Rural Land Resources Cover Inventorying and Monitoring: An Evaluation of a Low Level Aerial Photographic Sampling Method

by

Ruben Sinange Kimanga

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presented to the University of Manitoba
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ABSTRACT

The primary objectives of the study were to evaluate the methodology in its information accuracy and consistency, timeliness, and cost-effectiveness. The information needed was on land use and land cover for eventual use in regional and national resource planning and management in Kenya. The research included literature search, aerial photo sampling of Meru district in central Kenya, and ground and photo interpretation. Guideline procedures for before and during photo interpretation were developed so as to increase interpretation accuracy, as well as reduce to a minimum personal biases in photo interpretation.

The results indicated that interpretation consistency, and accuracy were high for the extensive classes. Classes most confused with each other were detected by the use of confusion matrices and thus future improvement on classification accuracy was deemed feasible through the recommendations given. It was also concluded that the method (1) provides fairly accurate and precise statistics and maps for regional and national planning and that it is possible to improve them further; (2) it can provide the information quickly, to within a month for areas of less than 10,000km^2; and (3) it is cost-effective for the Kenyan conditions.

ACKNOWLEDGEMENTS

My training in Canada was supported by the Government of Kenya through the assistance of Canadian International Development Agency (CIDA), while my field research was supported by Kenya Rangeland Ecological Monitoring Unit (KREMU) in the Ministry of National Planning and Development. To all I am grateful. My sincere thanks go to my project and dessertation committee for their valuable counselling and guidance: Mr H.T. Pokrant of the Manitoba Remote Sensing Centre; Professor H. Lapp of Department of Agricultural Engineering, University of Manitoba; Professor R.C. Tiwari of the Department of Geography, University of Manitoba; and my faculty advisor Professor T.J. Henley of the Natural Resources Institute, University of Manitoba.

The hard work by D. Wambua and W. Muyodi, the field assistant interpreters, and our driver G. Njenga, made the field work enjoyable and a success. Their cooperation was invaluable. Thanks to many others who assisted in one way or another and I can not mention all due to space.

Special thanks to my family - my wife Phyllis and children Kemunto, Kwamboka and Bonareri for their love, perserverence, understanding and a special permission to be away from them during the study period.

GLOSSARY OF ACRONYMS USED IN THE TEXT

CIDA - Canadian International Development Agency

DDC - District Development Committee

DIP - Digital Image Processing

GIS - Geographic Information System

GNS - Global Navigation System

KREMU - Kenya Rangeland Ecological Monitoring Unit

KTDA - Kenya Tea Development Authority

LUNR - New York's Land Use and Natural Resources survey

MSS - Multispectral Scanner

Pixel - Picture Element

TM - Thematic Mapper

TVA - Tennessee Valley Authority

USGS - United States Geological Survey

UTM - Universal Transverse Mercator

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INTRODUCTION

1.1 GENERAL BACKGROUND

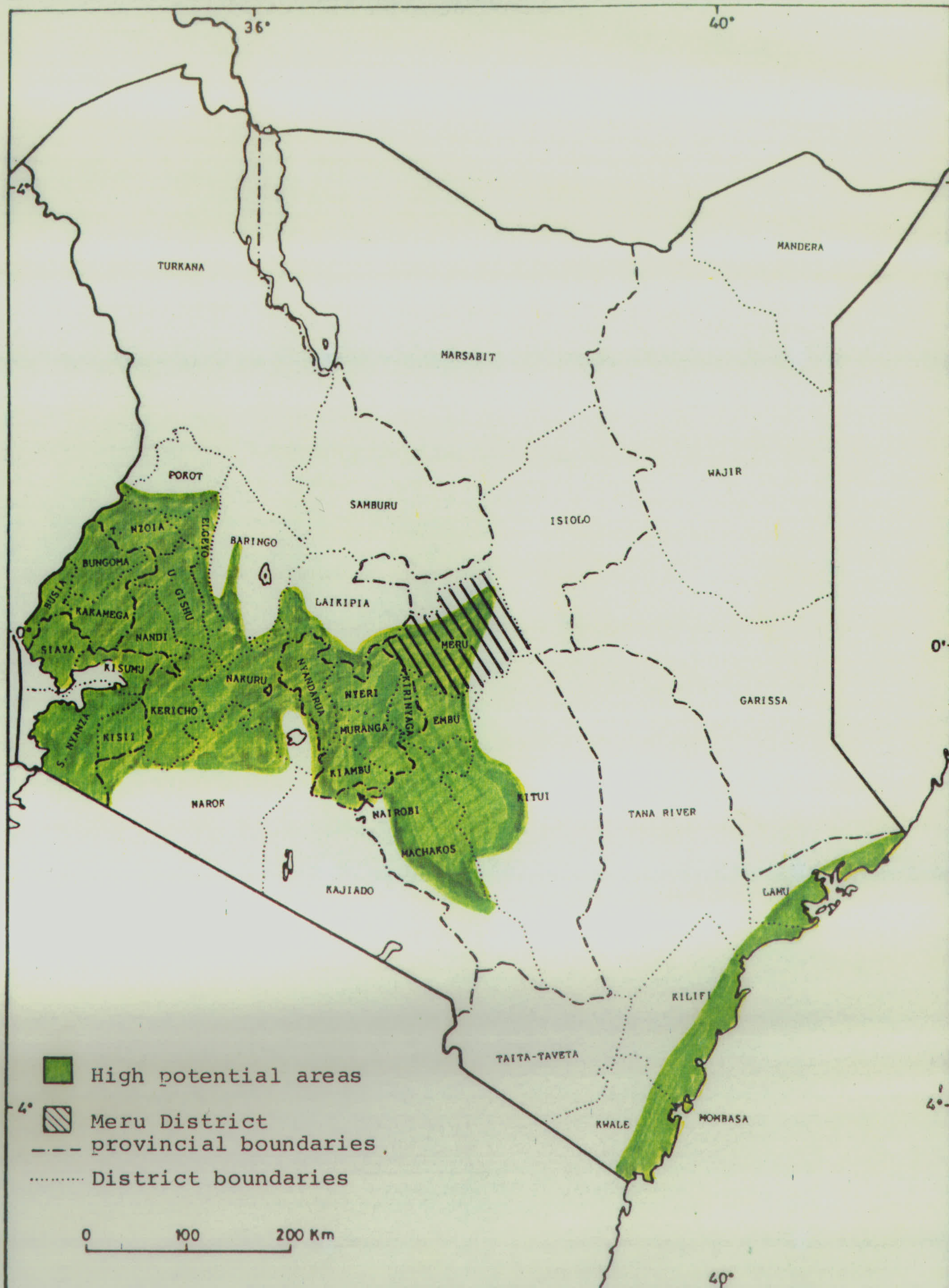
In recent years national development planning agencies have began to focus on plans that lead to provision of basic human needs rather than for more economic growth (de Man and Schaap 1979). Basic human needs include food, water, health, clothing, shelter, freedom, employment and the required political structure and infrastructures of the nation so that individuals can realize those needs. Political freedom and structure are assumed as being present in democratic states.

The distribution of the basic natural resources that provide the basic human needs are uneven, their availability often scarce, and the efficiencies of exploitation always changing. Development plans are therefore for the redistribution of the resources and efficient exploitation. Normally, a region exports a commodity which is in excess to receive another basic need which is in short supply.

For planners, demographic and natural resources data are essential to make sure that basic human needs like food are sufficiently provided and that the environment is in optimal balance with the human population. Synthesized data are what points to the planner what should be done (Campbell 1983). The improvement and adoption of a simple and practical aerial survey method for gathering natural (especially land use) resources information for Kenyan planners is the subject of this practicum.

Kenya lies astride the equator between 4^0 40'S and 5^0 02'N and 33^0 55'E and 41^0 55'E and has an area of about 647500 km^2, Figure 1. It is a country of wide regional contrasts in climate, vegetation, topography, and land use patterns - mainly due to the effect of altitude, geologic formations, cultures, and influence of the Indian Ocean and inland Lake Victoria. Three very broad physical regions readily identifiable are: the humid, hot and wet narrow coastal lowlands; the semi-arid to arid region which is dry, hot, with erratic rainfall of below 600 mm and which comprise about 75% of Kenya's area; and finally the highlands which are cool, wet and mostly above 1500 m elevation. Together with a narrow coastal strip, the highlands form the high potential areas and are the bread basket for the whole country; comprising approximately 20% of Kenya's land area but contain over 80% of the population, Figure 1. Population density as high as 500 per km^2 occur in some areas of the highlands. Thus the importance of the highland to Kenya cannot be over-emphasized. Land and what it provides is the most important resource in Kenya. Similar variations are evident within several administrative districts.

Figure 1. Map of Kenya showing agricultural areas and Meru district.



Demographic information from the 1979 national census indicated Kenya had a population of 15.2 million (Kenya 1980) and in mid-1984 was estimated to be 19.8 million (Goliber 1985). The country's population growth is one of the highest in the world at approximately 4% per annum. This population growth rate has put pressure on the land and led to very rapid changes in land use patterns in Kenya. As a result, a large number of excess population are moving into drier rangeland areas and introducing new land uses in those regions (Bernard 1985). Changing habits, tastes, and product prices in many of Kenya's regions and communities are also rapidly altering regional land use activities. Productivity of any area however, depends on the physical environment, stress on the land, and husbandry.

Beginning in the 1983/84 fiscal year the development planning process was decentralized (Kenya 1983). A District Development Committee (DDC) became responsible for planning, implementation and execution of each district's development programmes except for certain specified national and trans-district programmes which remain in the jurisdiction of the central government. The policy directive from the central government was that the districts should use local resources optimally and minimize external sources of support.

Accurate environmental and resources information for development planning therefore became a goal and a priority for each district.

1.2 GENERAL PROBLEMS

As pointed out, a planner requires reliable information (maps and statistics) on land resources to formulate development plans. A surveys scientist, who supplies the information, has to make a choice from six main categories of methods which to use in surveying the study area to provide the required information:

1. historical information from literature, records and maps;
2. ground surveys on foot using basic topographic or planimetric maps to record land use on every parcel of the land area being surveyed;
3. questionnaire sampling as variously practiced by different countries and organizations for example the Canadian National Farm Survey (Horn et al 1984), the Kenya small farm survey (Kenya 1977), and Nigeria's cluster agronomic and agroeconomic surveys (Nigeria 1984);
4. low altitude aerial survey methods from approximately 90m to 3000m above ground level using various sensors for example: visual methods, or cameras employing black and white or color films;
5. high altitude photography from 3000m to 15000m above ground level; or
6. very high altitude satellite remote sensing using digital multispectral scanner (MSS), thematic mapper (TM), or SPOT imagery.

Any of the above methods or a combination of any of them can be used to generate the information needed by the planners. The method(s) chosen, however, depend on and revolve around six main criteria or determining factors; all intricately interconnected:

1. Costs. The affluence of a planning authority may determine several things on data gathering. A very poor authority may do planning with little or no information, while an affluent one will use the most accurate methods to acquire the information on a continuous basis.
2. Technology Available. The technology here concerns sensors, platforms, analytical tools, maps and mapping technology. The most primitive sensor available is the naked eye, and progressively advance in sophistication through the camera and film types to the spaceborne electronic multispectral scanners (MSS), thematic mapper (TM) and SPOT. Platforms also range from the primitive foot and vehicles on ground through balloons, aircraft and satellites in space. The analytical tools available are an important component. These include manual, stereoscopes, computer hardware and software including the recent Geographic Information Systems (GIS). Base maps at appropriate scales for surveys, field checks and plotting the information are essential for resource surveys.

3. Nature of Study Area. What is the terrain like? Are communications adequate for ground work? What is the intensity of land utilization? few large farms with one type of crop or numerous very small farms with many types of land uses? In that case which sensors and platforms are most appropriate?

4. Time Available. Time available is a function of the objectives of the survey. Many ad hoc reconnaiscence surveys, for development of specific areas for specific goals, generally are urgently required and take shorter periods depending on area and detail required. Inventorying and monitoring projects on the other hand require more time for planning and experimentation before committing implementation. Normally over two years, depending on area and detail, are required.

5. Purpose (or Needs) of Study. What is the information needed for? For an irrigation development plan? For a wildlife reserve creation? or is it for regional and national development plans? In that case what level of accuracy is needed? Would there be a need to count every tree in the forest and indicate its geographical position?

6. Manpower. Is trained or trainable manpower for photographic interpretation, cartography, and computer analysis available? This normally is associated with costs because hiring expertise is possible from any part of the world.

In many instances cost overrides all other factors. The other five criteria take the scientist closer to the method(s) he should use in his particular situation. The first basic problem therefore is choosing the right method for a survey for a particular need and situation.

Kenya's ministry of national planning and development has chosen to try a low altitude systematic photographic sampling method to acquire information on crop types, cover, distribution, and trends for land use and land cover mapping as well as for regional and national development planning. The greatest influences which led to the adoption of the sample photography method were mainly the nature of the study area which is very varied in terms of land use and land cover types; terrain and communications; the ministry already had appropriate facilities especially aircraft platforms for the photography as well as computer and cartographic facilities; the method was not manpower intensive and therefore did not require additional recruitment; and finally the objectives of the methodology fitted well in the long term national aspirations of development planning.

Figure 2 is a simple model on how the method fits in the overall development programme. Each photo sample point is interpreted to give data on land use types. Analysis of the data provides (1) a map on the distribution and intensity of each land use and land cover type as well as (2) overall statistics on the percent cover or hectarage of each land use and land cover type. These two information types together with extra information from other sources can ultimately be used to assess and estimate expected crop production.

The planner then uses this basic information to propose development plans to increase or lower production [1] through the application of various stimuli for example, infrastructural developments; encouraging increased crop cultivation in certain areas; educational extension programmes on proper husbandry directed to certain areas or social groups; and commodity pricing policy changes.

The planner (or any other user of the data), however, might question whether that data, on which plans are based, are accurate and precise. In science one demonstrates the reliability of results through detailed description and logics of the methodology and statistics of confidence. And here lies the second problem for the scientist --- the reduction or removal of technical flaws associated with the chosen methodology. Four main stages identified as problematic in the method outlined above are as follows:

---

[1] Farmers are discouraged from growing coffee in the marginal areas. Farmers in the same areas are encouraged to grow the correct variety of maize for the area while at the same time the government has been increasing the price of maize. This is an example of lowering and and increasing the area under a type of land use so desired.

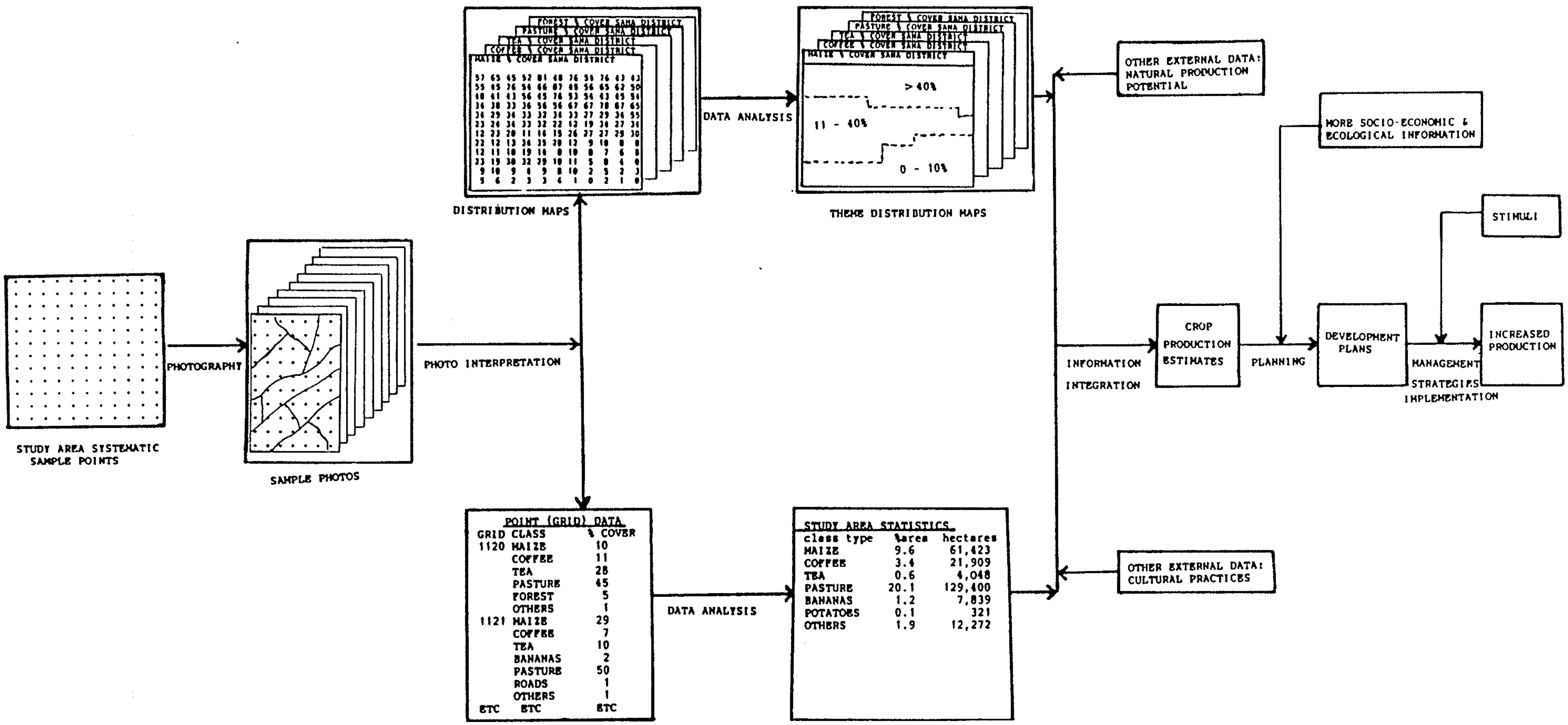


Figure 2. Model for information collection using
low level photographic sampling method

1. Sampling. The sampling methodology and intensity chosen often need justification. Sampling can be random, systematic or any combination of these, at a sampling fraction of from near zero to 100%. In the present methodology what needs to be described and justified is:
   (i) why photo samples were systematic;
   (ii) why dot samples on photos were systematic;
   (iii) the optimum dot density; and
   (iv) the optimum sample fraction.
2. Photo interpretation accuracy and consistency. This is normally answered through field checks. For example, it is possible that only 38 out of 50 fields were correctly identified in a photo analysis performed for a project. Field checks also identify the classes most confused with each other as well as the best interpreters. There are three main causes of photo misinterpretation:

   (i) Photo Resolution. This depends mainly on camera lens selection, flight elevation, film type, and sun angle;

   (ii) Interpreter. Training of the interpreter and familiarity with the study area are very important to avoid misinterpretation; and

(iii) Classification and Definitions. Description of land use classes in a hierarchical level has been found useful (Anderson et al 1976). Description of the classification to the lowest and specific details help clarify certain uses which can cause confusion. For example, is a field harvested of corn yesterday, a corn field or fallow land? What land is fallow --- one which has been lying unused for one year, two years, or four years? What is the difference between a bush and a woodlot? These must be clarified if interpretation has to be very accurate.

3. Field Verification Sampling. How many samples will give a reliable assessment of the interpretation accuracy? And, how many dots per land use and land cover class is also optimum?

4. Zoning Boundaries. How accurate are the boundaries in describing the land use zones so delineated? Which method was used to draw the boundaries? the naked eye? or some type of trend surface analysis?

1.3 SPECIFIC PROBLEM STATEMENT

1.3.1 Needs

A land use and land cover map of Kenya which gives a general regional crop mix and vegetation cover types has been documented using landsat imagery, local reference knowledge and field checks (Agatsiva and Mwendwa 1982).

Specifically however, among other things every DDC would ask these specific questions about food supply:

- What food crops are in the district?
- How much of each crop is (or can be) produced?
- Where in particular in the district is each produced?
- What are the trends in the crop's production, quantitatively and spatially?

1.3.2 Hectarage Estimation

Accurate information on the above questions would give the planner insight about the state of food supply and areal distribution within the district. A series of comparable surveys over a long period would show the areal spread and trends of a crop.

Land productivity, however depends on several factors including soils, climate, seed variety and husbandry. The productivity information should soon be available for the whole country through the Ministry of Agriculture which has reached advanced stages in an attempt to document crop productivities and requirements as well as revising agroclimatic regions for the whole country (Jaetzold and Schmidt 1982). Concurrently there are research efforts by KREMU in establishing procedures of estimating crop vigor and therefore estimated crop yields using airborne digital photometers. To accurately estimate district yield, crop hectarage within each physiographic or agroclimatic region must therefore be mapped precisely.

1.3.3 Real Time

The information must be acquired in time for either the one-year or five-year regular national development plans, whichever is the target. Capability in acquiring the information within one month, however, is also an important requirement, particularly during disaster times. For example, the rains either wholly or partially failed in a large section of the Kenya highlands when normally expected between March and June 1984. As a result the government then wanted two sets of information: expected yields of the staple crops at the end of the growing season and estimates of national stores. A plan for new food strategies could then be initiated if necessary. This information was needed within a space of two months. The solution to this problem required an accurate sampling method using an existing accurate map of the major growing areas of the crops in question. With this information in hand, planners could then have moved straight to the relevant areas to assess the situation.

1.3.4 Costs

The information gathering must also be cost-effective. The nation is developing and the diversion of a large sum of money to gather data normally is not well accepted by many administrators and politicians. It has been demonstrated however, that a good data base leads to good planning and planning without data is a risky venture. The first land use survey of Britain, for example, in the 1930s revealed a lot of land misuse and led to a 1947 Town and Country Planning legislation. The second land use survey of Britain in the 1960s indicated areas of rural-urban encroachment zones and should be a guide for planners new strategies (Coleman 1976). Vente (1970) gives some general historical examples in East Africa which emphasize the necessity of adequate data and planning for development projects.

Apart from information on food crops, planners have similar requirements for other land use and land cover types. For example: distribution and production of commercial crops; grazing lands and livestock in the intensive agricultural areas; rangelands and wildlife; and forestry and forest lands. The district development authorities will also ask about implications of how changes in any of these land uses and land cover types affect others. This is the type of information needed which will lead to planning and development of infrastructures and services for the distribution of the basic needs.

