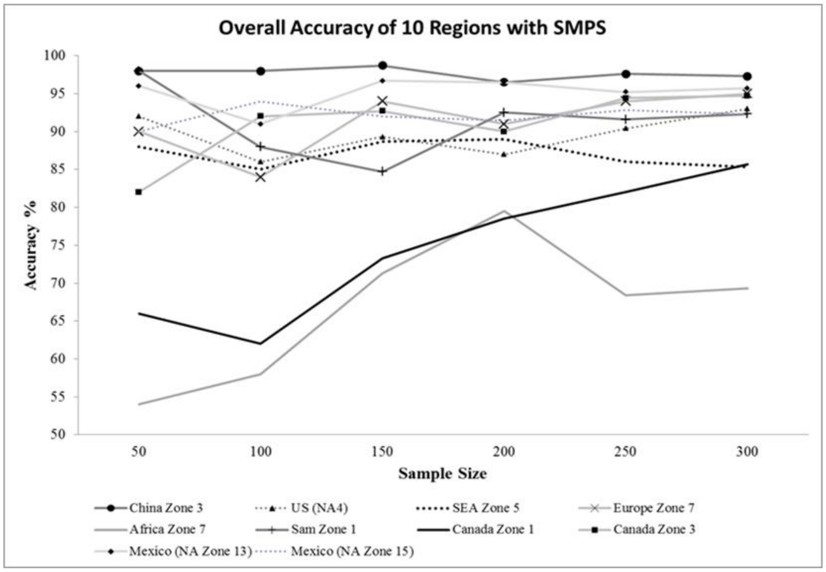

Fig. 4. Graphical representation of the overall accuracy achieved with SMPS design using the sample sizes from 50 to 300

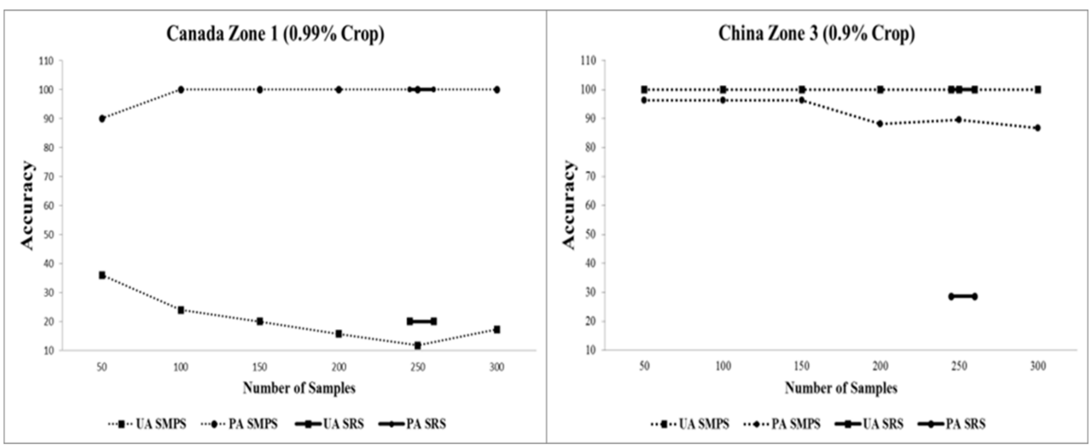

Fig. 5. Graphical comparison of the accuracy measures achieved with SRS and SMPS designs in very low cropland proportion regions

overall accuracy of eight of the cropland extent maps at a sample size of 250 using the SMPS design beyond which the accuracy did into increase with the addition of more samples. While two regions, Canada Zone 1 and Africa Zone 7, do not show this plateau a sample size of 250 was selected as optimal.

4.4 Accuracy Measures of the Cropland Extent Map in the Ten Cropland Regions

The SRS and SMPS designs resulted in different accuracy measures of the cropland map class of the GFSAD30m cropland extent map in the ten cropland proportion regions. These accuracies determined at a sample size of 250 are presented graphically and in error matrix form for each of the ten cropland proportion regions by five cropland probability classes.

