AERIAL PHOTOGRAPHY FOR DETERMINING LAND USE

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1. Introduction

In India, the statistics of land use are based mostly on the reports of field enumeration in areas where the land has been cadastrally surveyed and a primary reporting agency exists. The detailed survey maps and land registers available in such areas also serve as a frame for sampling plots for estimation of yield per acre on a scientific basis. However, there are several tracts accounting for about 19 per cent of the total geographical area of the country which are still not cadastrally surveyed. In order to place the statistics of area and yield for such areas on a sound footing, a cadastral survey is essential and work in this direction is in progress. The completion of such projects is not only costly but also takes a long time. An alternative method to compile statistics of land use and provide a frame for sampling for yield estimation in unsurveyed areas would be to use the technique of aerial photography. At present the use of aerial photography is confined by the survey of India to maintenance of topographical maps of India.

The Indian Council of Agricultural Research had undertaken in the past investigations to explore the feasibility of making use of the technique of aerial photography to bridge the gaps existing in the area and yield of crops in unsurveyed tracts. Aerial photographic surveys were conducted from 1946-49 in small selected tracts of Delhi, Uttar Pradesh and Bihar States. Identification of crops was done by persons who were specially trained in the use of stereoscope and in interpretation of photo prints. A comparison of the reading on the photographs with those available from the actual land use surveys completed through the village khasra showed that identification was done correctly in most of the cases where the standing crop was pure, while there appeared to be some difficulty in identifying a crop mixture due to the shadows and variable textures produced on

the photo prints. Identification of the latter type of cases could at the most detect the existence of a crop mixture although it was not possible to identify the component crops in the mixture with certainty. The use of colour filters in the photography did not improve the accuracy of interpretation of component crops in a mixture. Even for pure crops, a difficulty experienced some times was that a few crops like sugarcane and jowar had a similar appearance on the photo prints which resulted in some uncertainty in distinguishing these crops. However, one important observation from these investigations was that the field boundaries could be identified clearly, whereby the photographs could be used for defining a suitable frame which was essential in sampling for estimation of crop areas and yield. Moreover, the photographs could provide estimates of area of those crops which could be identified with certainty.

On the basis of the results of these investigations an aerial photographic survey was undertaken in the then unsurveyed tract* of Goalpara district of Assam State during November, 1956. With the aid of the photographs of this survey a study was made to evolve a suitable sampling procedure to be imposed on the photographs for estimating the area under different types of land use. The results of the study are presented in this paper.

2. Description of the Survey

The tract covered by the survey was a plain area of 20 square miles around Rupsi Airfield in Goalpara district of Assam State. Table 1 indicates the names of important crops in the tract and period of their harvest.

It is seen from the table (page 3) that winter paddy was the most important crop in the tract.

The photographic survey was carried out with the collaboration of the Surveyor General of India during the period 19th to 21st November, 1956. Black and white photographs of the tract were taken and 53 contact prints of scale 6″ to a mile and their enlargements on a scale of 16″ to a mile were supplied. These photographs had an overlap of 60 per cent fore and aft and 25 per cent lateral. The crops which could be covered by the photographs were winter paddy, shallow water type of autumn paddy, mustard and a few other minor crops like arhar, til, vegetables, etc.

*A Cadastral survey was undertaken subsequently and statistics of land use are being collected since 1962-63.

TABLE 1

Particulars of crops in the tract

Crop		*Period of sowing*	*Period of harvesting*	*Area under the crop expressed as a percentage of the total gross area (1963-64)*
1. Winter Paddy	Sali Paddy	June—July	Nov.—Dec.	47
	Bao Paddy	March—April	Dec.—Jan.	
	Boro Paddy	November	May—June	
2. Autumn Paddy	Broadcast Ahu	March—April	June—July	
	Transplanted Ahu	March—April	June—July	32
	Shallow water Paddy	March—May	Nov.—Dec.	
3. Jute		March—April	July—Sept.	8
4. Mustard		September	March	3
5. Other crops (arhar, til, vegetables, etc.)				10

3. Results of Land Use Study

The indentification of land use from photo prints was entrusted to persons who were specially trained in the survey of India office at Dehra Dun in the use of stereoscope and interpretation of the data. These persons have visited the tract during the period when photography was done in order (*i*) to study the crop appearances and topographical features of the land, and (*ii*) to fix an appropriate scale for the photographs. The staff had also received necessary training in various aspects of photogrammetry such as (*i*) stereoscopic fusion, (*ii*) preparation of mosaic, (*iii*) photo verification, and (*iv*) area measurement, etc.