Priority of the surveys have initially been given to the districts within the agriculturally high potential regions where there is acute demand and pressure on land resources (Figure 1). The surveys will most probably gradually move outwards to the marginal districts.

From the above discussion it is obvious that there are a multitude of problems pertaining to the choice of an appropriate methodology. This practicum was delimited to three only. The problems, therefore, were whether the chosen methodology delivers precise and accurate information, and whether the delivery is relatively timely and inexpensive.

1.4 OBJECTIVES

The main aim of this project was to evaluate the low altitude aerial sample photography as a rural land use and land cover inventorying method which could equally be useful in monitoring land use and land cover trends. The goal was therefore to demonstrate whether the method does or does not yield sufficiently reliable and detailed distribution patterns of land use and land cover types for regional and national development planning.

Specifically, therefore, the objectives were to evaluate and assess the method in:

- giving accurate crop hectarage estimates;
- giving accurate crop cover zones;

- giving timely results;
- its cost-effectiveness;
- its capability in being used to map all types of land use and cover across the country;
- its capability in giving comparable and specific geo-information so that results from all districts could eventually be juxtapositioned or aggregated to give a countrywide picture of the resources; and finally
- being bias free. The method was designed to remove subjectivity entering into the data collection. The method was also designed to overcome the disruption of manpower turnovers in institutions; if an individual should leave, another would smoothly continue with the project and results should not be affected by the change in personnel. An attempt was therefore made to detail the methodology in a manual of standard procedures.

By analysis and intuitive deduction, the mapping could indicate areas of land use conflicts, lands with potential soil erosion, and suitable areas which need further development for optimal productivity.

1.5 IMPORTANCE OF THE STUDY

This project had implications of interest to several agencies in the Government of Kenya and in particular Kenya Rangeland Ecological Monitoring Unit (KREMU). Approximately eight years ago KREMU was formed to make an inventory and monitor major resources in the rangelands. From 1982 the mandate was widened to include the agriculturally high potential highlands and lowlands which were previously outside its mandate. The Ministry of National Planning and Development to which KREMU belongs oversees the DDCs. KREMU, as a central agency, is therefore charged with the responsibility of providing the right information to the DDC's through the development of scientifically acceptable methods. Development of methodologies was emphasized as one of the main responsibilities of KREMU in the 1983-1988 national development plan (Kenya 1983). The target primary users of the information generated by the present method are therefore the DDC's.

When examined on a countrywide basis and compared between districts the information so gathered becomes of vital importance to national planning and policy directions through the ministries of:

- National Planning and Development;
- Energy and Regional Development;
- Agriculture and Livestock Development;
- Natural Resources (Department of Forestry);
- Tourism and Wildlife Conservation and Management; and
- Presidents Office (Commission on Soil Conservation).

In addition, the information should be useful for scholarly geographical information analyses in academic environments.

1.6 STUDY AREA

The study area was Meru District. It lies between 0^{0} 40'N and 0^{0} 28'S and 37^{0} 05'E and 38^{0} 28'E, Figure 1. Meru was chosen as a prototype because of existing wide variations in physiographic regions and land uses. Physiographic regions range from lowland dry scrublands to high mountain forests, moorlands and ice-capped Mt. Kenya. Land uses vary from wildlife parks and pastoralism to intensive agriculture and extensive forestry. Geographical analysts have also recognized that there are extensive land use changes taking place in the district with people migrating to marginal areas and attempting cultivation (Bernard 1972,1979,1985; Wisner 1977; Campbell 1981). Plates 1-12 are a sample of the many landscapes found in the district.

1.7 SUMMARY

This chapter outlined the need for land use surveys in respect to resource development planning in Kenya. The criteria used in choosing any one or a combination of methodological approaches to surveying were also discussed. A focus on several problematic areas in the photographic sampling methodology was given in which special attention is needed so as to get reliable results.

The next chapter outlines the historical development of land use and land cover surveys in a world-wide perspective to show state of the art in this field at a glance; identify reasons for lack of uniformity in survey approaches and also identify gaps in the area of aerial survey methods. This will then be followed by detailed description of the method applied in this study, after which the results, discussions, conclusions and recommendations will be presented.

PLATES 1-12

1. Aerial view of the high potential agricultural areas with plots under different crops - tea and coffee included.

2. Oblique of the same as (1) above.

3. Farm with bananas , coffee, tea and a homestead.

4. Natural forest in the high potential areas.

5. Edge of forest with agricultural land - tea and bananas in the foreground.

6. Aerial view of the transiton area as one moves from the high coffee zone towards the rangelands. The plate has few coffee plots the rest is mostly maize.

7. Oblique of same region as (6) above - farms are mostly under maize.

8. Aerial photo of the rangelands invaded by new cultivation.

9. Aerial photo of even drier areas than (8) above also newly invaded by recent cultivation.

10. Bulrush millet and sorghum farming in the rangelands.

11. LIvestock raising is a common activity in the rangelands.

12. Wildlife (Zebra in the foreground) in Meru National Park - a rangeland area.

PLATE 1

PLATE 2

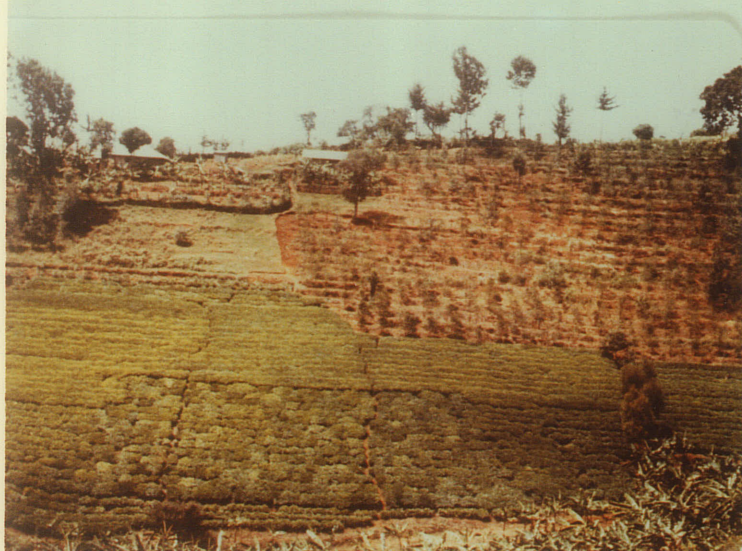


PLATE 3

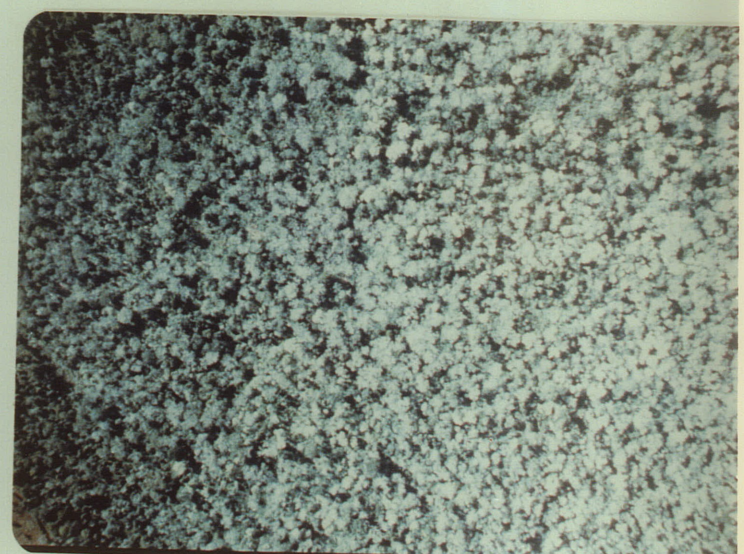


PLATE 4

PLATE 5

PLATE 6

PLATE 7

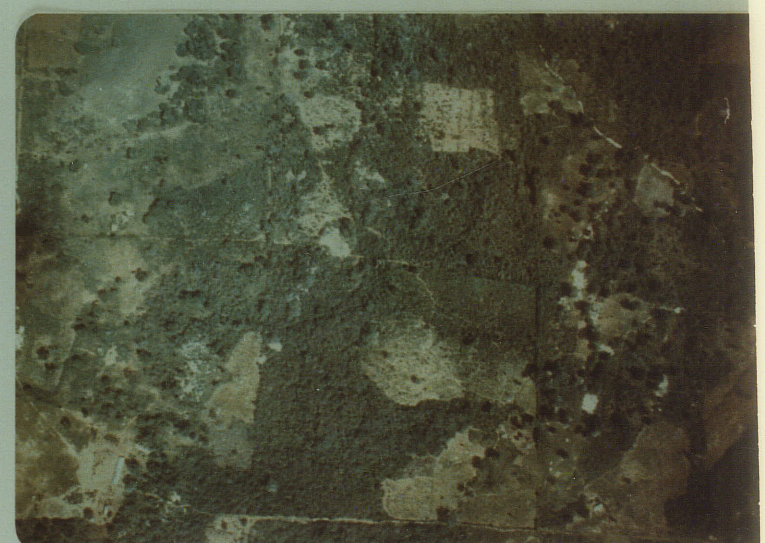


PLATE 8

PLATE 9

PLATE 10

PLATE 11

PLATE 12

Chapter II

REVIEW OF RELATED LITERATURE

The subject of land use and land cover invariably implies maps and statistics. Its development is therefore closely associated with the historical developments of planimetric and cadesteral mapping technologies as concerns property and territorial ownership. This chapter will initially survey the development of land use and land cover mapping in the context of the history of mapping and then trace the reasons for variations in study approaches to the subject. This will hopefully demonstrate the youthfulness of this science and that still there is no one commonly accepted approach to the surveys.

The latter part of the chapter will focus on the sample photography approach to identify advantages and gaps in it.

Wallis (1981) has traced the origin of land use mapping to the earliest cadesteral plans of ancient Babylon and Egypt in the 2nd and 3rd millenia BC; rudimentary topographical maps of England in the 15th and 16th centuries; property surveys in England and France in the 16th and 17th centuries; cadesteral and topographic mapping of England in the 19th century; and the city plans and insurance maps of the 19th century in Europe and Northern America. These maps depicted various aspects of land use on them not as a primary aspect of the map but to help describe the bounds of the land mass and main feature of concern. These led to the production of the first true land utilization map ever for the city of London and surrounding areas in 1800 by Milne. Milne was 130 years ahead of his time in cartographic techniques for land use mapping. The map drawn with boundaries, had 17 different types of land use distinguished by keys and hand colouring applied to each polygon --- the desired features in modern land use mapping. Not until the 1930s was a similar land use mapping of Britain done at a large scale (Stamp 1962).

The 'Domesday' survey, however, of 1085 - 1086 AD for the whole of England, ordered by King William the Conqueror, could be about 900 years ahead of its time. It accomplished what to this day has not been possible in terms of speed; combination of both land use and demographic data in a single survey; land use change records; and aspects of detail and accuracy of the data collected. The purpose of the survey was most probably for expanding scope and efficiency of the government administration as well as compilation of data to be used as a means of assessing resources subject to taxation. Thus the phrase "domesday". The survey covered 13,000 villages throughout the country within a period of two years. Campbell (1983) writes:

> The inquest recorded the names of manors, numbers of freemen, villeins, cotters, and slaves, resembling a modern demographic census. Also recorded

> were acreages of plowland, meadows, pastures, and the number of and sizes of fishponds. In this sense, the Domesday Book resembles a modern land use survey. The royal inquest also recorded ownership of land at three separate dates: (a) during the reign of Edward the Confessor [before January 1066] (b) at the time of the conquest [October 1066], and (c) in 1086, at the time of the survey.

No maps were made then, but have been constructed in retrospect using the great details in the Domesday Book.

Not until 1931 - 1938 was another national land utilization survey conducted for Great Britain (Stamp 1962), although not for taxation. Stamp op. cit. and Campbell (1983), discuss the history of land utilization in Britain prior to 1930 and the factors which led to the initiation of the first land utilization survey of Britain in the 1930s. This was mainly due to concerns expressed by contemporary British geographers to an obvious misuse and lack of planning in the lands of Britain.

Campbell (1983) and Rhind and Hudson (1980), on the other hand, have traced the evolution and spread of modern land use and land cover mapping mainly since the 1930s,an attribution to L.D. Stamp. The surveys, since then, have differed in approach from region to region and changed over time. The differences in their forms and organization have been due to <u>purpose</u> of the survey and ever changing <u>technology</u> in the collection and manipulation of the data. These are reflected in the first and second land utilization surveys of Great Britain by Stamp 1931-38 and by Coleman in the 1960s respectively; the land classification of the Tennessee Valley Authority (TVA) in the early 1930s; the World Land Use Surveys in the 1950s conducted in several parts of the world; Marschner's land use survey of the USA in the 1950s; New York's Land Use and Natural Resources (LUNR) survey in the 1960s; and the United States Geological Surveys' (USGS) land use and land cover mapping program which started in the late 1970s.

The other causes of the surveys' differences are really generic from purpose and technology, and have stemmed from lack of consistency in the definition of the term "land use" and a common classification of land use types. The classification details are especially influenced by the means by which the data is gathered. Thus the classification suggested by Anderson et al (1976) has gained wide acceptance for adoption due to the increasing use of remote sensing in the collection of data. Details of definitions and classifications as causes of confusion are also treated by Anderson (1961, 1971), Burley (1961), Campbell (1983), Dickinson and Shaw (1977, 1978), Rhind and Hudson (1980), Stamp (1962), and Scace (1981). And as yet there is not a complete agreement on any one particular system even within one country (Scace 1981).

There is a massive amount of literature on the techniques of land use mapping using satellite imagery since the early 1970s and even in anticipation of the launching of Landsat

1. The enthusiasm generated high expectations of satellite technology which tended to overshadow high altitude photography which had been making headways in the previous two decades in the field of land use mapping. However, in 1977, the USGS embarked on a 6 year program of land use mapping of the whole of the USA using basically high altitude photography. Total coverage of the USA land mass to the highest accuracy was intended but because of photo resolution and scale of working base maps (1:250,000 and 1:100,000), land use and cover types of less than 4 hectares for urban and 16 hectares for rural areas could not be mapped (Rhind and Hudson 1980). Anderson,s et al (1976) land use and land cover classification was the recommended system to be used throughout the project. When the USGS program is completed the USA will probably be the second country to ever have a baseline total coverage of land use maps. Great Britain is in the process of planning a third.

Great Britain was totally covered using ground survey in the 1931-38 period led by Dudley Stamp. The second, led by Alice Coleman, started in 1961 and took about 10 years to complete. The planning of the third one has generated some controversies about the methodological approach. Since there already exists the baseline land use maps, it has been argued that aerial photo sampling be used to monitor changes (Dickinson and Shaw 1978). The argument rests on the fact that planners do not always need data to the accuracy and detail generated by complete ground coverage surveys.

On the other hand it has been claimed that the strong movement towards remote sensing sample mapping as opposed to the Stamp method of comprehensive ground coverage is partly a craving for academic sophistication where it can still be applied (Coleman 1980). Coleman op. cit. emphasized that the Stamp method is superior in every way wherever it is applicable because it is inventory oriented; identifies accurately all use and cover classes present; area of resolution is best; it is very accurate in mapping and statistics; and as well claimed that it is over 5 times financially cheaper than using photography, (at least in Britain).

The conditions in Kenya would make such a survey very difficult. The land tenure system in Kenya allows a titled land parcel to be subdivided into as many pieces as there are inheritors. This tenure system has led to some parcels of land held per household to be smaller than one hectare. In such a parcel, a family may grow a variety of crops such as maize, beans, potatoes, and coffee. A few head of livestock are also occasionally kept. The resources needed to record such information in details would be formidable in terms of organization, personnel, communications, number and availability of maps at appropriate scales, and other costs. The extraction of such detailed information from landsat digital data would also be difficult because of the image resolution (79m X 79m). Digital analysis, on the other hand, would be relatively simple in say, the prairie region of

North America with large farms growing few major crops (Horn et al 1984). Landsat is also useful in delineating broad land classification for example between agricultural and forest and rangelands (Ochanda et al 1981), or the analysis of vegetation types in the rangelands (Epp and Agatsiva 1980).

Land use, land cover and land evaluation studies using total aerial photography coverage have however been common for specific regional development projects like river basin development studies, irrigation projects, habitat or vegetation mapping and the demarcation of parks. The use of this type of photography in land use studies properly took form and increased after Second World War (Rhind and Hudson 1980).

What seems to have not been tried anywhere at a large scale, however, is generating the baseline data from photo samples. The program being tried in Kenya (Epp et al 1983) has few precedents for comparison and therefore need to be evaluated carefully. The closest was concurrently being tried in Nigeria (Bauchi 1984; Nigeria 1984). Thomas (1970) has tried a relatively similar method in mapping London's green belt.

The method has been suggested before but not applied to large scale projects (Robertson and Stoner 1970; Frazier and Shovic 1980; and Berry and Baker 1968). Berry and Baker

(1968) particularly advocated this method and illustrated the theoretical and statistical treatments of the data derived from different sampling procedures. Fitzpatrick-Lins (1981) and Rosenfield (1982) discuss in detail sample distribution, sample size, and sampling procedures. Chorley and Haggett (1965) , Cliff and Ord (1981), and Lam (1983) discuss methods of presenting such data in map form; while Frolov and Maling (1969) demonstrate that statistical accuracy increases with the increase in number and distribution of sample units. And there are much stronger arguments particularly for systematic sampling than other sampling procedures, for it produces better distribution maps, lower standard errors, and is easier and faster to administer, (Bauchi 1984, Nigeria 1984, Coleman 1980).

The interpretation accuracy of such aerial sampling data has recently been of major concern and is discussed in several papers such as Hay (1979), Ginevan (1979), Genderen (1977), Aronof (1985), Hord and Brooner (1976), Kalensky and Scherk (1975) and Kalensky et al (1978). And not all agree in their details of statistical approaches to the measurement and evaluation of interpretation accuracy. The discussions of these papers are based on the accuracy of photo interpretation for photography and satellite imagery applied to total coverage mapping where the interpreters go to the field for 'ground truth' sampling. This approach was adopted and made applicable to sample-photo surveying and mapping.

Sources of inaccuracies due to misinterpretation and ways of rectification are discussed in details by Campbell (1978, 1983), Baker et al (1979), Rhind and Hudson (1980), and Nunnally and Witmer (1970). Kalensky and Scherk (1975) proposed four categories of accuracy evaluation methods all expressed as percentages: classification accuracy for each class; overall weighted classification for each class; mapping accuracy for each class; and overall weighted mapping accuracy. Classification accuracy is the ratio of correctly classified points out of the total true number of points belonging to the class, and is the most important in interpretation accuracy evaluation. Kalensky and Scherk op. cit. emphasized that

> the overall weighted classification and mapping accuracies may be strongly affected by one or two classes which are large in their areal extent but have little economic importance. In such cases , the overall accuracies would reflect the map accuracy but not its usefulness and should be replaced or complemented by overall weighted classification and mapping accuracies calculated for the significant classes or areas only.

None has definitely set the levels of accuracy and consistency to be achieved except for the USGS which has set a minimum of 85% accuracy (Anderson et al 1976). This is probably because different studies and projects have different objectives and need different acceptance levels of accuracy. However it is necessary to set up standards for any particular project so as to achieve best results.

Cost-effectiveness (that is least-cost approach) relative to other methods would therefore be difficult to derive, for it is rare to find different methodologies used in similar environments and situations and for the same intended end results. At times it is even inappropriate to compare certain methods for the same area because one of them may not even be applicable, as described above for some parts of Kenya in the case of Landsat.

It is also true that when different approaches give different details of the needed information the long term benefits from each approach should be evaluated so that when cost-effectiveness analysis is being carried out one does not compare methods which are disparate and meant for different purposes.

Cost-effectiveness of surveys at different sampling intensities is however theoretically possible as discussed by Robertson and Stoner (1970) in which they concluded that it is possible to estimate a compromising level of sampling intensity and minimum possible costs. Costs of total coverage photography at different altitudes is discussed by Ulliman (1975) in which he reckoned that there are seven factors which are most involved when one is contracting or biding for an aerial photographic survey:

1. Internal to firm
    a. Business activity
    b. Depreciation
    c. Insurance
    d. Facilities available
2. Personnel
    a. Management

   b. Crew
   c. Lab personnel
3. Equipment
   a. Aircraft available
   b. Cameras, lenses, filters etc
4. Specifications of contract
   a. Area coverage
   b. Type of photos (vertical, oblique)
   c. Camera, and lenses specifications
   d. Film type
   e. Stereo coverage (overlap)
   f. Standards of accuracy (crab, tilt, drift, flight line positioning, and orientation)
   g. Final product (negatives, prints, mosaics furnished)
5. Physical elements
   a. Weather
   b. Season (ground conditions)
   c. Conditions of vegetation
6. Flying
   Distance to project area
7. Processing
   Distance film shipped for processing.

These factors still remain relevant for any institution anywhere except that some will weigh more than others for different areas. To effectively compare costs of different methodologies these factors should be enumerated and correctly accounted and costed. This would be a whole project on its own. Secondly, some of these information items are kept classified for different reasons by different institutions. Sometimes capital costs of equipment or personnel hirings in an institution are not solely for the project in consideration and therefore real costs may be under- or over-estimated. It has been claimed before, for example, that the research that went into and the launching of Landsat satellites were extremely expensive and were highly subsidized by the USA government and therefore proper costing of the imageries were not given. Rhind and Hudson (1980) also review briefly the difficulties of comparing costs of different methodologies. The recent move to commercialize the Landsat products may lead to a fairer reflection of its proper costs.

However, certain assumptions on some of the factors (Ulliman op.cit.) are possible so that a few can be used to compare different approaches to a survey. For example, if one institution were to compare the costs of different approaches to survey an area certain factors can be assumed constant - e.g. factors 1, 2, 5, 6, and 7 in Ulliman op. cit.