4.4.1 Very low cropland proportion regions of less than 1% CAP (Class 1)

Canada Zone 1 and China Zone 3 are grouped as very low cropland proportion regions of <1% CAP determined from the GFSAD30m cropland extent map. The accuracy measures (i.e., user's and producer's accuracy) of the cropland map

Table 4. Error matrices showing the accuracy measures achieved with SRS and SMPS designs in the very low cropland proportion regions

SMPS		Canada zone 1 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	6	45	51	11.7%
Data	No-Crop	0	199	199	100.0%
Total		6	244	250	
Producer's Accuracy		100.0%	81.5%		82.0%

SRS		Canada zone 1 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	1	4	5	20.0%
Data	No-Crop	0	245	245	100.0%
Total		1	249	250	
Producer's Accuracy		100.0%	98.4%		98.4%

SMPS		China zone 3 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	51	0	51	100.0%
Data	No-Crop	6	193	199	96.9%
Total		57	193	250	
Producer's Accuracy		89.5%	100.0%		97.6%

SRS		China zone 3 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	4	0	4	100.0%
Data	No-Crop	10	335	345	97.1%
Total		14	193	349	
Producer's Accuracy		28.6%	100.0%		97.1%

Table 5. Error matrices showing the accuracy measures achieved with SRS and SMPS designs in the low cropland proportion regions

SMPS		South America zone 1 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	44	9	53	83.0%
Data	No-Crop	12	185	197	93.9%
Total		56	194	250	
Producer's Accuracy		78.5%	95.3%		91.6%

SRS		South America zone 1 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	3	5	8	37.5%
Data	No-Crop	3	239	242	98.8 %
Total		6	250	250	
Producer's Accuracy		50.0%	98.0%		96.8%

SMPS		Europe zone 7 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	43	10	53	81.1%
Data	No-Crop	5	192	197	97.5%
Total		48	202	250	
Producer's Accuracy		89.5%	95.1%		94.0%

SRS		Europe zone 7 reference data			
		Crop	No-Crop	Total	User's accuracy
Map	Crop	8	0	8	100.0%
Data	No-Crop	1	241	242	99.6 %
Total		9	241	250	
Producer's Accuracy		88.9%	100.0%		99.6%

Table 6. Error matrices showing the accuracy measures achieved with SRS and SMPS designs in the medium cropland proportion regions

SMPS		**Canada zone 3 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map Data	Crop	43	14	57	75.4%
	No-Crop	0	193	193	100.0%
Total		43	207	250	
Producer's Accuracy		100.0%	93.2%		94.4%

SRS		**Canada zone 3 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	10	1	11	90.9%
Data	No-Crop	0	239	239	100.0%
Total		10	240	250	
Producer's Accuracy		100.0%	99.7%		99.6%

SMPS		**Africa zone 7 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	29	29	58	50.0%
Data	No-Crop	50	142	192	73.9%
Total		79	171	250	
Producer's Accuracy		36.7%	83.0%		68.4%

SRS		**Africa zone 7 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	3	14	17	17.7%
Data	No-Crop	5	228	233	97.9%
Total		8	242	250	
Producer's Accuracy		37.5%	94.2%		92.4%

SMPS		**North America zone 13 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	49	7	56	87.5%
Data	No-Crop	5	189	194	97.4%
Total		54	196	250	
Producer's Accuracy		90.7%	96.4%		95.2%

SRS		**North America zone 13 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	10	2	12	83.3%
Data	No-Crop	2	236	238	99.2%
Total		12	237	250	
Producer's Accuracy		83.3%	99.6%		98.8%

Table 7. Error matrices showing the accuracy measures achieved with SRS and SMPS designs in the high cropland proportion regions

SMPS		**North America zone 15 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	54	11	65	83.0%
Data	No-Crop	7	178	185	96.2%
Total		61	189	250	
Producer's Accuracy		88.5%	94.1%		92.8%