A comparative study of the readings of the photographs with the observations available from the actual land survey indicated that identification of paddy fields could be done with a high degree of accuracy. The field boundaries could clearly be identified except in a few cases where the bunds were over-shadowed by the crops. All the physical features like water, trees, huts, roads, etc., could be

identified well. The position on the field corresponding to the one on the photograph could also be located accurately. The paddy fields appeared in the photographs as a smooth ash coloured or blackish uniform mass and were clearly perceptible. The dual appearance was possibly due to the different stages of growth of the crop. The fallow land appeared as a smooth white patch. The harvested fields had a light ash coloured appearance distinct from that of a paddy field or fallow area. Other crops like mustard, arhar, til and vegetables had the same dark black appearance deeper as compared to paddy but not distinguishable among themselves. Water had a typical appearance of its own and a water pond or water-logged area looked tar black.

The study made for determining adjustment of the scale for the photographs indicated that for the enlargements no correction was needed. This was so because the tract photographed was a plain area and a small one.

4. Procedure of Statistical Study

For the purpose of sampling, two methods, *viz.*, (*i*) dot or point sampling and (*ii*) grid sampling were used. A sample of 230 dots was located at random on the mosaic prepared from the contact prints. For each sampled dot the land use of area around it was identified with the help of stereoscope and classified. The number of sample dots falling in a land use class expressed as per cent of the total number of dots gave an estimate of the percentage of area of the class. For the second method, a subsample of 40 dots was selected at random and these were transferred to the appropriate enlarged photos. For each such dot, 3 square grids of sizes, $1'' \times 1''$, $2'' \times 2''$ and $4'' \times 4''$ were marked accurately on the enlarged photographs with the sampled dot as their centre. The land use under different classes in each of the grids was identified and accurately measured with a planimeter. The data so collected for the various classes by the different methods of sampling were statistically analysed and the results of the analysis are given in the subsequent sections.

5. Results

(*i*) *Estimate of percentage of area under different classes*

Table 2 gives the estimate of proportion of area in various land classes obtained from the two methods of sampling :—

TABLE 2

Estimated percentage of area in different classes

	Dot sampling		*Grid sampling (No. of grids=40)*		
	No. of dots sampled =230	*No. of dots in the sub-sample =40*	*1″×1″*	*2″×2″*	*4″×4″*
1. Standing crop of winter paddy (percentage standard error)	45 (7·4)	48 (16·8)	44 (11·7)	43 (9·8)	43 (7·6)
2. Harvested fields	13	25	23	23	21
3. Water-logged area	19	17	16	15	15
4. Fallows	10	10	8	8	9
5. Miscellaneous crops (vegetables, mustard etc.)	1	—	2	2	2
6. Non-agricultural use (roads, paths, ponds, streams, houses, etc.)	4	—	6	6	7
7. Other classes (grazing land, groves, etc.)	8	—	1	3	3

The estimated percentage area under winter paddy varied from 43 per cent to 48 per cent for the different methods of sampling and measurement. The other classes like harvested fields, water-logged area and fallows need some definition here. A reference to Table 1 indicates that the harvested fields could possibly include crops like jute, autumn paddy, a few fields of winter paddy which might have been harvested prior to photography and a few other crops like til and vegetables. It was reported that the tract was under floods during 1956 and although the water which had submerged the fields subsided in July, 1956, there were traces of water in some of the fields at the time the photographs were taken in November. Such fields were classified as water-logged area. Some of the fields of shallow water cultivation of autumn paddy which could not be identified as paddy might also possibly be included under this group. The area classified as paddy should thus relate to the winter paddy crop standing in the field at the time of the photography. 'Fallow'

included current fallows and seasonal fallows as well. The area under this class is somewhat high since the tract is known to be a mono-cropped area.

(*ii*) *Comparison of survey estimates with official estimates*

As already indicated in the foot-note earlier, a cadastral survey was undertaken in the district subsequent to the photographic survey and the statistics of land use, are being collected since 1962-63 on an annual basis. The official estimates of the areas under different classes relevant to the period of photography expressed as percentages of total geographical area are given in Table—3.

TABLE 3

Comparable official estimates of land use (1963-64)
(Estimate of area as a percentage of total geographical area)

Winter paddy	*Current fallows*	*Non-agricultural use*	*Culturable waste*	*Burren and uncultivable land*	*Other crops and seasonal fallows*	*Total*
45	3	6	8	2	36	100

The official estimate of percentage area under winter paddy for the year 1963-64 is seen to be 45 per cent which is close to the estimate in Table 2. The assumption in comparing the survey and official estimates that the cropping pattern has not changed much over the years seems to be reasonable for the area studied.