Timeliness, although sometimes closely connected with project costs (methodological approach and equipment), is normally important for other reasons. This is especially so in times when natural disaster strikes and an urgent assessment of the situation is needed. Timeliness of the photo sampling method is inadequately covered in literature but is briefly discussed by Robertson and Stoner (1970) and Epp et al (1983). Crop hectarage has been estimated intermittently in the past using a few clusters of households scattered over Kenya (Kenya 1977). The method incorporates a questionnaire type of sampling survey. This method is commonly associated with late reporting of results (Nigeria 1984).

There are other inherent weaknesses and inconsistencies in the cluster method from region to region, between the interviewers, between those interviewed, and from season to season. The method would monitor land use changes only in the established clusters and would ignore areas which were not agricultural in 1975 when the project was initiated and therefore is unrepresentative. The clusters system may also give indices of trends about the clusters themselves but will not give an empirical total number of hectares of any crop in the region, nor the distribution pattern of the crop. Accuracy, precision, repeatability and timeliness are therefore major disadvantages of the cluster method.

Epp et al (1983) of KREMU photo-sampled Kisii District, Kenya, at 5km intervals. The land use classes proportions from all the sample in an administrative unit were aggregated and averaged for that administrative unit. These average proportions were then used to estimate the area under each land use type in the administrative unit but no attempt was made to show distribution patterns independent of administrative units. The present study was envisaged as an improvement over the Kisii study in accuracy and mapping techniques as well as assessing its relative advantages especially in timeliness and costs. The Kisii report only gives a listing of land use and land cover classes and their cover proportions in the administrative district and subdistrict locations.

Chapter III, which now follows, describes the methods used in Meru District in order to achieve the objectives set out in Chapter I as well as set out the framework of the method itself in details. But it should be born in mind that details of the photographic system can be varied according to project requirements.

Chapter III

METHODS

The method entailed multistage sampling techniques using low altitude aerial vertical photographs. The district covering approximately 9850km^2 was divided into 5x5km square sampling units using the Universal Transverse Mercator (UTM) grid system and east-west sampling flight lines were placed 5km apart. Two sample photographs were taken systematically at every 2.5km UTM grid intersection in the high potential region and at 5km in the marginal rangelands. Flight height was approximately 610m above ground level. Navigation was performed using the Global Navigation System (GNS) fitted in the twin-engine Partenavia aircraft.

The photographic system used was a 35mm Nikon F3 camera with a 20mm lens and 35mm ektachrome 200 slide films. This gave positive transparencies covering approximately 720 x 1080m on the ground, with a scale of 1:30,000. The positive transparencies were overlayed and fixed with 91 (7x13) systematically placed dots on a transparency and observed under a hand held slide viewer or sometimes projected onto a screen. Crop and other cover classes coincident with each dot were identified by photo interpretation. The area covered by each class type was then estimated by the proportion of dots for that class type to the total number interpreted in the 5x5km sample unit and expressed as a percentage. This was the basis for the construction of overlays for each class type in terms of distribution, density, and crop mix zones.

A framework of procedures for regional and field familiarization before and during interpretation were established and followed to increase accuracy and consistency in photo interpretation. Before actual district-wide photo interpretation began these preparatory procedures involved literature review; increasing relevant local knowledge through discussions; choosing one or two training photo samples and making trial runs on them in interpretation and then ground checking them for every major ecological region in the district. This last exercise enhanced the three interpreters' familiarization of the land use and land cover classification system which was being used. Procedures were also laid down on how to classify dots falling on non-pure class types like mixed fields, field boundaries and single trees to avoid personal bias.

The identification of land use and land cover types for every dot on the photograph was done for at least the first three levels of classification levels as described by Anderson et al (1976) and modified for local conditions. Accuracy and consistency of identification of class types were assessed using 'confusion tables' as outlined by Kalensky

(1975,1978) and linear regression analysis between photo interpretation data and field sample checks data, at every level of identification using class aggregate data of every photo-sample field checked. The correlation coefficient was considered a measure of consistency in interpretation. Near perfect interpretation would have a regression line of y = x and a correlation coefficient (r) > 0.90.

Mapping was done using Map Analysis Package (MAP) a Geographical Information System (GIS) software developed at Harvard and Yale Universities (Tomlin 1980, 1986).

The low level aerial photography method avoids the problem of satellite imagery delays since Kenya does not have a receiving station. The method also avoids the difficulties which would be met in analyzing satellite imagery in the densely populated and heavily utilized highlands. Assessment of timeliness was based on estimates of time taken from the start of the field survey to the time of first preliminary results.

A study in southern Alberta, Canada, indicated that the use of satellite imagery is not always very significantly cost-effective compared to conventional photography for the acquisition of similar data (Marczyk et al 1984). At same time a cooperative study is continuing in Manitoba, by the Manitoba Remote Sensing Centre, Department of Agriculture and Statistics Canada, to estimate the annual crop area using Satellite imagery, sample questionnaire survey, and field checks (Horn et al 1984). A comparison of the method discussed herein and the Manitoba's was attempted. Costs of the projects were discussed.

Costs of the survey at different sampling intensities per unit area were calculated and compared with costs of satellite imageries (assuming they were applicable).

Extensive literature and independent data sources were often used where available to compare and check the validity of the method's results, and thus gave an indication of its accuracy and effectiveness.

Chapter IV

RESULTS AND DISCUSSIONS

4.1 ACCURACY,CONSISTENCY AND AREA ESTIMATION

For accuracy and consistency tests twenty-seven (27) photo samples, each with 91 dots, were interpreted and ground checked by each of the three photo interpreters. The dots overlay method was used in assessing their interpretation accuracy and consistency. Each dot was fixed and examined by each interpreter and therefore making it possible to compare their performance.

4.1.1 Interpretation consistency and accuracy

Correlations were carried out between photo interpretation and ground truth for those class types which had sufficient data and occurrence. This was performed for the three interpreters separately as well as for the three combined to give an average. Figures 3 to 7 illustrate this for the land cover types maize, coffee, cultivated lands, pasture, and bushlands. Each dot on the graphs (Figures 3-7) represent a photograph interpreted and ground checked; and each photograph had 91 dots. The axes represent the percentage of the 91 dots which belonged to the class type as interpreted from the photograph (x axis) and the percentage of the 91 dots which truly on the ground belonged to the class type (y axis).

Consistency was found to be high and fairly similar between the three interpreters as discerned from the regression equations and correlation coefficients (r) (Figures 3-7). All the equations were close to y = x and r ranged from 0.88 to 0.99.

Classification accuracy (i.e. the interpretation accuracy for a class) was the percentage of correctly identified points out of the true number of points in that class. The interpretation accuracy test, Table 1, showed that land under cultivation as a class was interpreted with an average accuracy of 86% with r=0.94; improved and unimproved grazing lands (pasture) 78% with r=0.92; bushlands 80% with r=0.95; and forests 91%. Most of the balance of the third level classes had few (<50) dots and photo sample occurrences. The overall classification accuracy of the classes in table 1 was 82.4%.

For specific crops and cover classes, maize was interpreted with an average accuracy of 80% with r=0.94; coffee 86% with r=0.99; tea 86%; bananas 62%; cotton 53%; ploughed land 73%. The rest had insufficient data, see appendix D. Interpretation accuracy for the major cover types were also found to be fairly similar between the three interpreters

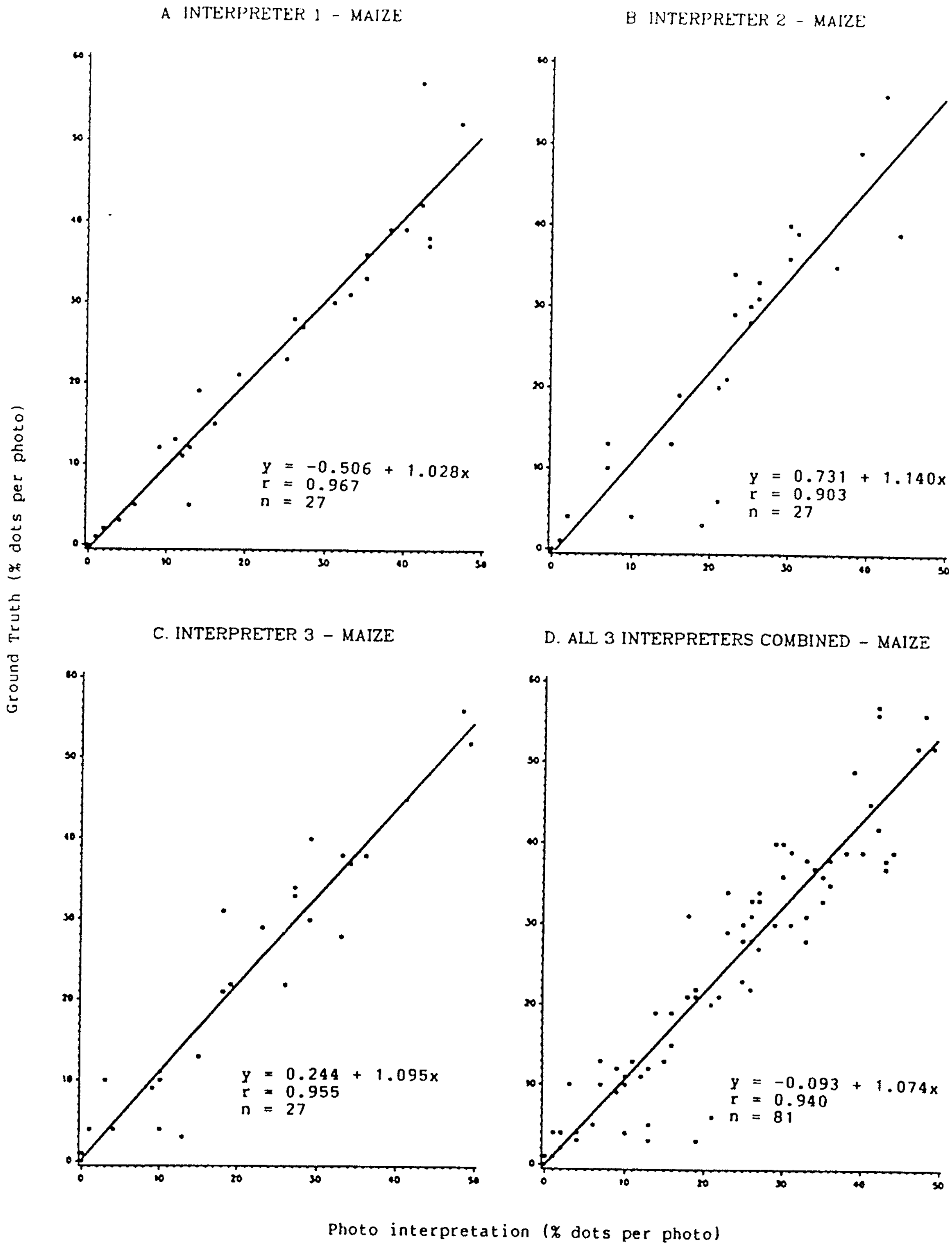


Figure 3. Correlation between photo interpretation and ground data for three interpreters for cover type 'maize', Meru district february 1985.

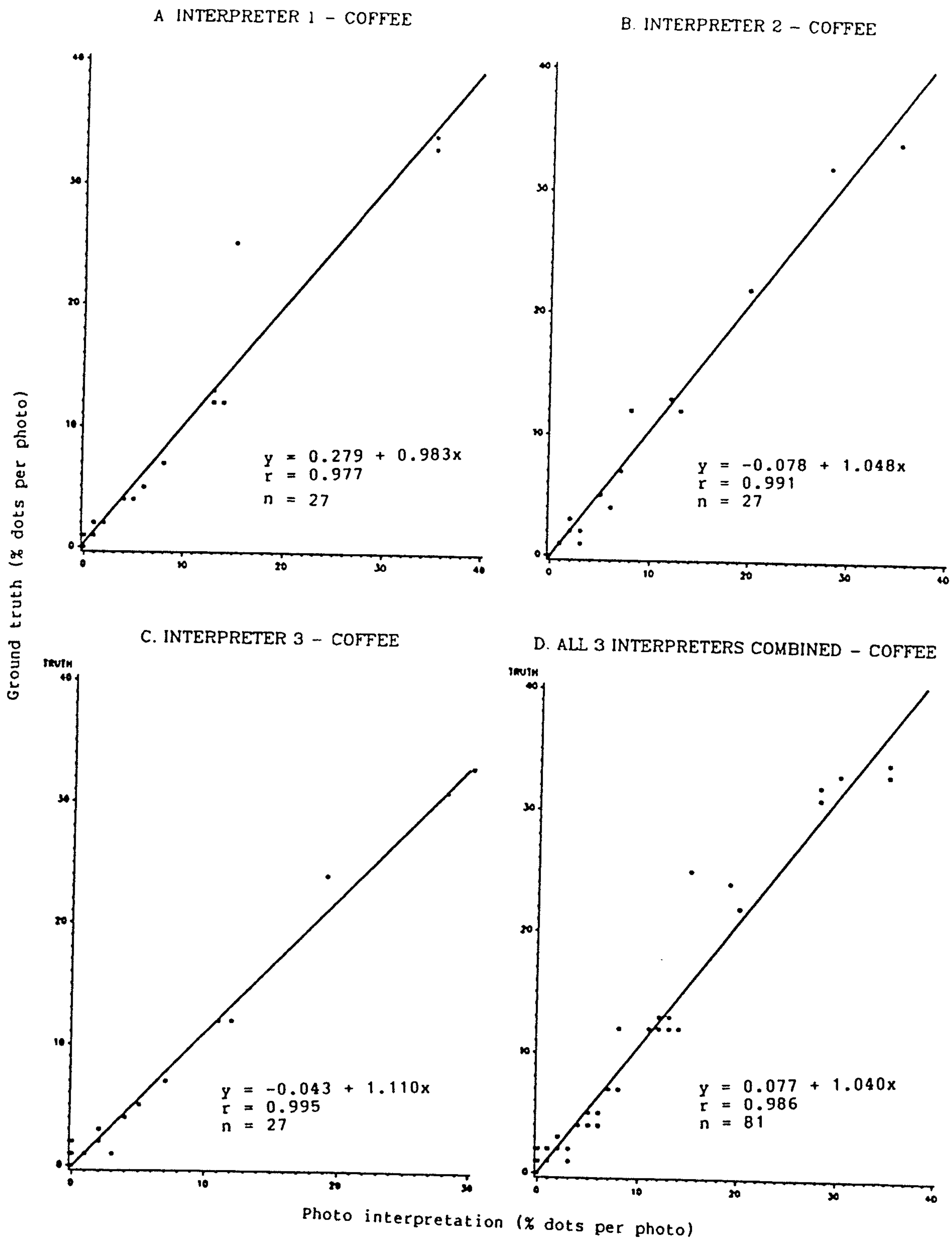


Figure 4. Correlation between photo interpretation and ground data for three interpreters for cover type 'coffee' Meru district February 1985.

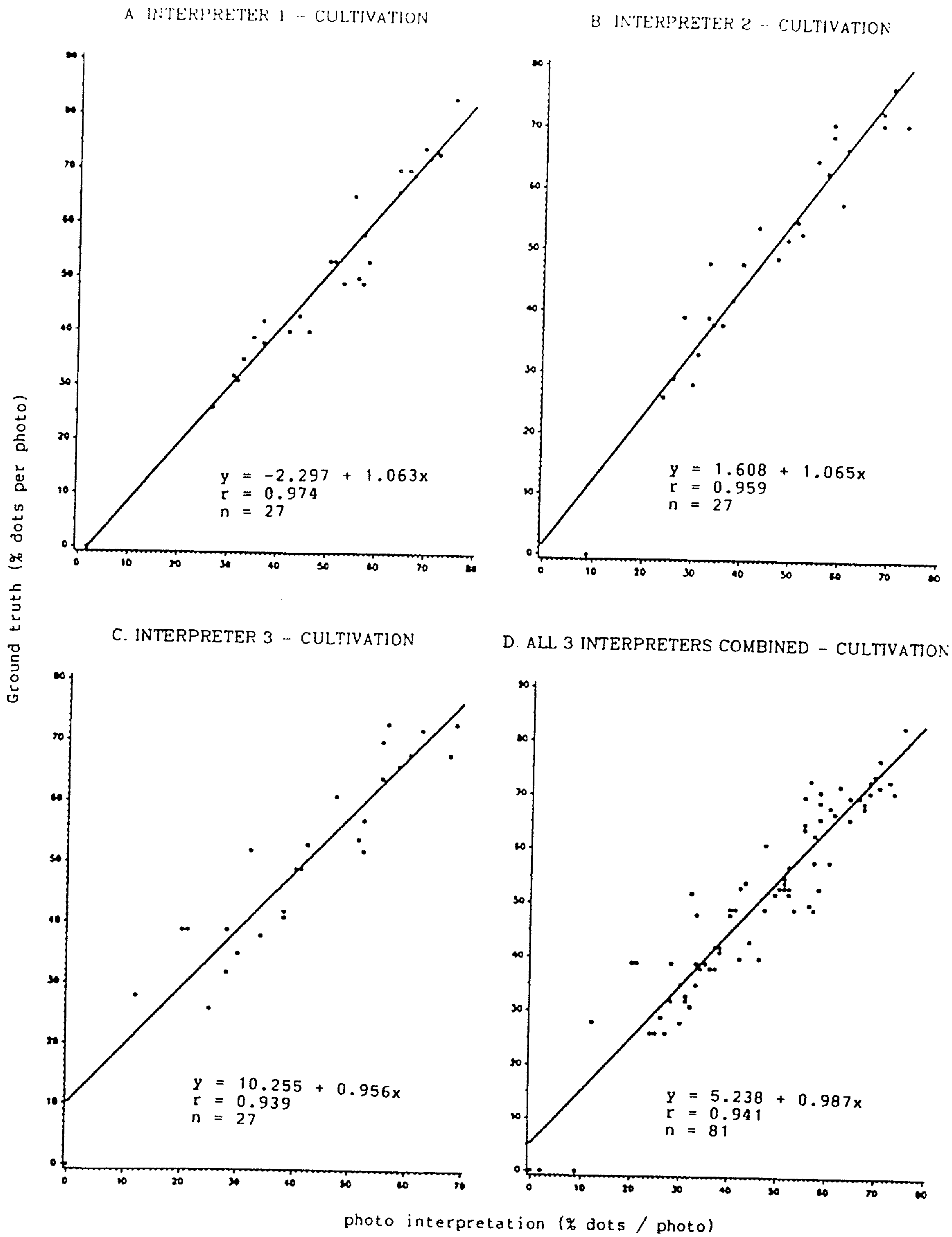


Figure 5. Correlation between photo interpretation and ground data for three interpreters, for cover type 'cultivated land' Meru district February 1985.

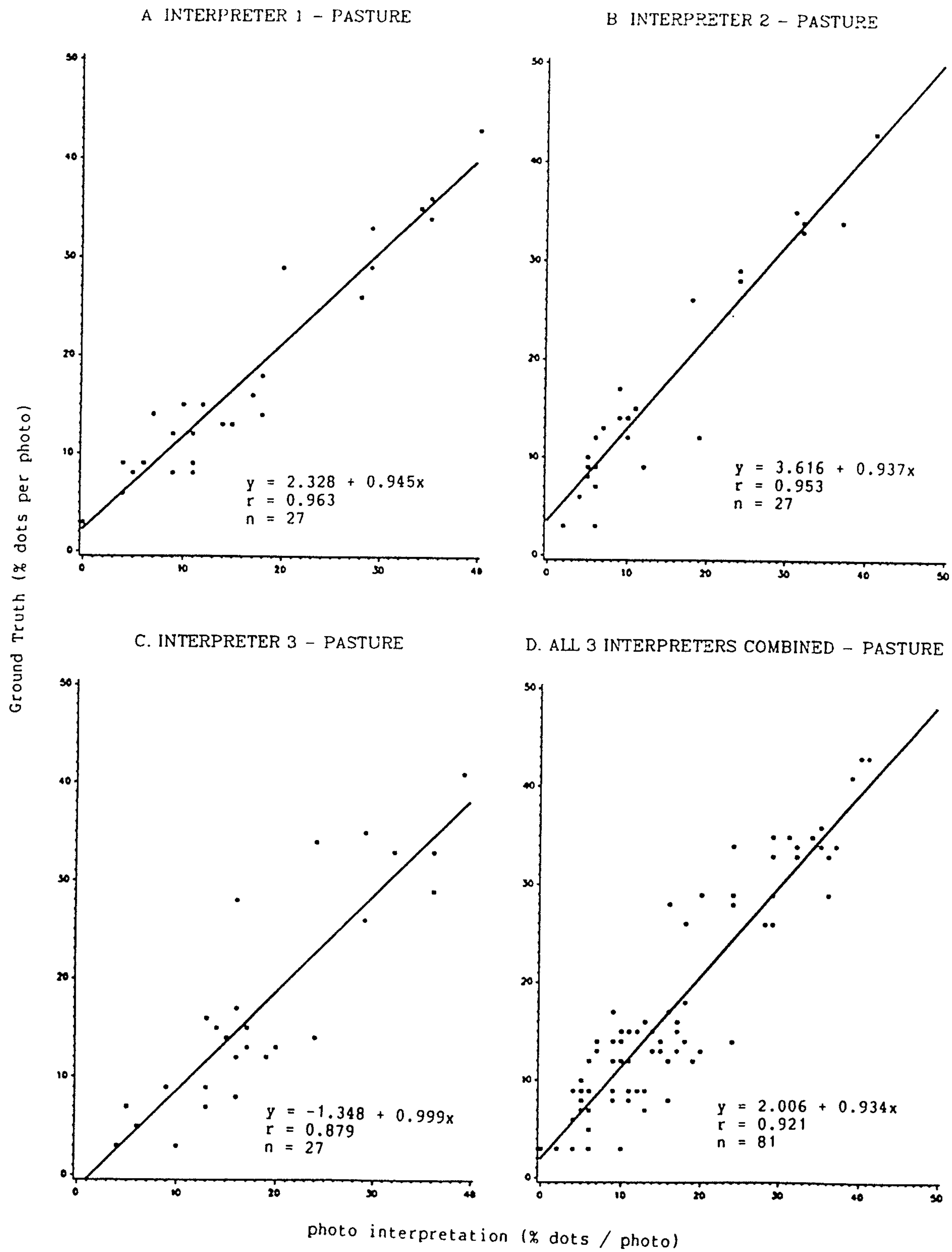


Figure 6. Correlation between photo interpretation and ground data for three interpreters for cover type 'pasture', Meru district 1985.