SRS		**North America zone 15 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	14	10	24	58.3%
Data	No-Crop	6	217	223	97.3%
Total		48	227	247	
Producer's Accuracy		70.0%	95.6%		93.5%

SMPS		**North America zone 4 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	48	24	72	66.6%
Data	No-Crop	0	178	178	100.0%
Total		48	202	250	
Producer's Accuracy		100.0%	88.1%		90.4%

SRS		**North America zone 4 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	25	10	35	71.4%
Data	No-Crop	2	213	215	99.1%
Total		27	223	250	
Producer's Accuracy		92.6%	95.5%		95.2%

Table 8. Error matrices showing the accuracy measures achieved with SRS and SMPS designs in the very high cropland proportion regions

SMPS		**South East Asia zone 5 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	92	23	115	80.0%
Data	No-Crop	12	123	135	91.1%
Total		104	146	250	
Producer's Accuracy		88.4%	84.2%		86.0%

SRS		**South East Asia zone 5 reference data**			
		Crop	**No-Crop**	**Total**	**User's accuracy**
Map	Crop	89	27	116	76.7%
Data	No-Crop	13	121	134	90.3%
Total		102	148	250	
Producer's Accuracy		87.3%	81.8%		84.0%

class of these regions achieved at a sample size of 250 using SRS and SMPS designs are presented graphically and in error matrix form for these regions (Fig. 5 and Table 4). Large differences in the producer's accuracy of the rare cropland map class were observed between the SRS and the SMPS sampling designs for China Zone 3 (Fig. 5). The user's accuracy of the rare cropland map class for the SRS sampling design more closely agrees with the SMPS design for Canada Zone 1. Insufficient samples in the rare cropland map class using the SRS design for these two regions results in accuracy measures that are not indicative of the actual errors (Table 4).

4.4.2 Low cropland proportion regions of >1-2% CAP (Class 2)

South America Zone 1 and Europe Zone 7 are grouped as low cropland proportion regions of >1-2% CAP derived from the GFSAD30m cropland extent map. The accuracy measures (i.e., user's and producer's accuracy) of the cropland map class of these regions using the SRS and SMPS designs are presented graphically and in error matrix form for these low cropland proportion regions (Fig. 6 and Table 5). Large differences in the user's and producer's accuracy of the rare cropland map class were observed between the SRS and the SMPS sampling designs for South America Zone 1 (Fig. 6). The user's accuracy of the rare cropland map class for the SRS sampling design more closely agrees with the SMPS design for Europe Zone 7. Insufficient samples in the rare cropland map class using the SRS design for these two regions results in accuracy measures that are not indicative of the actual errors (Table 5).

4.4.3 Medium cropland proportion regions of >2-6% CAP (Class 3)

Canada Zone 3, Africa Zone 7, and North America Zone 13 are grouped as medium cropland proportion regions of >2-6% CAP determined from the GFSAD30m cropland extent map. The accuracy measures (i.e., user's and producer's accuracy) of the cropland map class of these regions using SRS and SMPS designs are presented graphically and in error matrix form for these medium cropland proportion regions (Fig. 7 and Table 6). Large differences in the user's accuracy of the rare cropland map class were observed between the SRS and the SMPS sampling designs for Canada Zone 3 and Africa Zone 7 (Fig. 7). The user's and producer's accuracy of the rare cropland map class for the SRS sampling design more closely agrees with the SMPS design for North America Zone 13. Insufficient samples in the rare cropland map class using the SRS design for these three regions results in accuracy measures that are not indicative of the actual errors (Table 6).