6. Results of Study for Comparison of Units

The estimate of percentage area of winter paddy presented in Table-2 was obtained with fairly high precision in respect of dot sampling. Dot sampling is the simplest means of estimating area from the photographs and costs very little as compared to grid sampling. In regard to grids, for choosing the optimum grid size, the standard error will be of limited utility unless the differential costs of the operations of measurements are also taken into account. The various operations involved in the study for estimation of area are—(*i*) location of random point and marking of the grid ; (*ii*) identification of the land use; and (*iii*) measurement of area. The cost of each of these operations in terms of time taken for the area under winter paddy is given in Table 4.

TABLE 4

Average cost of the various operations of analysis (in minutes) for measurement of paddy area

Type of operation	*Time taken in minutes*		
	1″×1″	*2″×2″*	*4″×4″*
1. Location of random point and marking of grid	10	10	10
2. Identification of land use	30	40	50
3. Measurement of area under paddy	70	120	180
TOTAL	110	170	240

Note. The corresponding costs for dot sampling for a single dot were 3 minutes for item (1) and 10 minutes for item (2).

Utilisation of the estimates of variance per unit for the different grid sizes (0·1108 for 1″×1″, 1·1376 for 2″×2″ and 10·8544 for 4″×4″) and the costs of study for the different grid sizes, comparable costs for a given variance (5 per cent standard error) were worked out for each of the sizes. The results indicated that for the size 4″×4″, the cost was 364 hours, while for the other two sizes, it was higher, *viz.*, 436 hours for 1″×1″ and 434 for 2″×2″. It is thus seen that the grid size 4″×4″ was 120 per cent as efficient as the smallest size, *viz.*, 1″×1″ grid, while the grid of 2″×2″ was only as efficient as 1″×1″ grid. Another consideration which goes in favour of grid size 4″×4″ is the relative magnitude of errors in measurement. A study of this item indicated that the errors in measurement of area in the individual sample unit for the size 4″×4″ were much less compared to other two sizes. A small negative bias was also observed in measuring the individual areas of which the grid is made up and this bias also decreased with increasing size of the grid. These results are shown in Table 5.

TABLE 5

Percentage bias and percentage standard deviation in area measurement

	Grid Size		
	1″×1″	*2″×2″*	*4″×4″*
Percentage bias	—0·78	—0·54	—0·25
Percentage standard deviation	2·13	1·95	1·24

7. USE OF DOUBLE SAMPLING WITH REGRESSION IN RELATION TO THE DIFFERENT SIZES OF GRIDS

The figures given in Table 4 indicate that for each of the grid sizes a substantial proportion of the total cost of study of a single unit, *viz.*, 64 per cent for $1'' \times 1''$ grid, 70 per cent for $2'' \times 2''$ grid and 75 per cent for $4'' \times 4''$ grid was required for measurement of paddy area in the grid. One method to reduce the total cost of study may be to adopt a partial measurement method by which the area of land other than fields is measured, while for fields a scoring method is adopted. By this scoring method the total area under fields is divided into various classes in proportion to the number of fields in a class. Such a procedure would be less costly than complete measurement, since the area under fields alone accounted for more than 70 per cent of the total area (vide Table 2). The relative efficiency of the two methods was examined. In regard to the alternative procedure suggested above, the costs of the various operations are given in Table 6.

TABLE 6

*Average cost of various operations by method 2**

Type of operation	*Time taken in minutes*		
	1"×1"	*2"×2"*	*4"×4"*
1. Location of random point and marking of grid	10	10	10
2. Identification of area	30	40	50
3. Measurement of land classes other than fields	15	25	35
4. Scoring of fields	10	20	30
TOTAL	65	95	125

*Method 2—Measurement of area other than fields and scoring of fields.