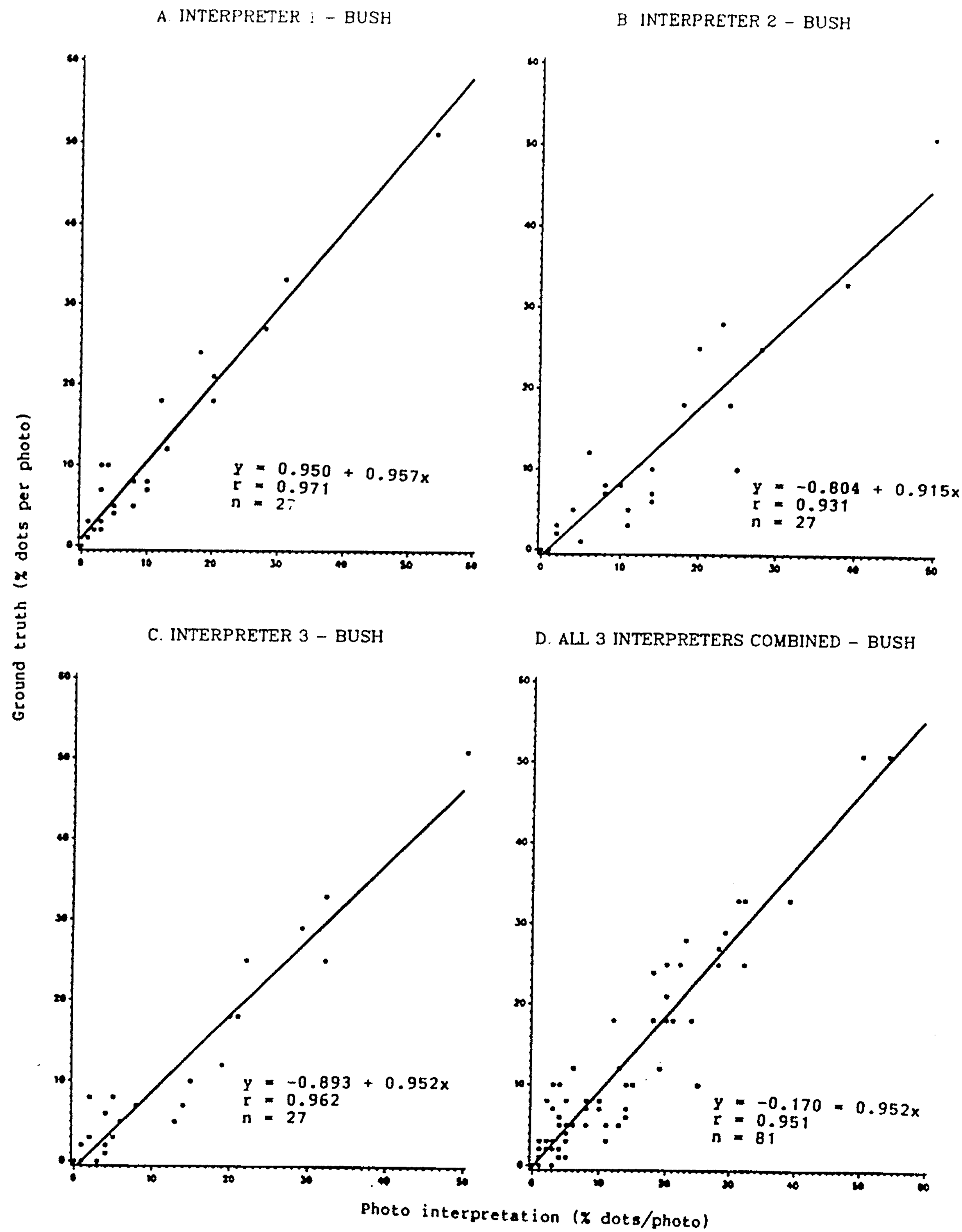


Figure 7. Correlation between photo interpretation and ground data for three interpreters for the cover type 'bush', Meru district February 1985.

TABLE 1. TABLE SHOWING THE LAND USE AND LAND COVER INTERPRETATION CONFUSION MATRIX FOR THE THREE INTERPRETERS (TOTALS) FOR MERU DISTRICT, 1985

GROUND TRUTH	PHOTO INTERPRETATION											STATISTICS			
CLASS	01	02	03	04	05	06	07	08	09	10	11	OM	CI	TT	A%
01 CULTIVATED	3477	173[1]	79[2]	2	15	5	29[3]	33[4]	-	42[5]	213[6]	591	3477	4068	85.5
02 PASTURES	91[7]	1058	109[8]	1	11	8	14	3	1	21	41[9]	300	1058	1358	77.9
03 BUSHLANDS	33[10]	68[11]	690	5	1	-	38[12]	7	4	7	15	178	690	868	79.5
04 FORESTS	-	-	5	125	6	-	2	-	-	-	-	13	125	138	90.6
05 TRANSPORT	3	3	3	-	237	-	1	13	-	5	-	28	237	265	89.4
06 STRUCTURES	2	5	-	-	-	95	3	-	-	5	3	18	95	113	84.1
07 WOODLOTS	13	3	33[13]	-	-	1	82	6	-	1	1	58	82	140	58.6
08 HEDGES	12	10	2	-	10	-	2	103	-	-	-	36	103	139	74.1
09 SWAMPS	2	-	2	-	-	-	-	1	70	-	-	5	70	75	93.3
10 BARREN	24	7	3	-	2	2	-	2	-	114	5	45	114	159	71.7
11 OTHERS	17	7	1	-	-	-	1	-	-	3	33	29	33	62	53.2

OM = OMMISSIONS
IC = INTERPRETED CORRECT
TT = TOTAL
A% = ACCURACY (%)

although one has to be careful about the significance of some classes which had few observations as could be discerned from confusion matrices (appendices A, B, C and D).

Table 1 also shows the major sources of confusion - a cause of low interpretation accuracy. These are the cells superscripted 1-13. Most can be paired and explained:

1. In 1 and 7, 173 dots which were cultivated lands were wrongly identified as pasture while 91 pastures were wrongly identified as cultivated lands. These were actually found to be confusion on the identification of mostly fallow lands and certain overgrazed lands which were identified as cultivated lands.

2. In 2 and 10, 79 dots which were cultivated lands were identified as bushlands and 33 dots which were bushlands identified as cultivated. Most of these were concerned with newly opened areas where bush clearance was not complete or total. A lot of trees and bushes were left standing and crops like maize and beans grown under the canopy. Some crops, especially pigeon peas, when not planted in the normal pattern of rows with other crops (intercropping) were misinterpreted as bush.

3. In 8 and 11, 109 pasture lands were identified as bushland, while 68 bushlands were identified as pastures. This was mainly a problem of differentiating between unimproved bushed pastures and bushlands. There is no clearcut definition to differentiate them.

4. In 3, 29 dots on cultivated lands were identified as woodlots. This was mainly cases of many trees left standing in cultivated fields. Under the canopy would be crops like yams, maize, and beans.

5. In 4, 33 dots on cultivated lands were identified as hedges and this was mostly found to be wrong judgment on the position of the dot and especially in cases where the shadows of the hedges obscured the thickness of the hedge.

6. In 5, 42 cultivated points were confused with barren lands and these were mainly confusion between bare grounds and ploughed lands, and not all bare grounds are barren. Therefore a better and clearer differentiation between barren and bare is needed.

7. In 6, a large group of points (213) which were cultivated had no major classification to fall under and these included very rare crops or a large mixture of crops in one garden. Others could not be identified because the ground checking was made over three months after photography - and there were no signs or information on what crop was there. This, and 1 above had the greatest impact on classification accuracy of cultivated lands.

8. In 12 and 13, 38 bushes were interpreted as woodlots, while 33 woodlots were interpreted as bushlands. Woodlots in many cases look similar to bushes. It requires personal judgment on the size, nature, and surroundings of the cover type to be classified as either woodlots or bushes. There was a tendency to misclassify bushes as woodlots in the rangelands.

9. In 9, there were 41 points classified as others and cannot be easily explained.

A more careful definition of the pairs of classes most commonly confused would go a long way to increase the interpretation accuracy. For example reducing the errors by half alone will increase the accuracies to much higher levels above 85% for all classes.

In a large project where several interpreters are involved consistency regressions identify those who are inconsistent in their interpretation, while the confusion matrices help identify the classes confused most and therefore rectify the anomalous by instituting specific remedial measures. Many authors recognize that interpretation accuracy required by any project depends on the end use of the information but the accuracy actually achieved should always be stated in the report. Unfortunately the accuracy is not always stated in reports or at times not rigorously tested. Epp et al (1983) tested the interpretation on 150 known fields (of different types) and reported an overall interpretation accuracy of 87%. The Bauchi (1984) experiments recognized the difficult in accurately identifying all crops and therefore field cross-checked sample photographs but accuracy was not expressed. In the computer-aided digital image processing (DIP) Kalensky and Scherk (1975) in their delineation and identification of a Canadian forest into three categories - conifers, deciduous, and nonforested - reported accuracies ranging from 67% - 81% derived from single-date image processing but a multidate combination image processing improved the accuracy to 83%. Kalensky et al (1979)in DIP again reported an accuracy of 78% when land resources were classified into 9 categories in Lombok Islands (where expansive water masses were excluded from the analysis).

Anderson et al (1976) suggested that the aim in land use classification accuracy should be a minimum of 85%. Baker et al (1979), however, further recommended that although some finer classification levels might yield lower accuracies, at level II the accuracy should be 90-95%. The confusion matrix, Table 1, shows that accuracy for the major classes were fairly high, some surpassing the 85% level.

In summary then, it was found that interpretation consistency was high for the major classes, most of them surpassing the r=0.90 mark. It was also shown that interpretation accuracy was high for many classes using the USGS bench mark of 85%. But as several authors have indicated the level of accuracy to be attained is normally set by each institution to suite its own requirements, technology and environment. Thus it should be noted that the 85% accuracy level could be a very high standard for the Kenyan agricultural areas' conditions. In the USA large scale monocultural practices are predominant as opposed to the Kenyan conditions where very small scale multicultural and intercropping are common. However, as it was demonstrated it was possible to isolate the classes most confused with each other using the confusion tables thus making it possible to handle those classes with particular care in subsequent interpretations. At the same time the district-wide photo interpretation was done using a team work approach by the same interpreters involved in the accuracy and consistency tests and therefore the district-wide photo analysis accuracy attained should have surpassed what was obtained in the accuracy tests, Table 1. It would therefore be advisable for KREMU to set acceptance levels of consistency and accuracy from interpreters - otherwise a re-analysis should be performed if the levels are not attained.

4.1.2 Statistical estimates precision and accuracy

A total of 443 photographs were examined for 263 sample units. Three areas of the district, Mount Kenya National Park and Forest; Meru National Park and surrounding area; and the Northern Conservation Area, were not surveyed mainly because their uses and cover types are well documented, see Figure 8. Terrain, air turbulence and cost considerations also contributed in arriving at this decision.

Forty land use and land cover types were identified in the district from the photo analysis. A few closely related land uses were combined to reduce the number to 35 classes. Table 2 shows these classes, their percent cover, hectarage and percent standard errors.

Percent standard errors were generally small for those classes which were widely spread in the district, and these included bushlands, ploughed fields (for this was the period of preparing for the second crop in the long rains), maize and pasture.

Table 3 is condensed version of table 2, in which the finer classes have been aggregated into 11 main classes.

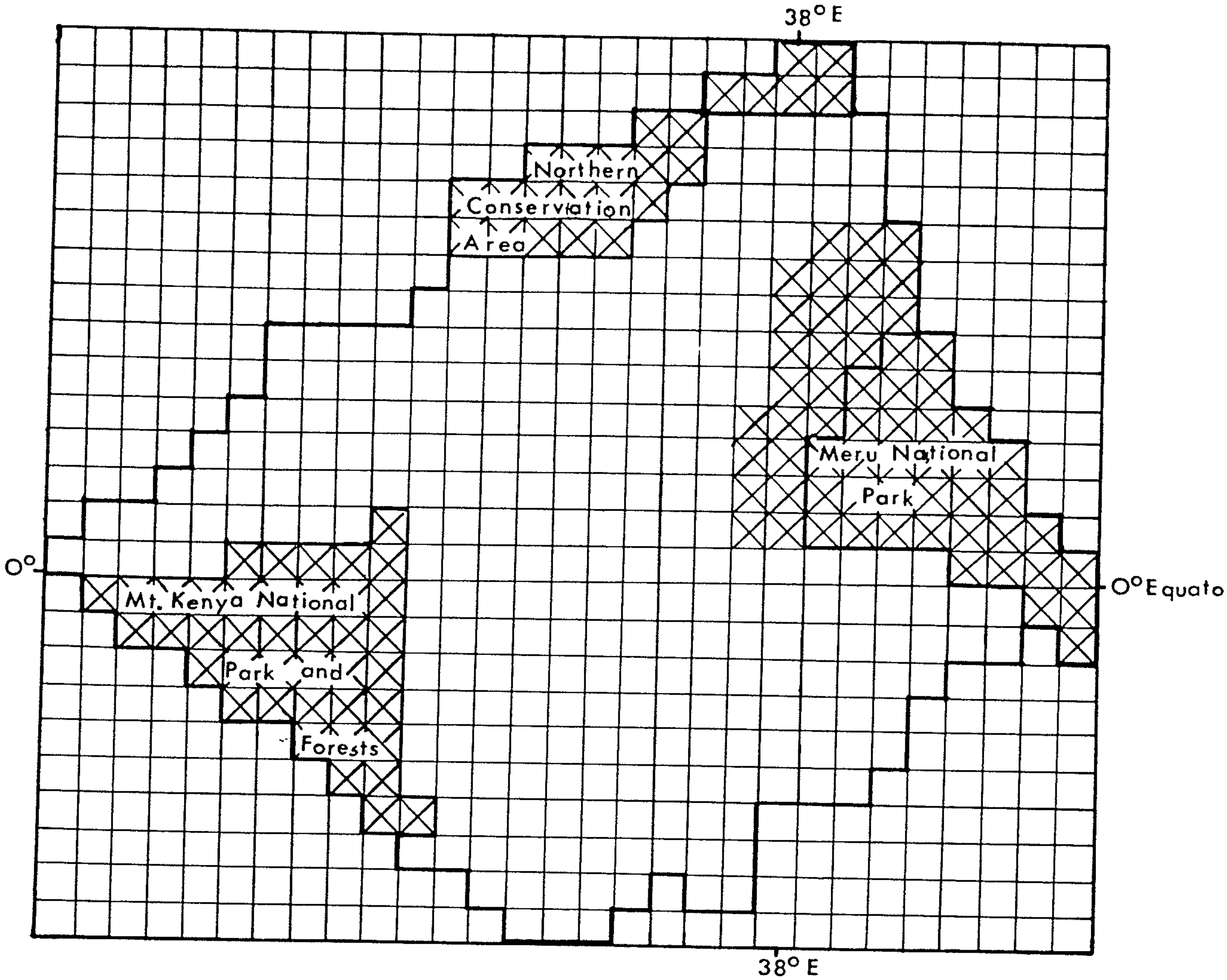


Figure 8. The study area, Meru District, in 5x5km UTM grid cells

TABLE 2

Specific land use and land cover classes identified, their percent cover, hectarage, and percent standard errors (S.E.), for the surveyed area of Meru district, February 1985

Class	%Cover	Hectares	S.E.
Maize	9.56	61423	9.1
Wheat/barley	1.53	9830	32.0
Rapeseed	0.03	193	100
Pasture	20.14	129400	7.4
Bush/Shrub	38.11	244857	6.1
Fallow/Fern	2.45	15741	13.2
Ploughed	2.93	18825	9.6
Coffee	3.41	21909	15.8
Tea	0.63	4048	27.7
Forest	8.09	51978	17.1
Road/Tracks	0.77	4947	9.1
Paths	0.52	2341	11.5
Woodlots	0.99	6361	15.2
Hedges	0.61	3919	13.1
Potatoes	0.05	321	40.0
Buildings	0.41	2634	12.2
Schools	0.16	1028	18.8
Napiergrass	0.07	450	28.6

Class	%Cover	Hectare	S.E.
Banana	1.22	7839	15.6
B.Millet	1.20	7710	20.0
Swamp	0.37	2377	37.8
Cotton	1.00	6425	19.0
S.Flower	0.05	321	40.0
Tobacco	0.15	964	26.7
P.Peas	0.55	3534	18.2
Sorghum	0.19	1221	26.3
Miraa	0.03	193	66.7
Lablab	0.03	193	33.3
Sugarcane	0.01	80	-
Pyrethrum	0.01	80	-
Gullys	0.19	1221	36.8
Rivers	0.42	2699	19.0
Rocky	0.14	900	35.7
Bare	1.94	12465	13.9
Others	1.91	12272	9.9

This gives each class more chances of occurring in more sample units and thus their standard errors are relatively smaller as compared to table 1.

In systematic sampling estimates, precision is a function of the number of sample units, which is also true for the sample clusters in the traditional ground surveys. But the number of sample clusters taken is severely limited by costs and manpower. It has been demonstrated that, overall, systematic sample survey consistently yield smaller standard

TABLE 3

Major land use and land cover classes identified, with their percent cover, hectares, and percent standard errors (S.E).

Class	% cover	Hectares	% S.E.
Cultivated	25.1	161895	6.1
Pasture	20.1	129645	7.4
Bush/Shrubland	38.3	247035	6.1
Forest/Woodland	8.1	52245	17.1
Transportation	1.3	8385	7.7
Structures	0.6	3870	14.6
Woodlots	1.0	6450	15.2
Hedges	0.6	3870	13.1
Swamps/Rivers	0.8	5160	33.4
Barren	2.3	14835	12.8
Others	1.9	12255	9.9

errors than the traditional cluster sampling (Nigeria 1984). In the systematic aerial survey the range was 7 - 26% while in the cluster system it was 8 - 38%, in the major crops only, in the Nigerian example.

Precise estimates at expressed sampling intensity is most useful in monitoring change of land use and land cover characteristics. The standard errors found in the other 9 districts studied in Kenya were comparable to the Meru study. The estimated areas of class types in the district are also given in Tables 2 and 3.

Verification of the statistical accuracy of these estimates would normally be more involved, because it needs controls in which the actual areas of class types are known so as to be compared with the results from the method. Total coverage measurements are the most accurate -- on ground or from photography -- the antithesis of this methodology.

Hectarage are often crudely estimated for certain crops by extensions officers in Kenya or on ad hoc basis by the cluster methods. However, those for tea and coffee are estimated differently by the Kenya Tea Development Authority (KTDA) and Coffee Cooperative Unions respectively and they were the only readly available statistics in the district.

The coffee cooperative unions keep records and update them on reports from farmers of new coffee plantings. As of June 1985 the records in the Ministry of Cooperatives, Meru, which coordinates the coffee statistics, showed that there was a total of 37,625 hectares under coffee in Meru Dis-

TABLE 4

Area under coffee in Meru district in 1982 and 1984/85, in hectares

Union	1982	1984/85
Meru North Coop. Societies Union	7352	7224
Meru Central Coop. Societies Union	17325	17401
Meru South Coop. Societies Union	9455	13000
Total	34132	37625

source: Meru District Cooperatives Office, Meru.

trict, Table 4.

The statistics are derived from interviews on cooperative farmers on the number of coffee bushes they have or have added in any one period. Because agronomic spacing recommended is standard, the coffee bush population is converted into hectarage.

Table 5 and figure 9 show the growth of area under coffee in Meru District over the years derived from various sources. The apparent large leap in hectarage since 1979 needs further examination. Coffee prices were high between 1976 and 1978. This was an incentive for farmers to increase hectarage under coffee, although, because of the world coffee market quota system the government was not encouraging increased hectarage. This same period had a lot of internal cooperative societies' feuds that led to the break-up of the Meru Coffee Cooperatives Union into three unions in 1981.

From 1978 the prices fell to their normal levels. It would seem then, that the sudden plunge in 1978/79 and then a steep and continued increase in coffee hectarage (see Figure 9) is not well explained. This is an enormous increase of between 25,168 and 31,325 hectares within 6 years -- a figure that had not been attained for 24 years since the introduction of coffee in Meru. The short fall in the statistics may be in that the crop was planted but failed, and those that have been uprooted are not accounted for. Normally permission must be sought and reasons given for uprooting a coffee crop. This may deter many farmers from reporting the truth - and thus the hectarage grows but rarely decreases. More investigation is also needed to check whether the unions feuds and subsequent break-up has any bearing to this enigma. Thus the estimate of 21,995 hectares from this aerial sampling study may be more realistic than the 37,625 hectares.

TABLE 5

Growth of coffee farming in Meru District, 1953-1985.