4.4.4 High cropland proportion regions of >6-15% CAP (Class 4)

North America Zone 15 and North America Zone 4 are grouped as high cropland proportion regions of >6-15% CAP derived from the GFSAD30m cropland extent map. The accuracy measures (i.e., user's and producer's accuracy) of the cropland map class of these regions using SRS and SMPS designs are presented graphically and in error matrix form for these high cropland proportion regions (Fig. 8 and Table 7). Large differences in the user's and producer's accuracy of the rare cropland map class

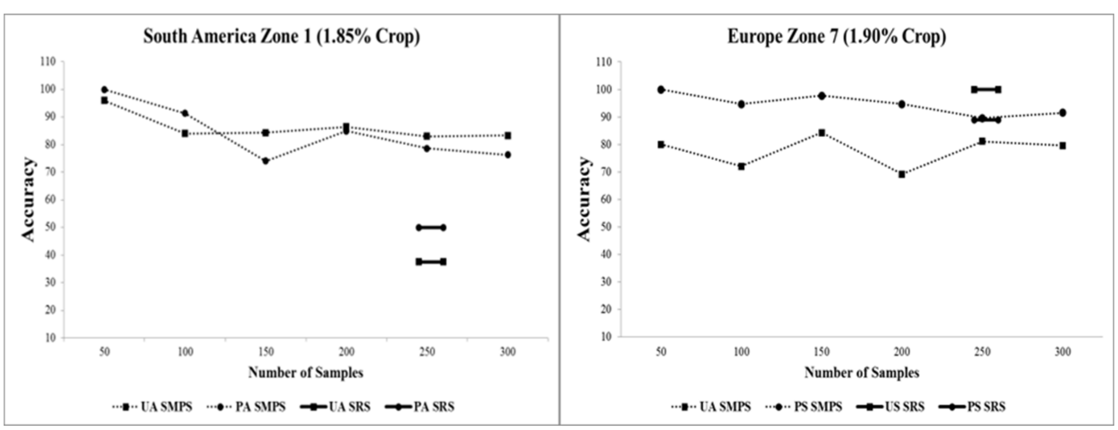

Fig. 6. Graphical comparison of user's and producer's accuracy achieved with SRS and SMPS designs in low cropland proportion regions