It is seen from the table above that the cost of study for a single sample by the field scoring approach (method 2) as compared to the complete measurement approach (method 1) was 60 per cent for the grid size $1'' \times 1''$, 56 per cent for grid size $2'' \times 2''$, and 52 per cent for grid size $4'' \times 4''$. The scoring method, however, cannot replace the complete measurement method since the fields under

different crops vary in their areas resulting in bias in estimation of area under the particular class in the grid. In view of the high correlation observed between the estimates of area under paddy in the individual samples obtained by the two methods, *viz*, 0·73 for 1″×1″, 0·93 for 2″×2″, and 0·96 for 4″×4″, a double sampling procedure with regression by which a large sample is observed by the scoring method and a small sample by complete measurement was tried. The relative efficiency of the regression estimate versus the estimate from simple random sampling (method 1) in relation to the different sizes of grids was also worked out. In this procedure, the variance of the regression estimate may be expressed as

$$V(\bar{Y}_{lr}) = \frac{V}{n} + \frac{V'}{n'}$$

where $\bar{Y}_{lr}$=Regression estimate of the percentage area under paddy,

$$V = S_y^2 (1 - r^2)$$

$$V^1 = S_y^2 r^2$$

S_y^2 =variance per unit.

r=Coefficient of correlation between the values of area under paddy obtained by Methods 1 and 2.

n'=Size of sample to be drawn by Method 2.

n=Size of sample to be drawn by Method 1.

The total cost is $C = cn + c' n'$ where c and c' are the costs by methods 1 and 2 respectively for a single sample unit. The values of c and c' are those given in Tables 4 and 6. Optimum values of n and n' have been worked out for a given precision (5 per cent standard error) in regard to the three grid sizes and the estimates of total cost are given in Table 7. An estimate of comparable cost by the method of dot sampling is also indicated in the foot-note of the table.

The results in the table (page 10) indicate that to obtain the estimate of area under winter paddy with a standard error of 5 per cent from grid size 1″×1″ a total sample of 238 units would be required to be sampled and the total cost of study for paddy area would be

TABLE 7

Complete costs of study (in hours) in grid sampling (5 per cent standard error)

		Values of n' and n and total cost		
		1''×1''	*2''×2''*	*4''×4''*
1. Method 1 (Complete measurement of paddy area)	*n*	238	153	91
	Total cost in hours	436	434	364
2. Methods 1 & 2 (Double sampling procedure)	*n'*	281	201	119
	n	202	59	23
	Total cost in hours	675	485	330

Note. For dot sampling the comparable values of sample size and total cost would be 530 dots and 115 hours respectively.

436 hours. The double sampling procedure would be less efficient for this grid size since there was not substantial reduction in cost per unit and the correlation was also not high. In regard to grid size 2″×2″ also the double sampling procedure would involve somewhat greater cost than method 1. In regard to the size 4″×4″, the regression estimate was found to be more efficient than the simple estimate. From these results one would conclude that the grid size 4″×4″ would be the best among the three sizes tried and the cost would be minimum when a regression estimate is used. As compared to these estimates, the cost of study by dot sampling would be much less as the number of dots required to be sampled to achieve the same precision (5 per cent standard error) would be 530 and the cost will be 115 hours only.

Conclusion

A statistical study made on the photographs of the aerial survey carried out in Goalpara district revealed the usefulness of the technique of aerial photography in estimating the area under crops as also of physical features. The technique would be more useful in areas where the crop is mostly grown pure and paddy is the important crop. While the surveys have so far been confined to the plain areas of unsurveyed tracts, the question of undertaking similar surveys in

the hilly areas which are mostly unsurveyed is under the consideration of the Institute of Agricultural Research Statistics.

Since dot sampling appears considerably more convenient and cheaper than grid sampling, it deserves further study to increase its efficiency. One approach would be to stratify the mosaic suitably, say into grids of a given size and sample by dots within each grid. This might reduce the standard error of the estimates further.

Summary

This paper gives the results of a statistical study made on the photos obtained from an aerial photographic survey in Assam. Two methods of sampling, *viz.*, dot sampling and grid sampling, the latter with concentric grids of sizes $1'' \times 1''$, $2'' \times 2''$ and $4'' \times 4''$ were used for the study. By dot sampling the estimate of proportion of area under winter paddy in the tract was obtained as 45 per cent with a standard error of 7·4 per cent. Similarly, by grid sampling the estimate for the size $4'' \times 4''$ was 43 per cent with a standard error of 7·6 per cent, while for the other two sizes the precision was somewhat lower. Considering the cost of study, dot sampling was found to be the cheapest, and among grids, the grid size $4'' \times 4''$ was found to be the best unit. An alternative approach for estimating the area under paddy in sampled grids consisting of a double sampling procedure was also tried. The relative efficiency of the alternative approach was slightly greater than that of simple random sampling for grids of $4'' \times 4''$ size. Further study on dot sampling is suggested.

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