Year	Area (hectares)	Source
1952/53	747	Bernard (1972)
1954/55	1142	"
1956/57	1780	"
1958/59	2823	"
1960/61	3793	"
1962/63	6752	"
1964/65	11189	"
1966	11430	"
1968	11734	"
1974/75	12452	Jaetzold & Schmidt (1982)
1975/76	12452	"
1976/77	12453	"
1977/78	12457	"
1978/79	6300	"
1979/80	15100	"
1982	34132	Coop. Office Meru (1985)
1984/85	37625	"
1984/85	21995 $\pm$ 15.8%	Kimanga (1986)

For tea, the situation is slightly different as shown on table 6 and figure 10. The area under tea has been under steady increase over the years. The sale of seedlings to

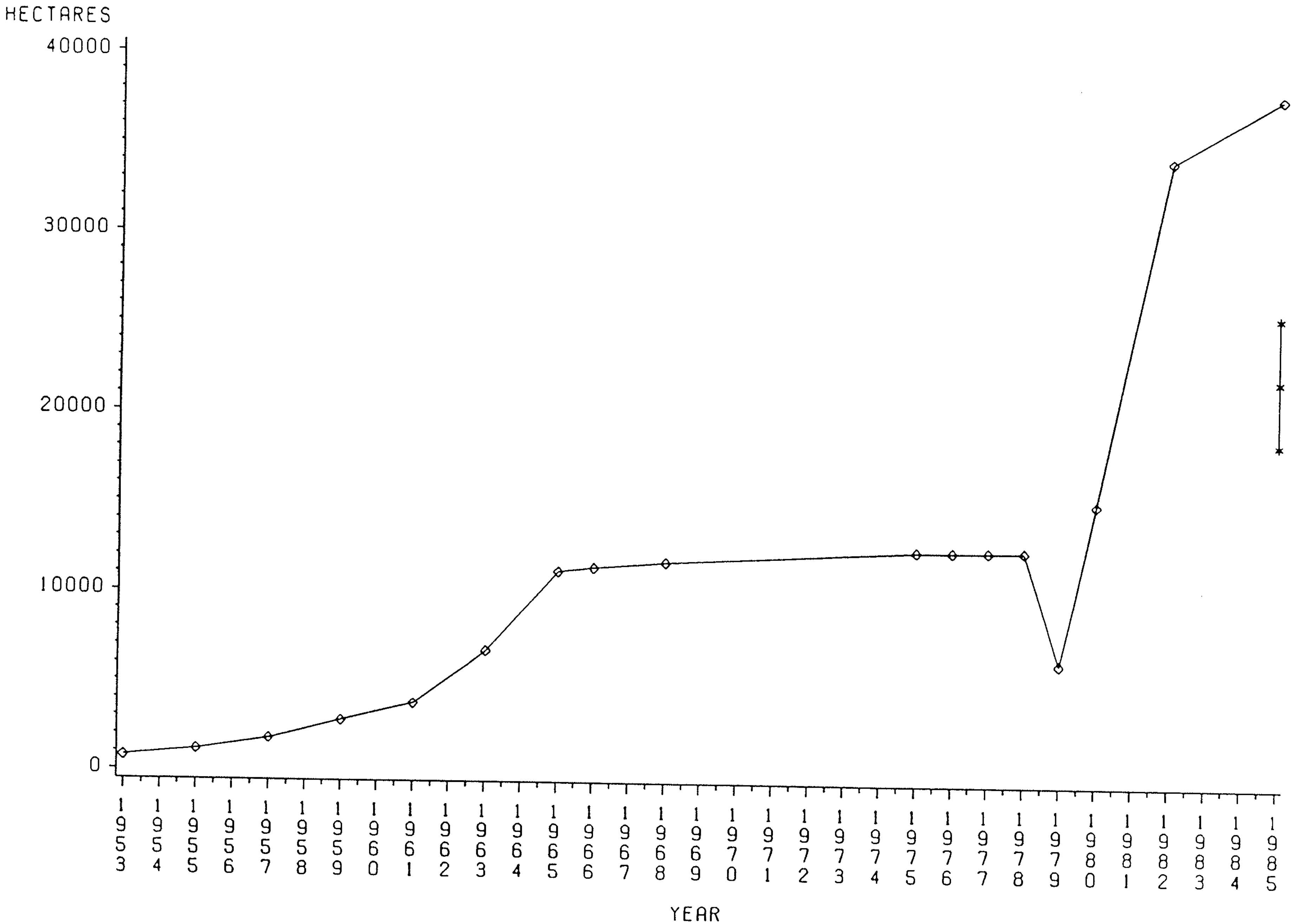


Figure 9. Graph showing growth of coffee farming in Meru district, 1953-1985; and the range of the 1985 aerial sample photography estimates (*).

Sources: Bernard 1972; Jaetzold and Schmidt 1982; Meru Coop. office 1985.

farmers is controlled by KTDA. The hectarage is therefore derived from cumulative sales over the years by KTDA. There is no strict requirement for farmers to report back seedling losses and for the planted but unkept bushes. It is therefore possible that the KTDA figures are slightly higher although most tea growers are known to care for their crop for the steady and regular returns they get for their produce. It would therefore seem to suggest that the estimates made by this study of 4,079 hectares was more or less correct. Tea is grown intensively in two small areas in Meru, figure 13. It is therefore possible that the sampling intensity used in this study was not enough to accurately estimate the area. Increased sampling intensity coupled with stratification should give a more accurate estimate and a smaller standard error.

TABLE 6

Growth of tea cultivation since 1960, Meru district.

Year	Area (hectares)	Source
1960	29	Bernard (1972)
1962	255	"
1964	471	"
1966	676	"
1968	1313	"
1975/76	4609	Jaetzold & Schmidt (1982)
1976/77	5250	"
1977/78	5614	"
1978/79	5759	"
1979/80	5952	"
1984/85	6557	KTDA Office, Meru (1985)
1984/85	4079 ± 27.7%	Kimanga (1986)

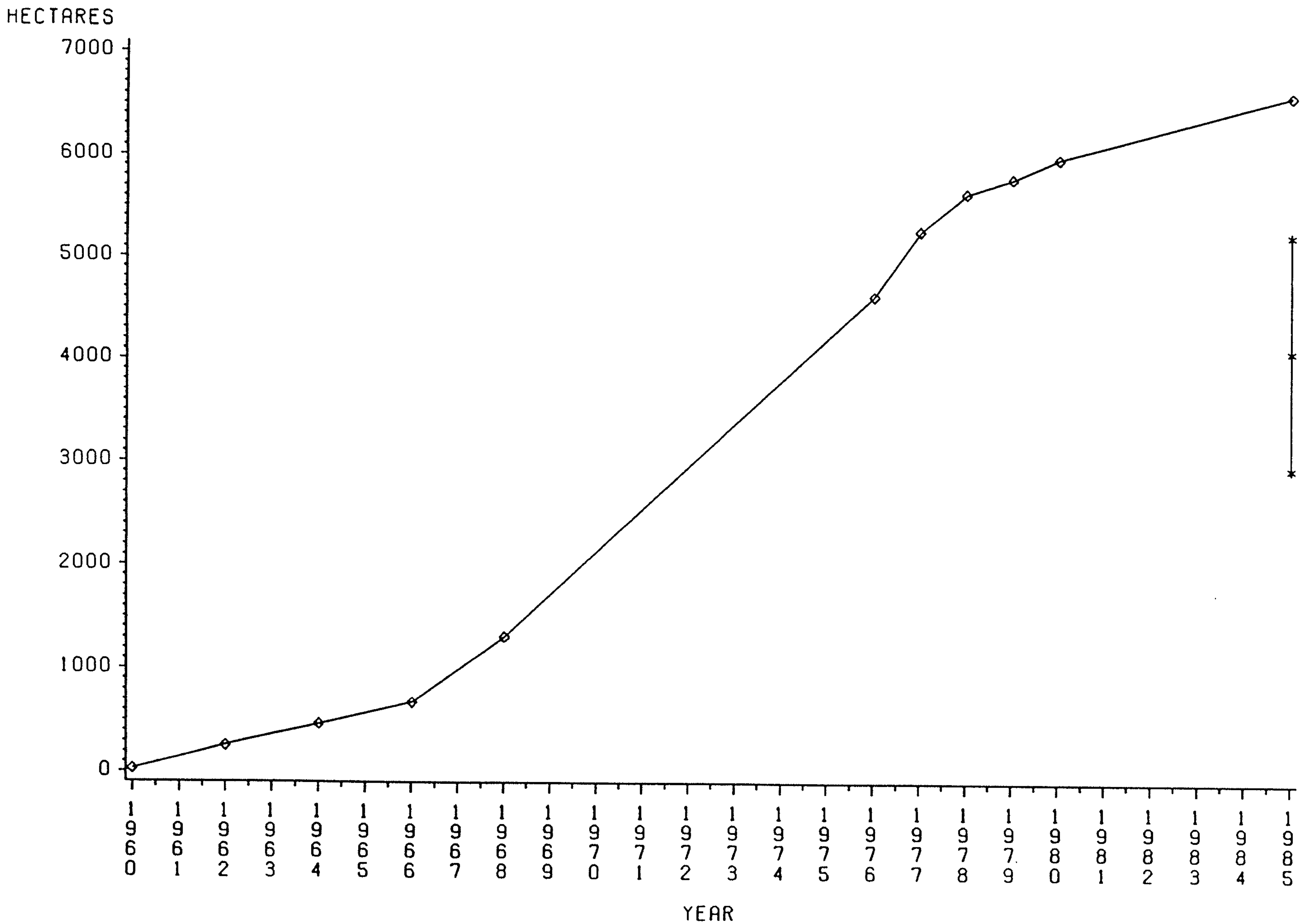


Figure 10. Graph showing the growth of tea farming in Meru district, 1960-1985; and the range of the 1985 aerial sample estimates (*).

Sources: Bernard 1972; Jaetzold and Schmidt 1982; Meru Coop. Office 1985.

Other class area coverages were difficult to verify because there were no independent statistical estimates available for the current period. Table 7, however, gives a comparison of the study results and two previous estimates of 1976 and 1982 (Kenya 1984). Assuming there was no significant changes between 1982 and 1984, there is very good agreement for areas under bananas, millet/sorghum, wheat/barley, and pigeon peas. But there are apparent changes in area under maize, cotton, sunflower, and pyrethrum. An explanation may partly be found in the growing seasons for the crops (Jaetzold and Schmidt 1982) and the timing of the survey.

Except for bananas and pyrethrum which are perennial crops, the others in Table 7 are annual. There is only one crop for cotton per year. It is grown in October-November and harvesting is spread between March and September. The best survey period for it would be when it is in flower, which was not the case in this survey hence probably the low estimates. Furthermore, in many areas cotton is intercropped with others like maize, millet, and sorghum in October-November and when they are harvested in February-March the cotton is left to grow and mature between March and September. Thus most cotton was not identified because it was still an undercrop at that time. This probably accounts for most of the underestimation by the aerial method for cotton.

There are two crops per year for the others. Ground preparations for all of them are done in February-March and Au-

TABLE 7

Comparison of the hectarage estimates with two earlier independent ones

Crop	1976*	1982*	1985**
Maize	36130	90700	61423
Bananas	5600	8000	7839
Millet/sorghum	6220	7900	8931
Wheat/barley	8074	9460	9830
Pigeon Peas	3276	3200	3524
Tobacco	695	-	964
Cotton	12053	15313	6425
Potatoes	7750	11000	321
Sunflower	695	1725	321
Pyrethrum	496	340	80

Sources: * Kenya 1984
** Kimanga (1986)

gust-September. Harvesting is staggered because of differences in maturity period for each crop. Harvest for potatoes is mainly in January and July. Thus most of the crop was missed. In addition potatoes were not easy to identify. Probably the best survey time for potatoes is November-December and May-June.

Harvest time for sunflower is January-February and June-August. The best survey time for sunflower would be December and June when it is in full flower for best discrimination.

For maize, harvest time is February-March and July-August. It is possible that most of the ploughed ground was already harvested maize fields which were being prepared for another crop. It is therefore possible that the area under maize in that season was underestimated. The best time for its survey probably is December-January and May-June. From the statistics in table 1, about 38% of the cultivated land was under maize. Therefore approximately 38% of the ploughed land can be assumed to be for or was under maize. Therefore, the area under maize can be adjusted accordingly and would be about 68,577 hectares with a standard error of 9.1%. Maximum area which could have been under maize that season would therefore be 74,818 hectares. This would still be below the 1982 estimates.

The case of pyrethrum is well explained in that the world market for pyrethrin dropped because of the use of cheaper and more specific synthetic insecticides and therefore farmers uprooted the crop. That explains the change but there was no independent source of current data to compare the amount of drop experienced during the 1982-84 period.

It is therefore apparent that the results of this survey were fairly accurate assuming that not much change had occurred between 1982 and 1984, except for coffee, maize, tea, and pyrethrum.

A close agreement between this study and that of Jaetzold and Schmidt (1982) however is at a coarse level in which they found that rural agricultural land is 82.6% of total land whereas for this study it was 83.5%. Agricultural land in this context is all but barren lands, lands under forest reserves, lakes, swamps, rivers, roads, and homesteads.

These were indications that the method proved to be useful in estimating extensive classes, and coupled with the high interpretation accuracy in the coarser classes, confidence in the statistics was build up. Precision was also found to be high in the extensive classes, but could be improved for the other classes by more intensive sampling as well as by stratification. The statistical accuracy of the less extensive classes could be raised by increasing the sampling fraction as well as interpretation accuracy. But care should be taken not to increase sampling fraction and therefore costs unnecessarily if the class of concern is environmentally and economically insignificant. Interpretation accuracy should be expected to improve after current investigations on appropriate photo resolutions are concluded by KREMU.

4.2 MAPPING AND CLASS TYPE INTENSITY ZONING

Table 2 gives the district-wide percent cover for all class types found in the district, while table 3 is aggregates of table 2. For example, of the cultivated land, 38% was under maize, 14% was under coffee, 12% was ploughed, 9% was fallow and the remainder 27% was distributed among 16 different crops. Distribution and intensities for each of the extensive class types were mapped and contouring approximated using MAP. Four examples: cultivated land, maize, coffee and tea are given below, figures 11 to 14.

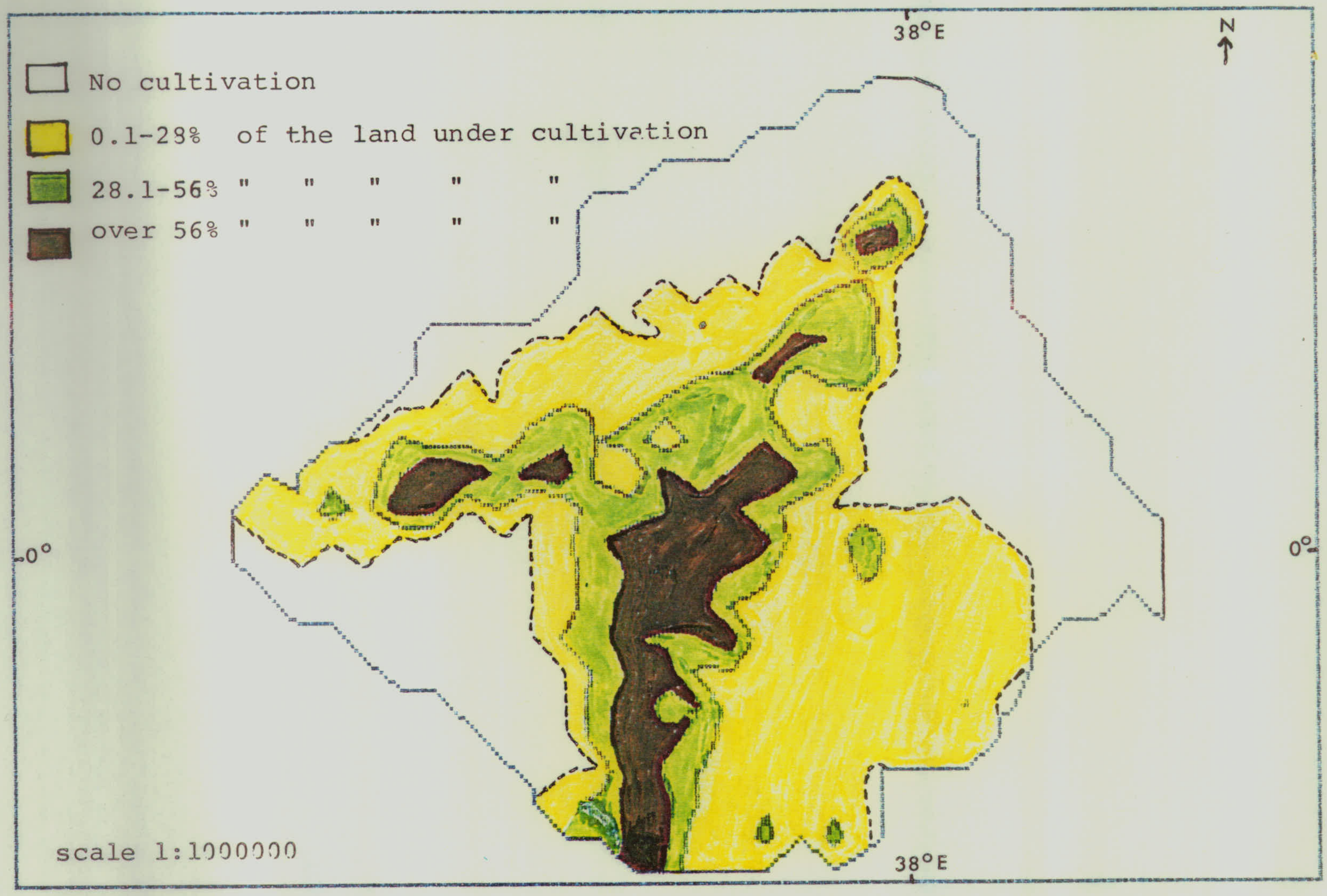


Figure 11. Distribution of cultivated lands, Meru district 1985.

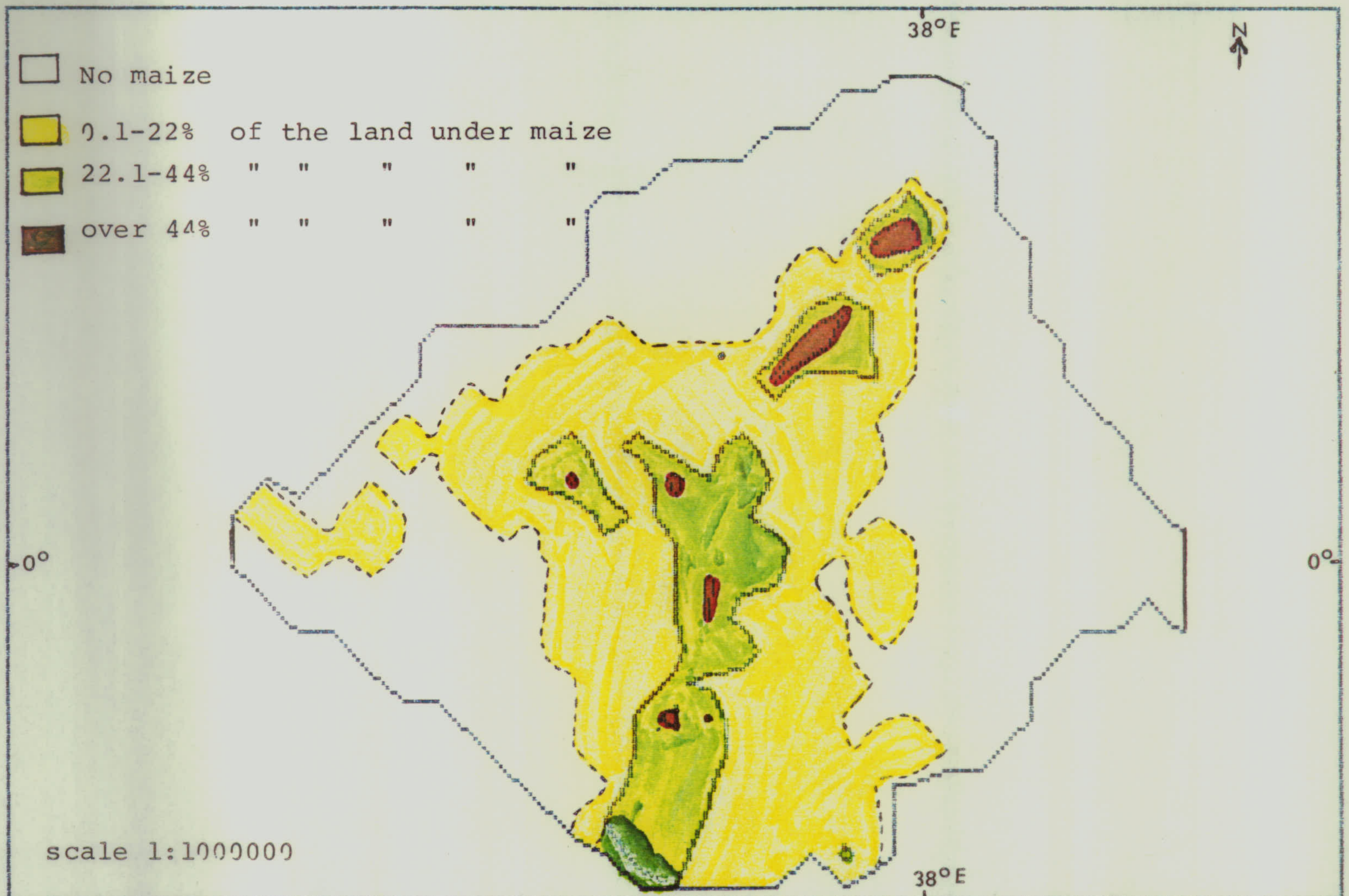


Figure 12. Distribution of land under maize cultivation, Meru district 1985.