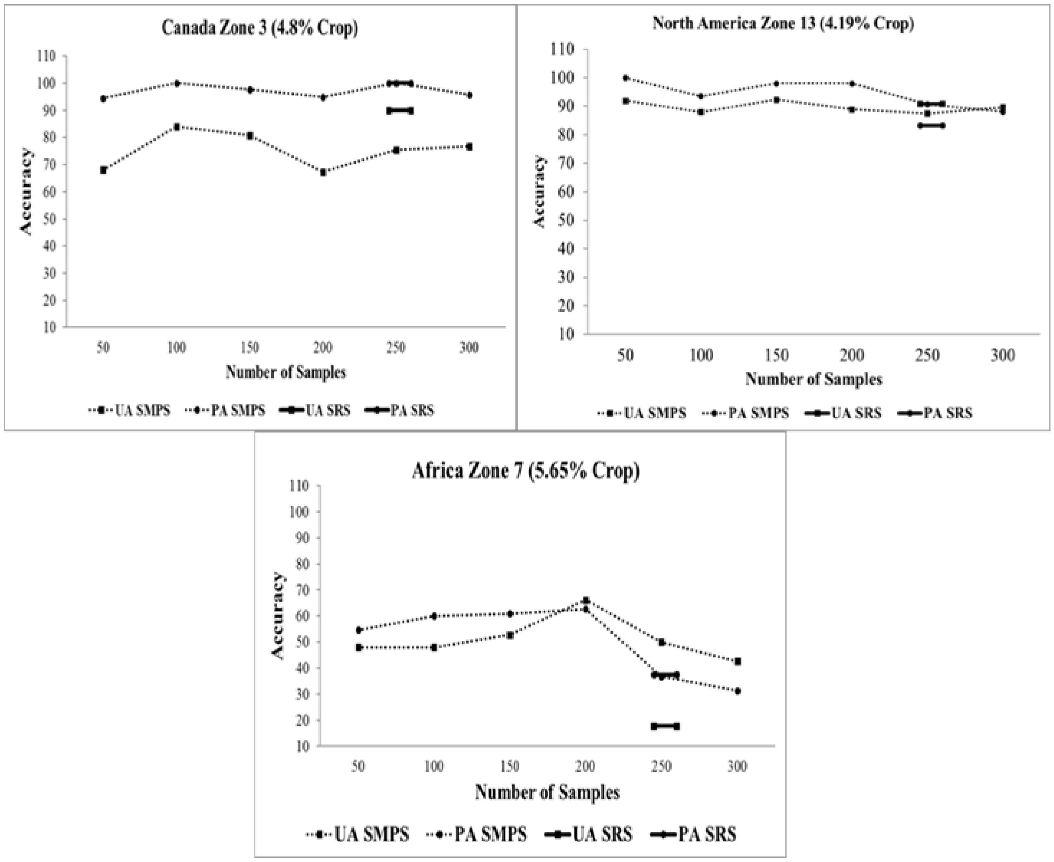

Fig. 7. Graphical comparison of the accuracy measures achieved with SRS and SMPS designs in the medium cropland proportion regions

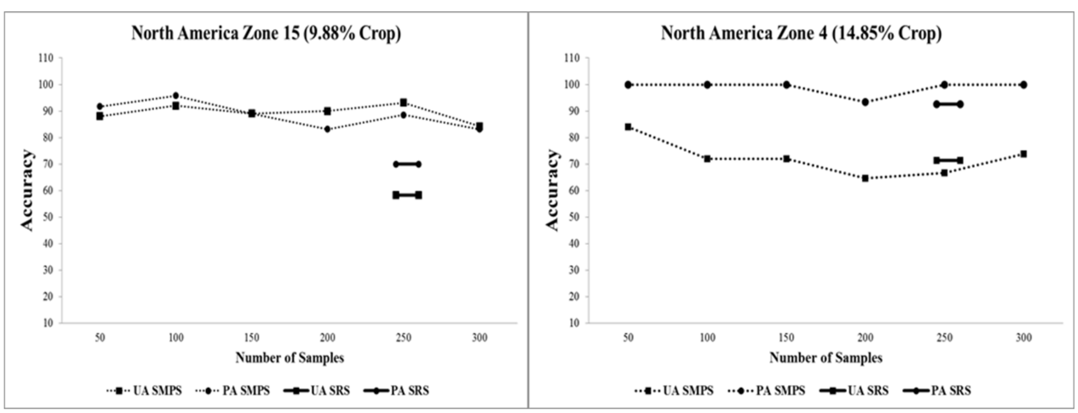

Fig. 8. Graphical comparison of the accuracy measures achieved with SRS and SMPS designs in the high cropland proportions regions

were observed between the SRS and the SMPS sampling designs for North America Zone 15 (Fig. 8). The user's and producer's accuracy of the rare cropland map class for the SRS sampling design more closely agrees with the SMPS design for North America Zone 4. Insufficient samples in the rare cropland map class using the SRS design for these two regions results in accuracy measures that are not indicative of the actual errors (Table 7).