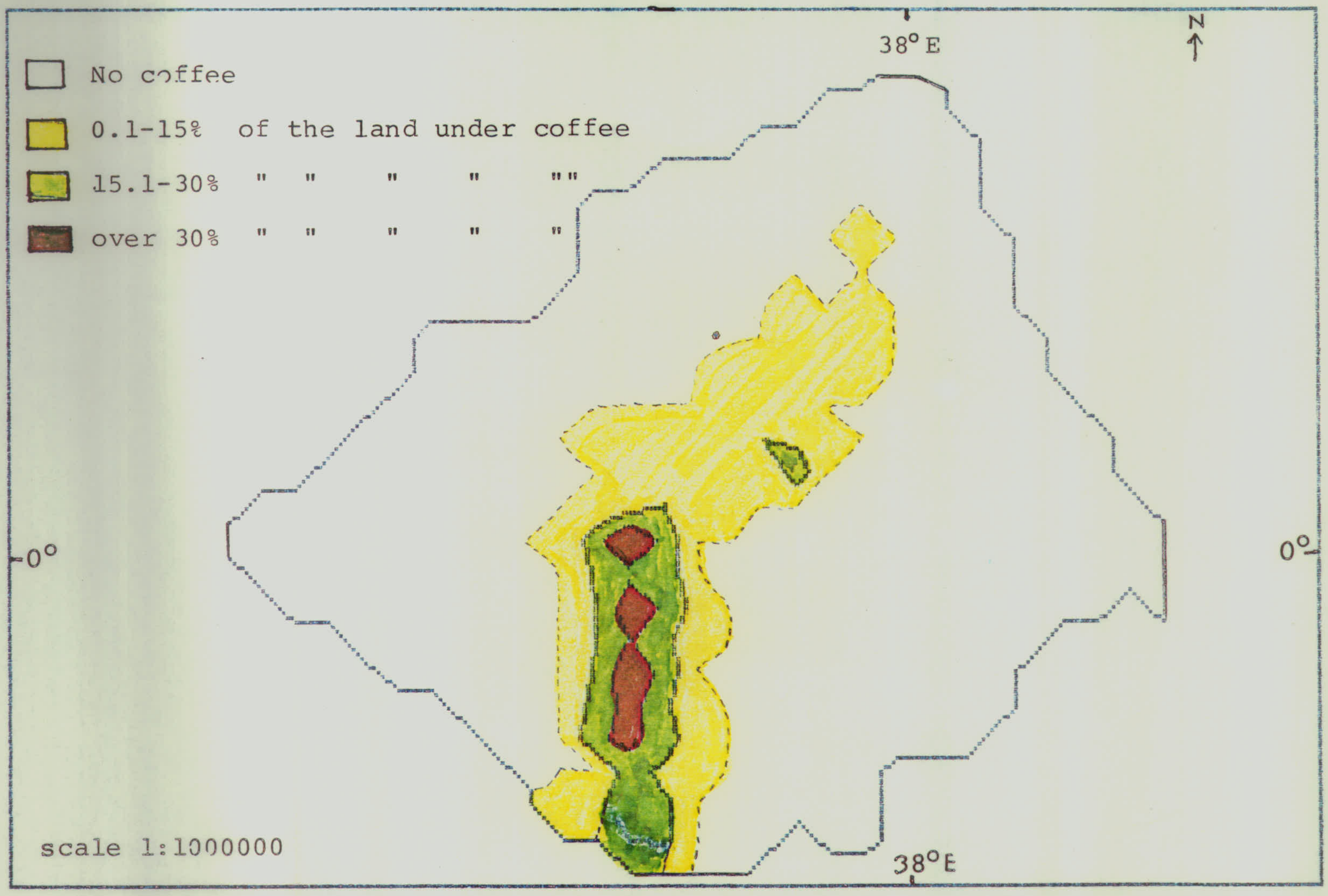


Figure 13. Distribution of land under coffee cultivation, Meru district, 1985

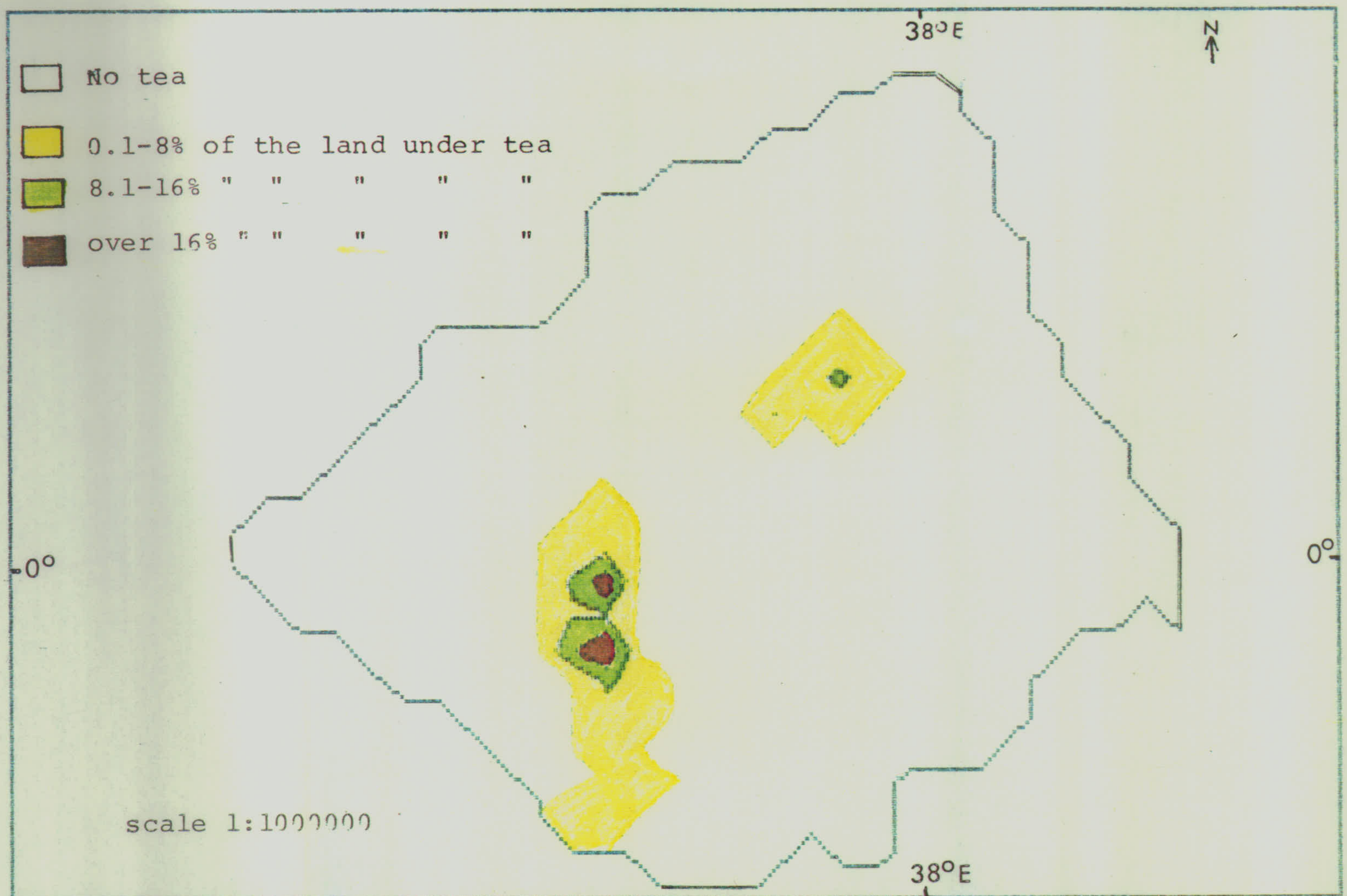


Figure 14. Distribution of land under tea cultivation, Meru district 1985.

Significant changes of any of these maps (and statistics) in any district in distribution or amounts will be a reflection of a process of changes going on as a reaction to certain pressures or certain management policies. A more detailed comparison between districts and detection of changes will be more useful when the data is disaggregated into different ecological strata.

The use of aerial sample photography for the mapping of resources has been advocated and discussed before by many authors for example Berry and Baker (1968) and Robertson and Stoner (1970). However, its application to a large scale mapping project was not found in literature. The Kenyan project was adopted after a trial run in Kisii District (Epp, et al 1983). In the Kisii study and those that followed the photo samples were stratified and analyzed on the basis of administration units. Thus when the average percent land covered by a class type was mapped, the distribution was depicted as evenly spread throughout the administration unit through differential shading or pie charts.

However for Meru District, class types' intensity and extents were first mapped independent of any factor. This method of mapping class type and intensities gives a picture close to real distribution within any type of stratification consequently overlayed. Stratification can be on basis of administration units, soils, vegetation, climate or human population for various types of studies (i.e. factors affecting a class type distribution) in an effort to make rational development plans. Present generation of GIS systems with analytical capabilities can now perform these functions much faster. It is anticipated that this this type of mapping will be most important when all districts' data are collated for regional and national overview.

A major use of this type of mapping is the detection and measure of the movement and cultivation activities into the marginal areas. Epp and Killmayer (1982) suggested that areas with land 10% or more under cultivation be designated as 'agricultural'. Jaetzold and Schmidt (1982) have however defined in detail agroecological zones in Kenya in which agricultural areas are ecologically delineated. Using these two criteria, newly settled areas as well as cultivation extending beyond ecologically acceptable boundaries can be detected using the photographic sample methodology by map overlays. For example it has been suggested that most of the increase in coffee hectarage since 1978 has been a shift into the marginal areas where its productivity is very low. If such data were available , measured to the same accuracy levels, then a test for significant change in area by coffee in the marginal zones would be attempted. Coleman (1976) used a similar principle to detect rural-urban fringe extensions into farmlands through the detection of changes in patterns of proportion of land under classes "farmlands", "settlements" and "rural-urban fringes" for any particular area.

A recent experimentation using similar principles of photo sampling methodology has been reported from Nigeria with success in providing fairly accurate statistics for planning (Bauchi 1984; Nigeria 1984). Mapping was done using two forms of graphics: a pie chart for each administrative area in which the proportion of major land use categories were represented by individual slices; and for each theme map, proportionate circles were used on each grid cell to depict coverage or intensity of the class type in the cell and therefore the region in general.

4.3 STANDARDIZATION OF PROCEDURES

Large scale land use and land cover mapping (inventorying and monitoring) through photographic interpretation is necessarily performed by several persons at any one period or through time. The above procedures (section 4.1) outlined ways of measuring the accuracy and consistency of interpretation and mapping of class types. To facilitate comparability of data in the same district as well as from area to area and through time, four things must necessarily be standardized:

- Range of accuracies that can be compared (sec.4.1.1);
- zoning methodology (sec. 4.2);
- the photo interpretation procedure; and
- Verification procedure.

This section concerns the photo interpretation and verification procedures, and fall into four parts.

4.3.1 photo resolution

The comparability of interpretation to the same detail by two or more interpreters need comparable ranges of photo resolutions. This is a research priority which has been started by KREMU. This involves camera lens selection, flight elevation, film type, and sun angle. The optimum interpretive conditions for the average interpreters are necessarily for subsequent stages.

4.3.2 Stages of interpretation process

Five stages were identified and closely followed in the actual interpretation process. In the first stage the training of the interpreters on the concepts of land use and land cover were discussed to improve accuracy and speed of interpretation.

Familiarity of the study area was recognized as very important and therefore emphasized as a second stage. The cultural practices of one land use type may differ significantly from area to area. A land use type pattern may well also change due to ecological conditions. Further, the tone of a class type may change through the growth stages or seasons. The interpreter must therefore be prepared before the start of interpretation on how to discriminately classify types or emphasize differentially the principles of object recognition on photos. These principles are size, shape, pattern, tone, texture, shadow and association. These were discussed and well reviewed in the office and an attempt made to inculcate them into the interpreters. This included the division of the study area into known broad regions and a list of what was expected therein.

The third stage was going to the field and identifying one or more training photo points for each ecological region. These photos were interpreted, ground checked and discussed on the spot. These training points were chosen to give a sufficient range of land use and land cover types expected in the whole study area.

In the fourth stage the verification or accuracy and consistency samples were selected and interpreted. They did not include the training points. Each verification photo was interpreted separately by each person. The photo point was then visited and the true ground feature of each dot on the photo compared with each person's interpretation. Thus the interpretation accuracy and consistency of each interpreter could be assessed separately and be compared with the others for several use types. This was one advantage of having the dot grid overlays fixed on the photos because the same dots were examined by all the interpreters.

In the final stage, the rest of the photographs for that ecological region were interpreted by those involved in the accuracy test. A difficult dot could be discussed among the interpreters to reach a consensus. Thus it is contended that the district-wide interpretation accuracy was higher than given by the accuracy tests. The systematic fixed dot method was therefore found to be quick and reliable for the identification and estimation of areas of each class type for every sampling grid cell and the whole district.

In retrospect, this should have, preferably, been done continuously by at least two interpreters per photo, for the region. The first person should have interpreted and the second also interpret using the same data sheet. The dots which showed differences would have been discussed by both and reconciled. This system would have assumed that interpretations' accuracy and consistency for the study area are above the levels of each person separately or on average. It is a check for not going below the average accuracy and also for improving consistency.

4.3.3 Classification

It was recognized that agreement on class types interpreted would also rest on a prior given classification and definition of terminologies. After several considerations and deliberations with senior KREMU staff the principle classification system of Anderson et al (1976) were appropriately recommended and adopted to local conditions and KREMU needs, (appendix E). In this respect local terminologies and concepts of certain use and cover types were defined to minimize confusion. A short list of terms which have been found confusing or used variably in previous studies by interpreters are listed herein (Appendix F).

As emphasised by Anderson et al (1976) the classification tries to be open ended towards finer classes. KREMU is more concerned with lands outside urban and built-up areas. For this reason the class has been left intact as originally given by Anderson op. cit.

The agricultural lands, forest and woodlands, and rangelands (comprising about 20%, 3%, and 75% of Kenya respectively) classifications used are presented in appendix E. The rangelands classification developed by KREMU (appendix G) was recommended in principle but, was found much more detailed than could be extracted rapidly from the photos and was therefore used at the coarser levels only.

The tundra and perennial ice classes although present, were considered insignificant in Kenya. The ice-capped Mt. Kenya is perennial and the immediate perimeter is tundra-like. For that reason the classes have been left in. Finer classification of the two is not necessary for Kenya at present.

4.3.4 Dot interpretation conventions

The methodology being documented uses a dot on a photo as the basic unit for gathering the data. A dot ideally has no area. It is infitismally small - although on the photo itself it is big enough to be seen. A typical dot size covered a ground area of about 3x3m. The idea was that the field on which the dot fell was the use or cover type that was counted. Because field sizes in Meru are small, of varied types and often of mixed cropping, 'edged', and ambiguous dots were not expected to be uncommon. A few rules were therefore set. Take a hypothetical slide photo with a few fields and dots as shown in Figure 15:

A - COTTON FIELD _ A is a single crop field
- dot 1 is clearly named 'cotton'.

B - GRAZING LAND - (pasture) with path running through
- dot 2 is named 'pasture'.
- dot 5 is named 'path'.

C - MAIZE FIELD - with path running through.
- dot 4 is named 'path'
- dot 3 is named 'maize'

D - MAIZE/BANANA - a mixed field.
- dot 6 is on border of two fields, C and D.
- dot 6 is named after field immediately to the EAST i.e. 'maize/banana'.
- dot 7 has two fields to its immediate east it is named after field to the north-east i.e. 'sunflower'.
- dot 8 falls on a banana bush in the maize/ banana field. The interpreter looks wider than the dot and names it after the major land use or cover devoted to the land - so it is named 'maize/banana'.
- dot 9 falls on maize in the maize/banana so it is named 'maize/banana'

F - BULRUSH MILLET/SORGHUM FIELD - where bulrush millet is broadcast and sorghum appears in wide rows on the same field.
- dot 10 falls on millet of the millet/sorghum field. It is named 'b.millet/sorghum'
- dot 11 falls on sorghum It is named 'b.millet/sorghum'.

- dot 12 falls on a lone tree in same field.
- dot 13 falls on a small bare patch in same field. Both are named 'b.millet/sorghum' after the larger field under which they fall.

G - PATH - bounded by hedges on either sides. Often because of resolution the two hedges and path merge and look like one continuous line. If interpreter decides that the dot is right in the middle then it is named 'path'. If interpreter decides that centre of dot is rather towards the edges then it is 'hedge'.

H - ROAD or TRACK - surfaced or graded. A long it is crown land which is classified as road. In some cases the boundary is clearly marked by a hedge from a neighboring landowner. Point 15 is covered by grass and therefore may be named 'grazing land', but its properly assigned use type is 'road'. Dot 16 further to the west on the same road has same cover type as 15 and is very close to the road. There is no hedge or demarcation to separate road from neighboring property. This is common in Kenya. To be consistent both throughout the country 15 and 16 are named after the cover type on which they fall i.e. 'grazingland'.

These rules and conventions removed many ambiguities and personal biases and therefore most probably increased classification accuracy.

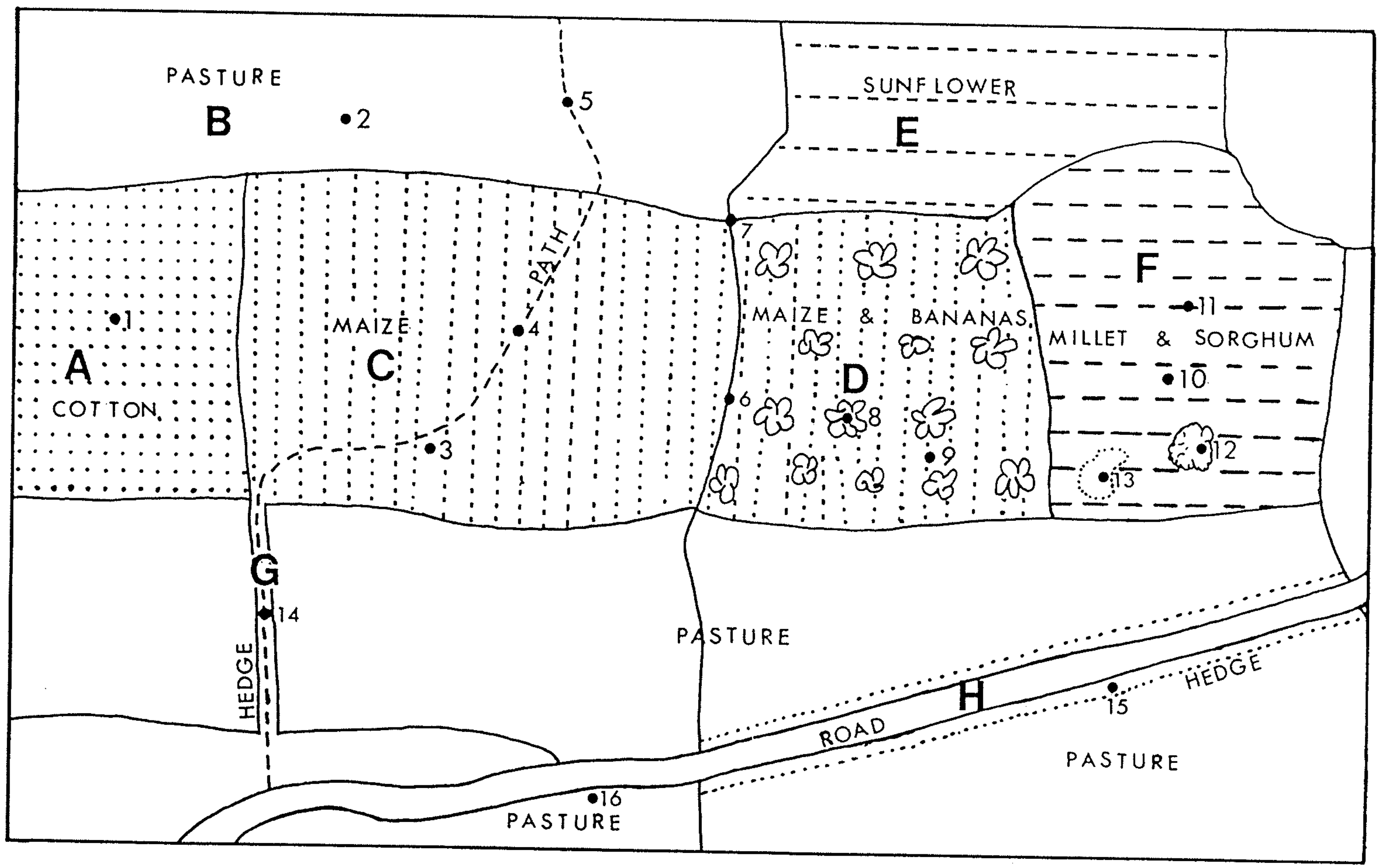


Figure 15. Model for the identification of land use and land cover classes for dots falling at various positions (see text).

4.4 CAPABILITY OF MAPPING ALL CLASS TYPES

A classification of land use and land cover types anticipated to be useful in Kenya was discussed and recommended as listed in appendix 2 after Anderson et al (1976). Urban or built-up areas (class 1), form a very small fraction of Kenya's land area but more important is that KREMU's mandate concerns more on the lands outside urban areas. Thus the urban classification given by Anderson op. cit. was left intact. Classes 2 through 7 were classified using the same principles as Anderson op. cit. but using the important Kenyan features and terminologies. Classes 8 and 9 are present around the peak of mount Kenya but insignificant in overall area as compared to the rest of the other land use and land cover classes.

Meru district represents all the above major classes, but the vast areas are comprised of rangelands, agricultural lands and forest lands. Finer classification of agricultural lands to level iv, for example the identification of specific crop types, was possible. As indicated in section 4.2 and Table 1 above, over 20 crop types were identified. Identification of rangeland types to level iii was strenuous and time consuming but relatively straight forward if done to level ii. For forests and woodlands identification to level ii was easy and at times to level iii, but was not possible beyond level iii.

One major difficult was the transitional zones between agricultural and rangelands. This was the region where it was difficult to classify a point either as agricultural or rangelands. Normally cultivation activities reduce gradually into the rangeland areas where pastoralism predominates. But classification of dots at levels ii was still possible. The approach taken was to tentatively assign each dot to either agricultural or rangelands. A method of differentiating agricultural lands from rangelands on the basis of present use and cover types, suggested by Epp and Killmayer (1982) was then applied. In this method lands are classified as agricultural if land under cultivation is more than 10%. This was mapped by contouring the 10% line of cultivation. Figure 16 shows the areas with lands less than 10% under cultivation but had the potential of being called agricultural, see figure 11 also. However, it should be realized that agricultural-rangeland boundary can also be drawn using agroclimatic potential criteria.

It was therefore demonstrated that it is possible to classify most agricultural activities to level iv to varying accuracies, while most others it was more accurate and proper to reach level ii or at most level iii.

As discussed under section 4.1 above the confusions that occur between certain classes, and thereby reducing interpretation accuracies, can be reduced by well thought and candid definitions as well as through experience and prac-

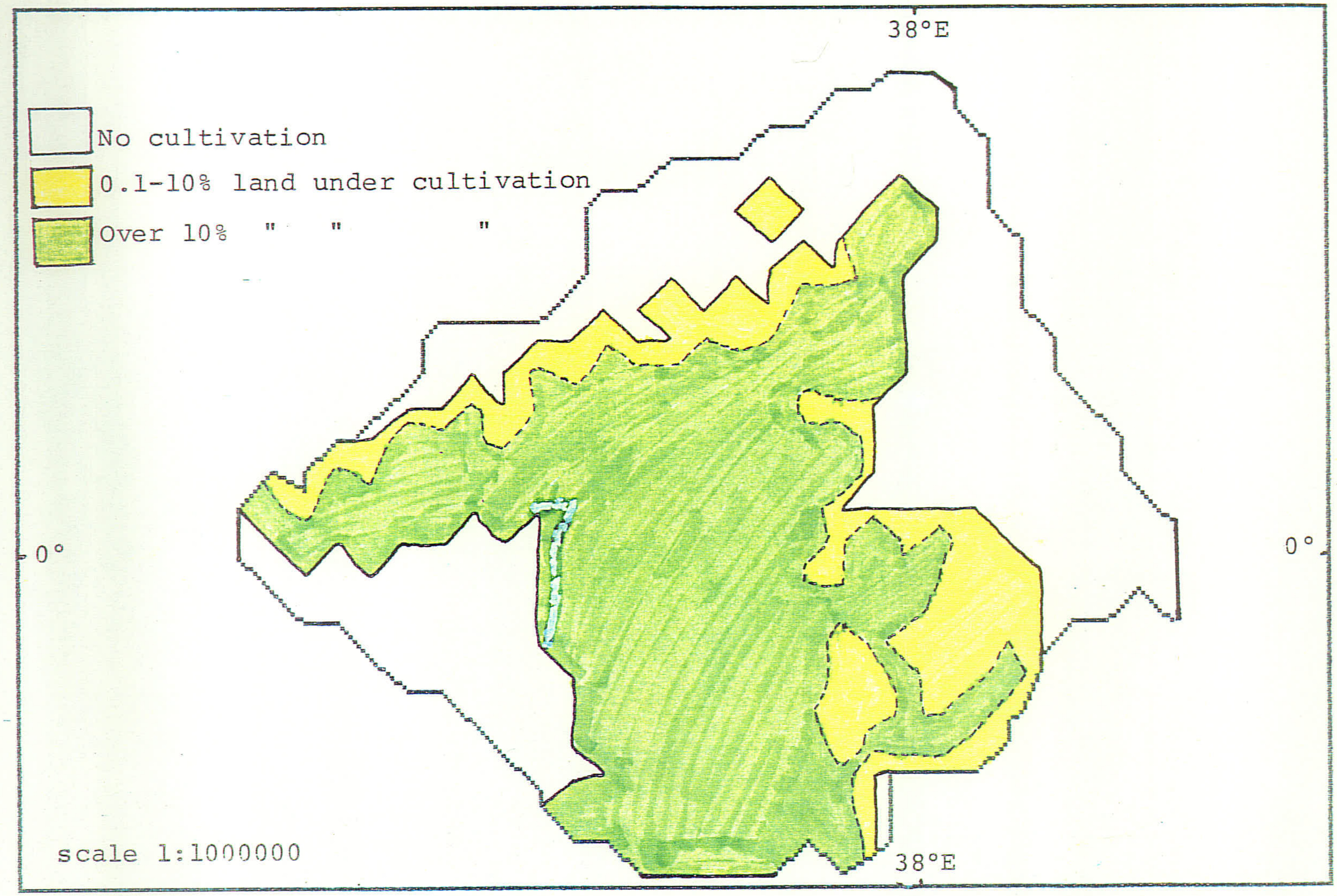


Figure 16. Map showing area with 0.1-10% land under cultivation, Meru district, February 1985.

tice. The most rewarding procedure presumably again, is training and practice of the interpreters especially when it comes to vegetation types in the rangelands whose definitions and differentiation revolve around the subjective estimation of physiognomic composition, their percent canopy covers, heights and naturalness. It is therefore possible with this method to map all the class types to different levels except probably built-up areas which normally need total photographic coverage to be accurate.

When KREMU acquires a better photographic system combination to provide a higher photo resolution it should be expected that more classes may be identified in any one area to a higher certainty. Higher resolution combinations may provide a chance for even minor classes to be detected and mapped when the national overview will be attempted in the future.

4.5 COMPARABLE BASIC GEOINFORMATION

The basic unit of all the information as described in the methodology was percent cover of each class type per unit grid cell (5x5km). The other districts' surveys have also used the 5x5km size of cells using the UTM grid array over Kenya. The method thus has the potential of having data for any class type from more than one district in a region or nationally eventually being juxtapositioned and analyzed as described herein. This will show the relative importance of each class type regionally or nationally and their distribution in relation to other land uses and cover types. This type of information is critical in regional and national planning for the country's resources. Data will therefore be analyzed to give statistics similar to tables 1 and 2 or mapped as in figures 5-9 or into any other desirable format. It is therefore anticipated that this method should work when similar data from other districts are collated and analyzed. For best results however the other necessary conditions are the unification of classification and terminologies and the establishment of a minimum acceptance interpretation accuracy. Although no formal classification was being used in the other districts, the interpretation was being done to the finest level possible and therefore classification and aggregation of the information will be possible.

4.6 COST-EFFECTIVENESS

As detailed in sections 4.1.1 and 4.4, it was possible to identify over 40 specific land use and land cover types in the district using the aerial photo sample methodology. This was despite the fact that:

- family holdings can be very small;
- individual crop fields are very small in most areas;
- crop type husbandry and agronomy vary within and from one ecological region to another;
- stages of growth of a crop type can vary in the

same family holding, or from one land holding to another in the same ecological region and immense variation between ecological regions at time of survey; and that

- intercropping was common.

Figure 17 attempts to demonstrate the difficulties of getting an accurate reflectance signature for any one class type in such heterogeneous fields, if satellite imagery were to be used. Signatures may become more and more specific, however, as one moves from 79x79m pixel resolution of MSS through 10x10m resolution from SPOT images. But even at 10x10m resolution there still will be intercropped fields, differences in agronomic practices, and differences in growth stages from field to field, and therefore may involve more ground verification or training than would be necessary for the dot method. For these reasons it was considered inappropriate to compare cost-effectiveness between satellite imagery and the photo sampling at the detailed and specific level described above for the intensive agricultural areas in Kenya.

Comparative cost-effectiveness of methodologies should also preferably be done for the same country where commodity and resource values and pricing are comparable. For example the labour rates are different from one country to another for the same job done and therefore should be handled carefully by economic experts in international comparative studies.

Figure 17. Photograph demonstrating the effect of image resolution in the recognition and identification of individual fields in the intensive agricultural areas of Meru district, as one moves from the low resolution of MSS through TM, SPOT, to the dotsoon the photographs used in the survey.

However, comparative costs were calculated, Table 7 below, to show the cost-effectiveness of satellite imagery where studies are required at very coarse and general levels.

Considered herein was the calculation of final cost of surveying a unit area . This varied with sampling intensity and number and/or area of the sample units because flying height and a photographic system were assumed constant. The sampling fraction (s.f.) was therefore varied by (1) changing sample units' area (10x10km, 5x5km, and 2.5x2.5km units and therefore flight transects at 10, 5, and 2.5km a part respectively), and (2) by increasing number of photographs per sample unit. The other factors considered were the running costs of the aircraft and photo production.

The average aircraft running costs for the year 1984/85, including checks, maintainance, and gas was Ksh.4000.00 per hour of flying. The average cruising speed of the aircraft was 240kph during surveys. This gives an average cost of Ksh.16.67 per km.

Cost of a 135mm ektachrome 200 of 36 exposures film (including processing) was Ksh.223.00 (i.e. Ksh.6.20 per photo). And, the cost of photographic batteries was Ksh.48.00 per 1000 exposures (i.e. Ksh.0.48 per exposure). Therefore cost of each photo was Ksh.6.68.

These basic costs gave an indication of what it costs to survey an area per km^2 with different sampling strategies, Table 7. This gave a cost of Ksh 3.60 (US$0.21) and Ksh 3.87 (US$0.23) per km^2 at one and two photographs respectively per 5x5km grid cell (US$1.00 = KSh.17.14, April 1985).

During the same period the cost of MSS standard CCT for a scene (185x185km) was Ksh.12410.00 (US$730.00) and that of TM was Ksh.74800.00 (US$4400.00). This gave a final image product cost of Ksh.0.40 (US$0.021) and Ksh.2.21 (US$0.13) per km^2 for MSS and TM respectively for the LANDSAT products. In effect LANDSAT images are cheaper than aerial surveys but cannot match the refinement and quality of the data derived from the aerial survey.

TABLE 8. COST OF PHOTO SAMPLING AT VARIOUS SAMPLING INTENSITIES AND NUMBER OF SAMPLES AT AN AIRCRAFT OPERATION RATE OF KSH.16.67 PER KM

	10X10KM CELL			5X5KM CELL			2.5X2.5KM CELL		
NO. OF PHOTOS	% S.F.	PHOTO COST	COST/KM²	% S.F.	PHOTO COST	COST/KM²	% S.F.	PHOTO COST	COST/KM²
1	0.78	6.7	1.73	3.12	6.70	3.60	12.5	6.7	7.74
2	1.56	13.4	1.80	6.24	13.40	3.87	25.0	13.4	8.82
3	2.34	20.1	1.87	9.36	20.10	4.14	37.4	20.1	9.89
4	3.12	26.8	1.94	12.48	26.80	4.41	49.9	26.8	10.96

S.F. - SAMPLING FRACTION (EXPRESSED IN PERCENTAGES)

4.7 TIMELINESS

4.7.1 Process Stages Time Efficiency

This study included the following major time consuming stages of activities:

1. study objectives formulation
2. literature review
3. survey planning and preparations
4. actual photography
5. film processing
6. field training and accuracy tests
7. actual district-wide photo interpretation
8. data organization and summary
9. computer time for preliminary statistics and maps and
10. report writing and production.

Some of these stages were carried out as on-going processes amongst other degree courses being taken at the same time. That is, no one continuous block of period was devoted to them with the exception of stages 4-7. This would be atypical of the methodology when it is well established in an institution where the process would as well start from stage 3 and would be assigned to a particular person or team of persons. Consequently, there was no strict track of hours spent at each stage. It was however possible to estimate the time taken by each of stages 3-9 thus:

stage 3. Maximum of two-man days.

stage 4. This depended on area to be surveyed and weather.

A typical day's flight plan would be about two hours of actual photography. This meant that 96 5x5km units could be surveyed in a day. More could be covered weather permitting. This means that an area of 2400km^2 could be covered per day. The 263 units surveyed in Meru should therefore have taken 3 days but it actually took 6 days because the survey period included some other activities, as well as bad weather. For convenience, therefore, 3 days were taken as the estimated time which was needed to survey the study area.

stage 5. Film processing took up to 3 days in Nairobi.

stage 6. Field training and accuracy testing normally took one day to visit two (and rearly three) photo points when the interpreters were working as a team. It required 18 days to visit the 37 photo points which were used for training, and consistency and accuracy tests. This time could be halved to 9 days by forming two teams.

stage 7. Actual district-wide photo interpretation would depend on the number of photos taken per 5x5km unit. It normally took one day to interpret 20-30 photographs for the 3 interpreters working as a team. Approximately 20 days were spent on the district-wide photo analysis. This could also be halved to 10 days by forming two teams.

stage 8. Data organization and summarizing, ready for computer entry, took the longest because it was done intermittently in Kenya and in Winnipeg. With the experience gained and assuming that the process became near mechanical, approximately 5-10 photos per man-day could be interpreted to the point of computer entry. This stage was performed by the author. It would have taken 15 days for the 3 interpreters in the team. Again assuming that this is a job to be carried out by a team in an institution, then stage 8 could be run concurrently with stage 7. The output of stage 7 could then immediately be passed on to personnel in stage 8 and therefore no time would be lost.

stage 9. Entry of data into the computer and computer time to produce preliminary statistics and maps was not strictly followed. As in stage 8 this was approximated, from experience, to have taken no more than two weeks. This stage could also be halved were a multi-team approach taken.

In summary then, it was approximated that the process from stage 3 to 9 should have taken 75 days, since the field personnel in stages 6 to 8 was one team. But in an institution like KREMU where team work could be organized, and where procedures presented herein could be exercised to have a data quality control mechanism, then a two team system could be organized so that time for stages 6, 7, and 9 could be halved. Further, as discussed above, stage 8 could be carried out concurrently with 6 and 7. This multi-team system would have then required 34 days to complete stages 3 to 9. It should also be noted that, often there was dead or 'lost' time between office and field activities and weekend days. In view of all these factors, preliminary results for a territory approximately the size of Meru District, from an institution like KREMU, are possible within 60 days - moving from stage 3 to 9.

The consultancy firm which did a similar experimental project in Nigeria (Bauchi 1984) reports to have been able to give a preliminary report based on 2600 photographs within two weeks of the completion of the survey - i.e. stages 5-9. But it is apparent that they did not have stage 6 in their process. It is, however, an indication that results within a month are feasible.

If one is lucky to get a cloud free satellite imagery for current land use and cover types, ordering and receipt of that imagery a lone in Kenya would take up to 30 days. The other stages of the image analysis and field checking would depend on the homogeneity of the study area. This was further indicative of the effectiveness of the aerial sample photography method in acquiring quick results when an urgent appraisal of a resource is required.

4.7.2 Biological window constraints

Kenyan climatic regions have either a unimodal or bimodal rainfall regimes. The first, commonly refered to as the 'long rains', occur between February and June. This is the main seasonal growing period in Kenya. Most crops would be flowering and mature between may and early August, and this would the best period for surveys. Those regions with a bimodal regime would have their second crop flowering or mature between late November and February and this would be another best survey period for those regions. During these two growing periods it would be possible to capture the widest range of land uses found in the agricultural regions.

The high potential areas comprises of 20% of Kenya and this translates to approximately 129,500km^2. This is equivalent to 5180 5x5km sample units. As discussed above, an average day's survey covers 96 5x5km sample units. The whole of the high potential area could therefore be covered in approximately 54 days, using one plane. But other logistical constraints do not work with such simple arithmetic. The possible use of two planes can half the needed survey time but it will also mean thining out ground personnel and vehicles moving to different regions for ground checks and accuracy measurements. But given enough ground support systems and two aircrafts, the whole of the high potential areas can be covered within those two biological windows with most diversified land uses, in a space of approximately two months to give preliminary results.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

At this point it is appropriate to recapitulate the low altitude systematic photographic sampling method examined in this practicum together with the objectives which were set out, and put them in their rightful perspective under which they were examined.

This project was an evaluation of the low level systematic aerial photographic method specifically in terms of the quality of its results, speed of acquisition of the data, and its cost-effectiveness. It should now be re-emphasized that the evaluation was done under much wider underlying contexts and conditions, which one should not loose sight of. These were mainly the national objectives, the local environmental conditions, factors determining choice and details of survey approach, and finally state of the science.

1. This method was examined for Kenya - a developing country. The national interests were that, on a long term basis, the method should be capable of being used for inventorying and monitoring of resources. And on an ad hoc and short term basis it should have the capability for rapid as-

sessment of resources in times of disasters. It should also be relatively inexpensive.

On the long term basis too, the information so acquired should be focused and be adequate for regional and national resource development planning, geared towards the provision of basic human needs. It should thus provide status quo information and trends in terms of statistics and areal distributions of the resources.

2. The methodology was examined under Kenyan conditions context - a land containing a wide spectrum of conditions in terms of terrain, climate, vegetation, soils and geologic formations, demographic and cultural characteristics, all of which result in a wide variation in land use and land cover patterns. In particular, the detailed application of the methodology was examined for the agriculturally high potential regions (and their marginal areas) which comprise 20% of Kenya but contains over 80% of her present 19.8 million people most of whom are rural. These are the regions with greatest demand and pressure on land based resources; with one of the highest population growth rates in the world; experiencing rapid land use and land cover changes; and have their own pressures and demands diffusing outwards into the marginal lands. Meru District, the study area, was taken as representative of these conditions.

3. A discussion of the broad approaches available for large scale land use and land cover surveying listed six as commonly used in the world:- historical information; ground surveys; questionnaire sampling; low altitude aerial surveys; high altitude aerial surveys; and space satellite remote sensing.

But the choice of which to use for any particular project is normally determined by any or a combination of six factors:- costs, technology available, nature of study area, time available, objectives, and manpower. Most of these factors played a role to various degrees when the Kenya Ministry of National Planning and Development chose to try the low altitude systematic aerial photographic sampling method. The onerous responsibility was then for the surveys scientist to demonstrate that (1) the detailed sampling strategies used were scientific; (2) photo interpretation accuracy and consistency was to an acceptable level; (3) field verification of the accuracy and consistency was scientific; and finally (4) that mapping of the results was possible to acceptable levels of accuracy to serve the primary national objectives.

4. Looking at the subject with a global perspective , the literature survey gave an impression that the subject of land use and land cover is relatively young and that few nations have carried out comprehensive land use and land cover surveys covering the whole country. Britain was the first in

the 1930s through the initiatives of an individual but not as government programme.

Because of diverse national interests; survey objectives; peculiar characteristics of lands; resources and peoples; stages of development; and others, no common survey approach seemed applicable globally. Consequently, few precedents and standards have been set from which an evaluation of any particular survey could be measured and compared. For example there still does not exist a single common land use and land cover classification system. And, when surveys are done in very great details, as it has been attempted in Britain, even the definition of the term land use begins to become an illusive concept. This is further complicated by the ever changing technology for the acquisition and manipulation of the data.

5.2 CONCLUSIONS

1. More class types can be accurately identified, quantified and mapped than can be accomplished by Landsat imagery.
2. Accuracy of inventory data for the extensive class types were relatively higher and could further be improved by implementing recommended photo interpretation procedures.

3. It is possible to use the method for monitoring class type changes in area and spatial extent especially for the extensive classes which gave low standard errors; and also

for localized intensive classes, such as tea, if stratification is done.

Reliable statistical and distribution information was obtained for Meru and could further be improved for regional and national resource planning.

4. The most important cover types in order of areal extent in Meru district, with their interpretation accuracies were:

Class	% Cover	Interpretation Accuracy (%)
Bush/Shrubland	38.11	80
Pasture	20.14	77
Maize	9.56	80
Forest	8.09	91
Coffee	3.41	86
Ploughed	2.93	73
Fallow	2.45	47
Bare	1.94	72
Wheat	1.53	85
Bananas	1.22	61
Bulrush Millet	1.20	27
Cotton	1.00	53

These interpretation accuracies are comparable to what has been achieved before using digital image analysis elsewhere. It was found that the accuracy improves to high levels when the finer classes are taxonomically aggregated. The other encouraging fact was that the the most important classes in area (accounting for about 92% of the land area) as listed above were interpreted with a fairly high accuracy. The classes most confused with each other and reasons for that were detected precisely in the field and by the use of confusion tables. One of the major causes of lowered accuracy was found to be lack of precise definition of terms. Image resolution may also have a contribution to lowered interpretation accuracy. It was therefore concluded that it is possible to increase interpretation accuracy greatly if the causes of confusion are eliminated or significantly reduced.

5. Statistical accuracy in the hectarage estimation needs more verifications by comparing the estimates with accurate independent sources of statistics.

6. Mapping of class distribution and intensities by contouring, using MAP, was possible and fast. It gave a realistic picture of the distributions of each class in the district and in relation to each other.

7. A procedural approach to interpretation of photography for every district was detailed and standardized to remove personal bias and eliminate the possibility of a project stalling due to personnel turnovers in institutions. It was concluded that these procedures would saveguard interpretation accuracy and comparability of data from district to district and through time. These procedures included:

stages of actual interpretation;

classifications and definitions; and

dot interpretation conventions.

Some classes need further discussions and research pertaining to definition and separation from other classes.

8. Over forty specific classes were identified during the district-wide photo interpretation, although some were extremely rare and were therefore combined with close relatives or placed under 'others'.

9. Data has been collected using one basic unit (percent cover) per 5x5km grid cells in all districts. This will make it possible for all data to be compared throughout the country.

10. The survey was done at a sampling intensity of between 3.12 and 6.24% and it cost between Ksh.3.60 (US$0.21) and Ksh.3.87 (US$0.23) per km^2. It would have cost about Ksh.2.23 (US$0.13) using TM or Ksh.0.36 (US$0.021) using MSS imageries per km^2. It however is futile to compare and even doubtful that TM would have provided adequate details as compared to the sample photography. The method is therefore cost-effective and worth improving on.

11. It is feasible to report on preliminary results on a survey area of about 7000km^2 within 30 days of photography with a team work approach which includes data quality control mechanisms. Therefore timeliness is an added advantage of this methodology.

5.3 RECOMMENDATIONS

From the above conclusions, the following recommendations are made:

1. Interpretation procedures recommended herein be discussed further by KREMU staff for ratification and followed for every survey.

2. Particular efforts be placed in discussing in detail the classification and definitions used and thereby lessen class confusions detected. This should take the form of practical field workshop for the concerned KREMU staff -- so that a procedural and classification methodology conducted above can be ratified to give data quality control mechanisms.

3. Accuracy and consistency tests should be included as part and parcel of all future land use and land cover surveys to indicate and safeguard data quality output, using the procedures developed for Meru District.

4. A synthesis of the districts' data already collected be started so that any unforeseen problems can be identified and rectified promptly and in time.

5. An effort be made by KREMU to rigorously compare cost-effectiveness of different sampling intensities of the method; methodologies; and combinations of methodologies so as to minimize survey costs.

6. An effort be made by KREMU to complete the photographic system combination for the surveys to be made standard. This should also raise the quality of data.