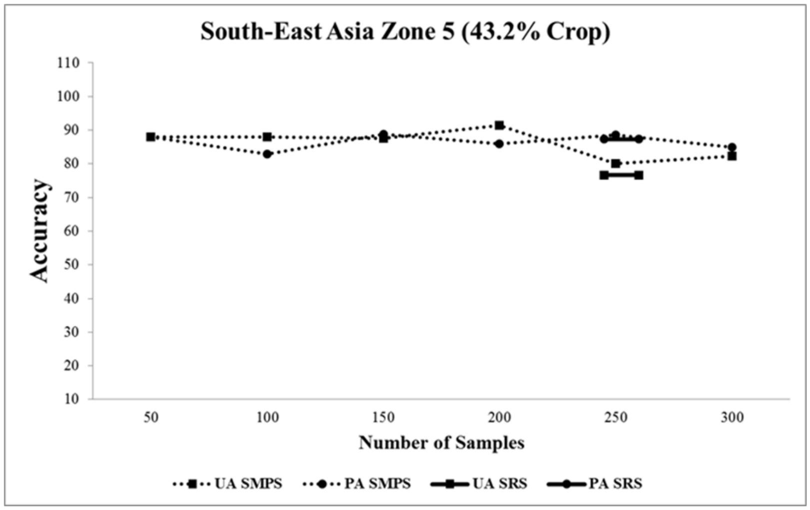

Fig. 9. The comparison of the accuracy measures achieved with SRS and SMPS designs in the very high cropland proportion regions

4.4.5 Very high cropland proportion regions of >15% CAP (Class 5)

South East Asia Zone 5 is grouped as very high cropland proportion region of >15% CAP derived from the GFSAD30m cropland map. The accuracy measures (i.e., user's and producer's accuracy) of the cropland map class of this region using SRS and SMPS designs are presented graphically and in error matrix form (Fig. 9 and Table 8). The user's and producer's accuracy of the rare cropland map class for the SRS sampling design more closely agrees with the SMPS design for South East Asia Zone 5 (Fig. 9). Sufficient samples in the rare cropland map class using the SRS design results in accuracy measures that are indicative of an effective and meaningful assessment of the cropland map for this region (Table 8).

5. DISCUSSION

The accuracy assessment of the GFSAD30m cropland extent map was initially performed using SRS design at a sample size of 250 for various cropland regions around the world [19]. This sampling design resulted in an insufficient sample and ineffective accuracy measures of the rare cropland map class in the low cropland proportion regions due to the cropland proportion, distribution, and pattern of the cropland extent map being assessed. Very limited research has been done so far to evaluate and choose an appropriate sampling design to perform an effective accuracy assessment of the cropland maps of different regions [33]. After thorough research, it was found that there are no suggestions available for employing appropriate sampling approaches to assess the cropland maps of different cropland regions in the literature. To achieve sufficient samples and effective accuracy measures of the rare cropland map class, an alternate SMPS design was applied in ten selected cropland regions. The comparison of two different sampling designs presents novel results by providing recommendations on performing an appropriate sampling for different cropland regions. Therefore, the novel results of performing an appropriate sampling in different cropland proportion regions are discussed in the following sections with respect to number of samples and achieved accuracy measures.

5.1 Assigning Cropland Probability Classes

The cropland area proportion (CAP) of the ten selected regions were estimated using the GFSAD30m cropland extent map to provide an effective sampling area for applying and evaluating the sampling designs. The ten cropland regions were grouped into five probability classes from very low to very high cropland probability based on their estimated percent of cropland area proportion from 0.9% to 43.2% (Table 2). The very high cropland probability class was assigned to the regions of >15% CAP while four probability classes (e.g., very low, low, medium, and high cropland probability) were assigned to the regions of <15% CAP. The cropland regions of <15% CAP were purposely grouped into four probability classes from Class 1 to 4 to evaluate the sampling designs in all the possible low cropland proportion regions. The grouping of the ten cropland regions into five cropland probability classes was necessary to determine the range of CAP of the low cropland proportion regions to be effectively assessed using an appropriate sampling design.