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APPENDIX A. TABLE SHOWING THE CONFUSION MATRIX FOR LAND USE AND LAND COVER INTERPRETATION FOR INTERPRETER 1, MERU DISTRICT 1985

GROUND TRUTH	PHOTO INTERPRETATION																													STATISTICS			
CLASS	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	OM	CI	TT	A%
01 MAIZE-------	546	-	-	12	6	8	10	1	-	-	2	-	-	1	-	-	-	3	1	-	3	1	1	12	1	-	-	2	21	85	546	631	86.5
02 WHEAT/BARLEY	1	34	16	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	12	34	46	73.9
03 RAPESEED----	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
04 PASTURE-----	14	-	-	366	19	9	12	3	-	-	1	2	2	-	3	-	-	2	2	-	2	-	-	2	-	-	-	5	15	93	366	459	79.7
05 BUSH--------	8	-	-	14	227	2	7	2	-	3	-	4	2	-	-	-	-	2	-	-	1	-	-	1	-	-	1	1	9	55	227	282	80.5
06 FALLOW/FERNS	2	-	-	7	-	31	2	-	-	-	1	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	10	24	31	55	56.4
07 PLOUGHED----	7	-	-	1	-	-	104	4	2	-	-	1	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	2	3	22	104	126	82.5
08 COFFEE------	6	-	-	2	-	-	3	136	1	-	-	-	2	1	1	-	-	-	-	-	-	-	-	5	-	-	-	-	2	23	136	159	85.5
09 TEA---------	2	-	-	1	-	-	-	2	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	7	70	77	90.9
10 FOREST------	-	-	-	-	1	-	-	-	-	38	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	81	88	92.0
11 ROADS/PATHS-	-	-	-	1	2	1	1	-	-	-	81	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	7	81	88	92.0
12 WOODLOTS----	4	-	-	2	9	-	1	3	1	-	-	21	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	24	21	45	46.7
13 HEDGES------	5	-	-	4	-	-	-	1	-	-	6	1	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	28	45	62.2
14 POTATOES----	-	1	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	5	0	5	0
15 HOUSES------	1	-	-	1	-	-	-	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-	-	-	-	1	1	4	21	25	84.0
16 SCHOOLS-----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	0	12	12	100
17 NAPIER GRASS	4	-	-	2	1	-	3	-	1	-	-	-	2	-	-	-	0	1	-	-	-	-	-	-	-	-	-	-	2	16	0	16	0
18 BANANAS-----	2	-	-	6	2	-	2	1	-	-	1	-	1	-	-	-	-	42	-	-	-	-	-	-	-	-	-	1	5	21	42	63	66.7
19 B. MILLET---	8	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	-	-	-	1	3	-	-	-	-	2	17	29	46	63.0
20 SWAMP-------	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	-	-	-	15	15	100
21 COTTON------	5	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	-	-	11	-	-	-	-	1	21	38	59	64.4
22 SUNFLOWER---	6	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	7	1	8	12.5
23 TOBACCO-----	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	13	-	-	-	-	-	-	3	13	16	81.3
24 PEGION PEAS-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	33	-	-	-	-	1	5	33	38	86.8
25 SORGHUM-----	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	6	-	-	-	-	2	6	8	75.0
26 MIRAA-------	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	3	1	4	25.0
27 RIVERS------	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	-	10	10	100
28 BARE--------	-	-	1	-	-	4	1	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	2	-	-	-	41	1	-	12	41	53	77.4
29 OTHERS------	2	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	13	7	13	20	65.0

OM = OMMISSIONS
CI = CORRECTLY INTERPRETED
TT = TOTAL
A% = ACCURACY (%)

APPENDIX B. TABLE SHOWING THE CONFUSION MATRIX FOR LAND USE AND LAND COVER INTERPRETATION FOR INTERPRETER 2, MERU DISTRICT 1985

GROUND TRUTH	PHOTO INTERPRETATION																													STATISTICS			
CLASS	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	OM	CI	TT	A%
01 MAIZE-------	473	3	-	16	12	7	14	3	1	-	4	5	6	6	3	-	2	5	2	-	7	1	1	2	5	8	-	-	29	143	473	616	76.8
02 WHEAT/BARLEY	-	56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	56	56	100
03 RAPESEED----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
04 PASTURE-----	10	1	-	361	39	1	1	3	1	1	7	8	8	1	2	-	3	-	-	-	-	-	-	-	-	1	1	6	16	110	361	471	76.6
05 BUSH--------	3	-	-	16	232	2	-	-	-	2	1	19	2	-	-	-	1	-	-	-	-	-	-	1	-	-	3	6	4	60	232	292	79.5
06 FALLOW/FERNS	8	-	-	4	5	32	-	-	1	1	-	1	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	9	32	32	64	50.0
07 PLOUGHED----	10	-	-	4	3	6	90	-	-	-	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	5	37	90	127	70.9
08 COFFEE------	1	-	-	1	3	1	1	134	2	-	1	2	1	-	-	-	2	-	-	-	-	-	-	1	-	2	-	-	1	19	134	153	87.6
09 TEA---------	-	-	-	1	1	1	1	2	60	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	8	60	68	88.2
10 FOREST------	-	-	-	-	1	-	-	-	-	45	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	45	48	93.8
11 ROADS/PATHS-	-	-	-	-	-	-	-	-	-	1	85	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	85	89	95.5
12 WOODLOTS----	-	-	-	-	13	-	-	1	-	-	-	32	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	-	16	32	48	66.7
13 HEDGE-------	1	-	-	-	1	-	-	-	-	-	2	-	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	42	47	89.4
14 POTATOES----	1	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	1	5	20.0
15 HOUSES------	-	-	-	1	-	-	-	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	-	-	-	1	1	3	24	27	88.9
16 SCHOOLS-----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	0	12	12	100
17 NAPIER GRASS	2	-	-	2	1	-	1	-	3	-	-	-	-	-	-	-	4	1	-	-	-	-	-	-	-	-	-	-	4	14	4	18	22.2
18 BANANAS-----	2	-	-	-	7	-	1	2	1	-	-	2	2	-	-	-	-	46	-	-	-	-	-	1	-	-	-	-	1	19	46	65	70.8
19 B.MILLET----	33	-	-	1	-	1	2	-	-	-	-	-	-	-	-	-	-	-	4	-	1	-	-	-	-	-	-	-	2	41	4	45	8.9
20 SWAMP-------	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	14	-	-	-	-	-	-	-	-	-	1	14	15	93.3
21 COTTON------	3	-	-	4	4	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	44	1	-	3	-	-	-	-	2	20	44	64	68.8
22 SUNFLOWER---	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	1	-	-	-	-	3	7	0	7	0
23 TOBACCO-----	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	3	-	11	-	-	-	-	-	-	6	11	17	64.7
24 PEGION PEAS-	-	-	-	1	-	1	-	1	-	-	-	-	1	-	-	-	-	1	-	-	5	-	1	16	2	-	-	-	2	16	16	32	50.0
25 SORGHUM-----	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	1	7	8	87.5
26 MIRAA-------	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	1	1	7	8	87.5
27 RIVERS------	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	0	10	10	100
28 BARE--------	-	-	2	2	-	9	2	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32	2	20	32	52	61.5
29 OTHERS------	4	-	-	2	1	-	1	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	2	13	11	13	24	54.2

OM = OMMISSIONS
CI = CORRECTLY INTERPRETED
TT = TOTAL
A% = ACCURACY (%)

APPENDIX C. TABLE SHOWING THE CONFUSION MATRIX FOR LAND USE AND LAND COVER INTERPRETATION FOR INTERPRETER 3, MERU DISTRICT 1985

GROUND TRUTH	PHOTO INTERPRETATION																													STATISTICS			
CLASS	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	OM	CI	TT	A%
01 MAIZE-------	476	3	-	44	5	2	16	2	-	-	2	2	6	-	1	-	1	3	3	-	1	-	-	1	14	-	-	7	36	149	476	625	76.2
02 WHEAT/BARLEY	2	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4	52	56	92.9
03 RAPESEED----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
04 PASTURE-----	11	-	-	341	51	5	4	-	-	-	3	9	9	-	3	-	1	1	-	-	-	-	-	-	1	-	-	10	10	118	341	459	74.3
05 BUSH--------	1	-	-	38	231	1	-	1	-	1	15	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	62	231	293	78.8
06 FALLOW/FERNS	6	-	-	10	9	23	4	-	-	-	-	-	1	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	6	41	23	64	35.9
07 PLOUGHED----	5	-	-	10	-	1	86	1	-	-	-	-	2	-	-	-	-	1	-	-	-	-	-	-	-	-	-	20	4	44	86	130	66.2
08 COFFEE------	4	-	-	4	3	-	1	127	-	-	1	8	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	3	25	127	152	83.6
09 TEA---------	2	-	-	4	2	-	1	1	61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	15	61	76	80.3
10 FOREST------	-	-	-	-	2	-	-	-	-	42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	42	45	93.3
11 ROADS/PATHS-	-	-	-	2	1	-	-	-	-	-	71	1	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	18	71	89	79.8
12 WOODLOTS----	-	-	-	1	11	-	-	2	-	-	-	29	4	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	19	29	48	60.4
13 HEDGES------	1	-	-	5	1	-	-	1	-	-	2	1	33	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	33	45	73.3
14 POTATOES----	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2	4	1	5	20.0
15 HOUSES------	1	-	-	3	-	-	-	-	-	-	-	3	-	-	14	-	-	-	-	-	-	-	-	-	-	-	-	3	1	11	14	25	56.0
16 SCHOOLS-----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	0	12	12	100
17 NAPIER GRASS	5	-	-	1	1	-	-	-	1	-	-	1	1	-	-	-	0	-	-	-	-	-	-	-	-	-	-	1	5	16	0	16	0
18 BANANAS-----	4	-	-	5	5	-	2	2	-	-	-	4	2	-	-	-	1	31	-	-	-	-	-	-	-	-	-	2	6	35	31	66	47.0
19 B.MILLET----	23	-	-	1	1	3	2	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	1	-	4	-	-	-	6	42	3	45	6.7
20 SWAMP-------	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	14	-	-	-	-	-	-	-	-	-	1	14	15	93.3
21 COTTON------	11	-	-	8	2	-	1	-	-	-	1	4	-	-	-	-	-	-	-	-	14	-	-	1	-	-	-	1	12	44	14	58	24.1
22 SUNFLOWER---	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	4	7	7	14	50.0
23 TOBACCO-----	3	-	-	1	2	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	7	1	8	12.5
24 PEGION PEAS-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	-	-	-	-	4	4	17	21	81.0
25 SORGHUM-----	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	1	6	3	9	33.3
26 MIRAA-------	-	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	4	0	4	0
27 RIVERS------	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	3	7	10	70.0
28 BARE--------	2	-	-	2	1	-	1	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	41	2	13	41	54	75.9
29 OTHERS------	3	-	-	5	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	7	11	7	18	38.9

OM = OMMISSIONS
CI = CORRECTLY INTERPRETED
TT = TOTAL
A% = ACCURACY (%)

APPENDIX D. TABLE SHOWING THE CONFUSION MATRIX FOR LAND USE AND LAND COVER PHOTO INTERPRETATION FOR THE THREE INTERPRETERS COMBINED, MERU DISTRICT 1985.

GROUND TRUTH	PHOTO INTERPRETATION																													STATISTICS			
CLASS	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	OM	CI	TT	A%
01 MAIZE-------	1495	6	-	72	23	17	40	6	1	-	8	7	12	7	4	-	3	11	6	-	11	2	2	15	20	8	-	10	86	379	1495	1874	79.8
02 WHEAT/BARLEY	3	142	16	3	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	26	142	168	84.5
03 RAPESEED----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
04 PASTURE-----	36	1	-	1058	109	15	17	6	1	1	11	19	19	1	8	-	1	6	2	-	2	-	-	2	1	1	1	21	41	321	1058	1379	76.7
05 BUSH--------	12	-	-	68	690	5	7	3		5	1	38	7	-	-	-	-	3	-	-	1	-	-	2	-	-	4	7	15	178	690	868	79.5
06 FALLOW/FERNS	16	-	-	21	14	86	6	-	1	1	1	1	1	-	-	-	-	2	7	-	-	-	1	1	-	-	-	-	25	98	86	184	46.7
07 PLOUGHED----	22	-	-	15	3	7	280	5	2	-	1	3	3	-	-	-	-	2	-	-	-	-	-	1	-	-	-	27	12	103	280	383	73.1
08 COFFEE------	11	-	-	7	6	1	5	397	3	-	2	10	3	1	1	-	-	3	-	-	-	-	-	6	-	2	-	-	6	67	397	464	85.5
09 TEA---------	4	-	-	6	3	1	2	5	191	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	7	30	191	221	86.4
10 FOREST------	-	-	-	-	5	-	-	-	-	125	6	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13	125	138	90.6
11 ROADS/PATHS-	-	-	-	3	3	1	1	-	-	1	237	1	13	-	-	-	-	-	1	-	-	-	-	-	-	-	-	5	-	29	237	266	89.1
12 WOODLOTS----	4	-	-	3	33	-	1	6	-	-	-	82	6	-	1	-	1	1	-	-	-	-	-	-	-	-	-	1	1	58	82	140	58.6
13 HEDGE-------	7	-	-	10	2	-	-	4	-	-	10	2	103	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	103	139	74.1
14 POTATOES----	1	2	-	1	-	-	1	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	13	2	15	13.3
15 HOUSES------	2	-	-	5	-	-	-	-	-	-	-	3	-	-	59	-	-	-	-	-	-	-	-	-	-	-	-	5	3	18	59	77	76.6
16 SCHOOLS-----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	36	100
17 NAPIER GRASS	11	-	-	5	3	-	4	-	5	-	-	1	3	-	-	-	4	2	-	-	-	-	-	-	-	-	-	1	11	46	4	50	8.0
18 BANANAS-----	8	-	-	13	14	-	5	5	1	-	1	6	5	-	-	-	1	119	-	-	-	-	-	1	-	-	-	3	12	75	119	194	61.3
19 B. MILLET---	64	-	-	5	1	6	2	-	-	-	-	-	-	-	-	-	-	-	36	-	1	-	2	3	4	-	-	-	10	98	36	134	26.9
20 SWAMP-------	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	43	-	-	-	-	-	-	-	-	-	2	45	47	95.7
21 COTTON------	19	-	-	17	8	1	1	-	-	-	1	-	5	-	-	-	-	-	1	-	96	1	-	15	-	-	-	1	15	85	96	181	53.0
22 SUNFLOWER---	11	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	1	-	-	-	-	7	21	8	29	27.6
23 TOBACCO-----	5	-	-	2	2	-	-	-	-	-	1	1	-	-	-	-	-	1	1	-	3	-	25	-	-	-	-	-	-	16	25	41	61.0
24 PEGION PEAS-	1	-	-	2	-	1	-	1	-	-	-	-	1	-	-	-	-	1	-	-	8	-	1	66	2	-	-	-	7	25	66	91	72.5
25 SORGHUM-----	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	16	-	-	-	1	9	16	25	64.0
26 MIRAA-------	1	-	-	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	3	8	8	16	50.0
27 RIVERS------	-	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27	-	-	3	27	30	90.0
28 BARE--------	2	-	-	7	3	-	14	5	1	-	1	-	2	-	2	-	-	-	-	-	-	-	-	2	-	-	-	114	5	45	114	159	71.7
29 OTHERS------	9	-	-	7	1	-	6	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	3	33	29	33	62	53.2

OM = OMMISSIONS
CI = CORRECTLY INTERPRETED
TT = TOTAL
A% = ACCURACY (%)

Appendix E

LAND USE LAND COVER CLASSIFICATION USED IN MERU DISTRICT 1985

(adopted after Anderson et al 1976)

LEVEL I	LEVEL II	LEVEL III	LEVEL IV
1 Urban/Built-up Lands	11 Residential	-	-
	12 Commercial & Services	-	-
	13 Industrial	-	-
	14 Transportation Communications & Utilities	-	-
	15 Industrial & Commercial Complexes	-	-
	16 Mixed Urban or Built-up Land	-	-
	17 Other Urban types	-	-
1 Agricultural Lands	11 Cropland	111 Perennials	Coffee
		212 Annuals	Maize etc
		213 Horticulture	Citrus
		214 Ploughed	ploughed
		215 Fallow	fallow
		216 Nurseries	tea
	22 Grazingland	221 Feedlots	hogs
		222 Improved	themeda
		223 Unimproved	bushed
	23 Other Agric. Lands	231 Structures	buildings
		232 Transport & Communication	roads,paths telephones
		233 Woodlots	wattle
		234 Bare	
3 Rangelands (use appendix G)	31 Grasslands	311 Bushed	themeda
	32 Bushland	321 Grassy	combretum
	33 Shrubland	331 Wooded	acacia
	34 Scrubland	341 Bushed	sanchveria
	35 Others	351 Desert	
4 Forest/Woodland (use appendix G)	41 Indigenous	411 Protective	Meru Oak
		412 Productive	
	42 Plantation	421 Protective	
		422 Productive	
	43 Mixed Forest	431	

5 Waterbodies	51 Watercourses	511 Rivers	
		512 Streams	
		513 Canals	irrigation
	52 Lakes		
	53 Reservoirs	531 Natural	oxbows
		532 Artificial	fishbonds
	54 Bays and Estuaries	541	
	55 Seas (ocean)		
6 Wetlands	61 Permanent	611 Forested	mangrove
		612 Swamps	pyparus
	62 Temporary	621 Bogs	
		622 Marshlands	
	63 Others		
7 Bad Lands (Barren)	71 Dry salt pans		
	72 Beaches		
	73 Sandy areas (other than 72)		
	74 Bare Rocks		
	75 Strip mines, Quarries, pits		
	76 Gullys (erosion)		
8 Tundra	81 Shrub & Scrub		
	82 Herbaceous		
	83 Bare Ground		
	84 Wet		
	85 Mixed Tundra		
9 Perennial Ice or Snow	92 Glaciers		

Appendix F

WORDS COMMONLY USED IN KREMU REPORTS WHICH ARE SOMETIMES CONFUSING OR NOT EXPLICIT

Fallow - age?

Woodlot - size, shape, natural, planted?

Grazing land - improved , unimproved

Bushed grazing

Pasture

Bare

Barren

Ploughed

Roads, Tracks, Paths

Buildings, houses, structures

Appendix G

KREMU'S HABITAT CLASSES

HABITAT	CHARACTERISTICS	SYMBOL
	WOODLAND-FOREST (Trees >10m tall, canopy cover >20%)	
Woodland	Little else but woodland-forest apparent from the air.	WL
Palm	Palm trees and often some acacia or other trees.	PA
Bush	Trees & shrubs 6-10m tall also conspicuous e.g. Tana Delta	BW
Shrub	Shrub & trees 1-6m tall of second importance.	SW
Dwarf-Shrub	Shrubs such as Indigofera predominate as ground flora.	DW
Thicket	Woodland with >80% canopy cover.	TW
Grassy	Herbaceous cover >20% e.g. Combretum - Grass.	GW
Flooded	e.g. Mangrove swamps >10m tall.	FW
	BUSHLAND (mostly shrubs & trees 6-10m tall, canopy >20%)	
Bushland	Little else but shrubs & trees 1-6m tall.	BL
Thicket	Bushland with >80% canopy cover	TB
Dwarf-Shrub	e.g. Acacia with dwarf-shrub understory.	DB
Grassy	Herbs form >20% cover.	GB
Flooded	e.g. mangrove swamp 6-10m tall.	FB
	SHRUBLAND (mostly shrubs and trees 1-6m tall, canopy >20%)	
Shrubland	Little else but trees and shrubs 1-6m tall.	SL
Wooded	Woody vegetation >10m tall forms 10-40% of canopy cover.	WS
Bush	Woody vegetation 6-10m tall forms 10-40% of canopy cover.	BS
Dwarf-Shrub	Dwarf shrub <1.0m tall form main ground cover.	DS
Thicket	Shrubland with >80% canopy cover.	TS
Grassy	e.g. Salvadora with Sporobolus; herbaceous cover >20%.	GS
Flooded	e.g. mangrove swamps 1-6m tall.	FS
	DWARF-SHRUBLAND (mostly woody cover <1m tall, canopy >20%)	
Dwarf-Shrubland	Little else but shrubs <1.0m tall.	DF
Wooded	Trees >10m tall forms 10-40% of canopy cover.	WF
Bush	Trees & shrubs 6-10m tall forms 10-40% of canopy cover.	BF
Shrub	Woody vegetation 1-6m tall forms 10-40% of canopy cover.	SF
Grassy	Herbaceous cover >20%.	GF
	GRASSLAND (woody cover <20%, herbaceous cover >20%) .	
Grassland	Little else but herbaceous vegetation.	GL
Isolated Trees	Animals <5m of isolated tree on grassland. Trees >200m apart	IT
Wooded	Scattered/grouped trees (<20% cover) with trees <200m apart	WG
Bush	Wooded vegetation 6-10m tall forms <20% canopy cover.	BG
Shrub	Wooded vegetation 1-6m tall forms <20% canopy cover.	SG
Dwarf-Shrub	Semi-desert areas with basement soils; e.g. Loita Plains	DG
Flooded	Herbaceous cover <2m tall.	FG
	PERMANENT SWAMP (wet lowland with herbaceous layer >2m tall)	
	Often with conspicuous shrubs. Excludes mangrove swamps.	
	DESERT (<20% vegetative cover)	
Grassy	e.g. annual grasslands with <2-20% cover in N. Kenya.	GD
Dwarf-Shrub	Shrubs <1.0m tall predominate, 2-20% cover.	DD
Shrub	Shrubs 1-6m tall predominate, 2-20% cover.	SD
Bush	Shrubs & trees 6-10m tall predominate; 2-20% cover.	BD
Barren	<2% vegetative cover.	BA
	RIVERINE (habitat within 50m of stream channel).	
Wooded	e.g. Acacia xanthophloea >10m tall.	WR
Bush	Woody vegetation 6-10m tall predominates.	BR
Shrub	Woody vegetation 1-6m tall predominates.	SR
Dwarf-Shrub	Shrubs <1.0m tall predominate	DR
Grassy	Herbaceous vegetation predominates.	GR
	POND-LAKE (includes water & upland within 50m of water edge).	PO
	ECOTONE (area within 50m of 2 habitat types).	
	Record symbols for 2 habitat types with type most animals are in listed first e.g GL/SL.	
	INSELBERG (rocky hill on plain)	IN
	CULTIVATED LANDS	CL