5.2 Distribution and Allocation of Samples with SRS and SMPS Designs

The distribution and allocation of samples of the rare cropland map class at a sample size of 250 using SRS and SMPS designs were compared spatially and in tabular form for the ten cropland regions. An example comparison of the distribution and allocation of samples of the rare cropland map class at a sample size of 250 using SRS and SMPS designs was presented for Canada Zone 3 (Fig. 3 and Table 3). This comparison shows an allocation of only 11 samples in the rare cropland map class using the SRS design at a sample size 250 due to the equal probability of selecting a sample area in the low cropland class. As a result, computation of producer's and user's accuracy is problematic as even a small number of incorrect classifications can generate very low accuracies. Similar insufficient sample allocations for the rare cropland map class were also observed in other cropland regions of <15% CAP (Table 8). Therefore, an alternate SMPS design was developed and achieved appropriate distribution and allocation of samples of the rare cropland map class in the LCP regions (Table 8) [21]. The SMPS design resulted in an appropriate distribution and allocation of 57 samples of the rare cropland map class at a sample size of 250 for Canada Zone 3 (Fig. 3). In contrast, the high cropland proportion regions of >15% CAP achieved appropriate distribution and sufficient number of samples at a sample size of 250 both with SMPS and SRS designs due to more uniform and prevalent cropland distribution in these regions. These results demonstrate that the sampling designs achieve different distribution and allocation of samples of the rare cropland map class in the ten cropland regions and therefore, the appropriate design must be selected according to the proportion of cropland extent in the maps to be assessed.

5.3 The Optimum Number of Samples for SRS and SMPS Designs

The sample simulation analysis performed by Yadav and Congalton [39] determined an optimum sample size of 250 for the SRS design in various cropland regions. Similarly, the optimal sample size for the SMPS design was also determined by plotting the overall accuracy of the cropland extent maps at sample sizes from 50 to 300 for each of the ten cropland proportion regions (Fig. 4). The graphical representation shows a plateau in the overall accuracy of eight of the cropland extent maps at a sample size of 250 using the SMPS design beyond which the accuracy did into increase with the addition of more samples. However, the overall accuracy of the cropland extent map of Africa Zone 7 decreased while that of Canada Zone 1 increased with the addition of more samples beyond the sample size of 250. Unlike the other low cropland proportion regions, these two regions did not reach a plateau in the overall accuracy at 250 samples due to errors (i.e., omission or commission) in the rare cropland map class of the cropland extent map.

The rare cropland map class of the cropland extent map of Africa Zone 7 had serious omission errors when compared with the Google Earth imagery. The methodology used to accurately classify the cropland regions of the entire African continent do not seem to have worked as well to map the very small fields of Africa Zone 7 (Madagascar) given their unique cropland distribution and pattern. On the other hand, the rare cropland map class of the cropland extent map of Canada Zone 1 had a large number of commission errors. These errors are a result of missing cropland patches in the AAFC (Agriculture and Agri-Food Canada) reference cropland layer that was used for the assessment. Comparing this reference data with Google Earth imagery showed that for this region the reference data missed a large number of cropland patches. It is clear that the overall accuracy of the cropland extent map of Africa Zone 7 and Canada Zone 1 did not reach plateau at a sample size of 250 due to omission and commission errors of the rare cropland map class, respectively. Therefore, a sample size of 250 was selected as optimal for SMPS design based on the simulation analysis of eight of the cropland regions excluding Africa Zone 7 and Canada Zone 1. Finally, the results demonstrate that choosing an alternate design (i.e., distribution and allocation of samples) is more important than increasing the sample size to achieve sufficient samples and effective accuracy of the rare cropland map class in the ten cropland regions.

5.4 Accuracy Measures with SRS and SMPS Designs

The SRS and SMPS designs resulted in different accuracy measures of the cropland map class of the GFSAD30m cropland extent map in the ten cropland proportion regions. The SRS design resulted in insufficient and ineffective accuracy measures of the rare cropland map class in the Low Cropland Proportion (LCP) regions around the world [19]. However, the alternate SMPS design achieved effective and useful accuracy measures of the rare cropland map class in the LCP regions of <15% CAP (e.g., China Zone 3, South America Zone 1, Africa Zone 7, and North America Zone 15) (Figs. 5, 6, 7, and 8). The reasons for achieving different accuracy results with the two sampling designs can be explained by examining the cropland proportion, distribution, and pattern of the cropland extent maps of the different cropland regions to be assessed. It should be noted that not all the LCP regions produced the same result. In a few of the LCP regions of <15% CAP, the accuracy measures of the rare cropland map class were the same for the SRS and SMPS designs due to: (1) omission errors in the cropland class of the reference cropland extent map (e.g., Canada Zone 1) (Fig. 5) and (2) the more evenly scattered and uniformly distributed cropland pattern (e.g., Europe Zone 7) (Fig. 6).

The evaluation of the SRS and SMPS designs in the regions of >15% CAP (e.g., South East Asia Zone 6) did not show any change in the accuracy measures of the rare cropland map class (Fig. 9). The high cropland proportion regions (>15% CAP) can be sampled using either of the sample designs at a sample size of 250. It is important to note that regions of more than 85% cropland proportion (i.e., <15% non-cropland area proportion (NCAP)) should be considered the same as the LCP regions. In this case, non-cropland becomes the rare map class and the sampling issues are the same. Therefore, the evaluation of SRS and SMPS designs demonstrates that the regions of <15% CAP or NCAP need to be assessed using the SMPS design while the regions between 15-85% cropland proportion can be assessed using either of the sampling designs.

6. CONCLUSIONS

In this paper, we have evaluated two sampling designs to effectively assess the cropland extent maps of the ten selected cropland regions. The evaluation of the SRS and SMPS designs with respect to the sample allocation and accuracy of the rare cropland map class at a sample size of 250 demonstrates their suitability for implementation given different cropland probability classes and cropping patterns (Table 9).

Based on the evaluation and comparison of the sampling designs (Table 9), the following conclusions can be used to perform an effective assessment of the cropland extent maps of various cropland regions:

1. To perform an effective assessment of the cropland extent map in various cropland regions, the three P's must be determined for each cropland region to be assessed: (1) Proportion of cropland, (2) Possibility of rare map class, and (3) Predetermined minimum sample size of the rare map class.
2. While choosing a sampling strategy to effectively assess the rare cropland map

Table 9. The comparison of sampling designs in different cropland probability classes

Class	Cropping pattern	Sampling	Sample size	Accuracy
0-1%	No Significant Pattern	**SMPS**	**Sufficient**	**90-100%**
		SRS	Insufficient	20-30%
1-2%	Clustered, confined	**SMPS**	**Sufficient**	**80-90%**
		SRS	Insufficient	40-50%
	Scattered, well-distributed	SMPS	**Sufficient**	Remain same
2-6%	Confined	SMPS	**Sufficient**	70-90%
		SRS	Insufficient	80-90%
	Evenly distributed	SMPS	**Sufficient**	Remain same
6-15%	No Significant Pattern	**SMPS**	**Sufficient**	**85-90%**
		SRS	Insufficient	70-80%
>15%	No Significant Pattern	SRS/SMPS	No Difference	70-90%

class of various cropland regions, the distribution of samples is more important than increasing or decreasing the number of samples (once a sufficient number of samples is determined).
3. The distribution of samples combined with the predetermined minimum number of samples must be chosen appropriately to achieve sufficient sampling and effective accuracy assessment of the rare cropland map class in the low cropland proportion (LCP) regions.
4. The regions of <15% CAP that have clustered and limited to small areas cropping pattern can be effectively assessed using the SMPS design as compared to the scattered and uniform cropping pattern. However, the regions of >15% CAP (those maps that do not contain a rare cropland map class) can be effectively assessed using either of the sampling designs at a sample size of 250.

ACKNOWLEDGEMENTS

The research is funded by NASA MEaSUREs (Making Earth System Data Records for Use in Research Environments). The United States Geological Survey (USGS) provided supplemental funding as well as numerous other direct and indirect support through its Land Change Science (LCS), Land Remote Sensing (LRS) programs, and Climate and Land Use Change Mission Area. The NASA MEaSUREs project grant number: NNH13AV82I, the USGS Sales Order number: 29039. Partial funding was provided by the New Hampshire Agricultural Experiment Station. This is Scientific Contribution Number 2813. This work was supported by the USDA National Institute of Food and Agriculture McIntire Stennis Project #NH00077-M (Accession #1002519).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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